

TOPOGRAPHY OVER TYPOLOGY: INTEGRATING BLUE & GREEN INFRASTRUCTURE NETWORKS INTO FRAGILE HIGH ALTITUDE LANDSCAPES

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ABSTRACT

Rapid urbanization and the high sensitivity of high-altitude urban areas are causing increasingly large ecological problems. Rapidly expanding unplanned urban growth is causing habitat fragmentation, loss of natural landscapes and ecological connectivity in Kanju Township, located in the ecologically sensitive Swat Valley. The purpose of this research is to analyze the application of ecological urbanism in introducing the ecological corridors to become the part of the urban landscape in Kanju Township for supporting sustainable development, adaptation to climate change and the environmental resilience. The study examines the current state of the natural environment such as the Swat River, seasonal streams, agricultural land and other mountain ridges – to assess potential to establish a network of green and

blue infrastructure. Context-sensitive planning strategies are guided by a comparative analysis of high altitude international cities, namely Davos, Switzerland. The results demonstrate that structured river buffers, native vegetation networks, urban green streets, and wildlife friendly land use planning have the potential to drastically improve habitat connections, reduce environmental degradation and strengthen urban quality of life by integrating biodiversity corridors. Finally, the current research suggests a pragmatic approach to incorporating ecological corridors into high altitude urban planning that provides a practical guide for balancing growth and conservation in mountain townships in developing areas.

Keywords: Ecological Urbanism, Biodiversity Corridors, High-Altitude Urban Planning, Mountainous Landscape, Kanju Township Swat.

INTRODUCTION & BACKGROUND

Urban highlands are characterized by complex topography, sensitive microclimates and highly sensitive ecosystems. Mountainous settlements are tightly bound by steep topography, dynamic hydrology and natural hazards, and are not open to horizontal expansion as in the lowlands where contiguous plains exist (Taraky et al. 2021). Within Pakistan these spaces are experiencing an unprecedented spatial transformation, especially in the northern alpine areas including the Hindu Kush range. At the same time, population growth and evolving economic forces are driving the pace of natural wilderness transformation into built-up areas (Mumtaz et al. 2023).

This is a typical example of the new spatial turn of the century that is Kanju township in the beautiful Swat Valley of KP. The town, once renowned for its well-balanced socio-ecological territory farming system, seasonal streams and prolific riparian biodiversity, has quickly become a growing urban hub (Mehmood et al. 2021). This increase is socially and economically necessary, but is threatening to ecological bases that support the valley. The old balance between human settlement and the mountain landscape is being superseded by a negative spatial relationship, with the aim of building concrete structures to the detriment of conservation. Rural development in mountainous areas is more likely to put pressure on ecosystems than in flat areas, due to its exponential nature (Khan and Mohmand 2011). Impervious

concrete surfaces increase soil erosion, erode weak slopes, and hinder natural surface hydrology. In high elevation settings, wildlife species depend on continuous elevational and riparian connections to ensure their survival through seasonal changes, to access food and to protect their genetic diversity. These paths are being destroyed by unplanned horizontal expansion, which results in diminishing and fragmented stretches of native flora and fauna that pose a risk to species survival (Rehman et al. 2022).

Moreover, these intrinsic weaknesses are exacerbated by climate change, resulting in irregular rainfall, short duration of major flood events along mountain torrents (khwars), and climate cycles (W. Ullah et al. 2025). Loss of this natural protection due to development increases the potential for slope failures and catastrophic runoff, posing a threat to human settlement and biodiversity throughout the region. All of this change of pace and the climate exposure of these lands puts landscape architecture and proactive planning strategies at a regional survival level. Current planning models need to change, and adopt an ecological approach to urbanism, to resolve the conflict between development and ecology (Shahzada et al. 2025). The idea is not to oppose nature vs the built environment, but rather to put natural processes as the design framework for the city. Ecological urbanism is a mindset that sees cities as dynamic, living ecosystems and calls for the creation of a network of green and blue infrastructure to maintain them, while allowing for human development. This design philosophy is about incorporating ecological knowledge into spatial planning, and thus building ecological resilience and maximizing ecosystem services (Ahmed et al., 2024).

Ecological urbanism is a kind of architectural and planning discipline in a high elevation township. It requires that the building typologies, road layout and civic areas follow the natural bends of the landscape, the stream beds and drainage. Ecological urbanism does not make the landscape conform to the city by imposing on it the force of verticalization and steel and concrete walls, but allows the natural landscape to enter the city, filter and reflect it, making urban facilities that are positively conducive to the biodiversity of the surrounding environment. Biodiversity corridors, the essence of ecological urbanism, are implemented. These

are purposely maintained or re-established linear landscape networks, which link disconnected habitat patches (Ahmed et al. 2024). Corridors can be green (forested ridges, continuous Tree Street vegetation, urban parks) or blue (protected riverfronts, wetlands, seasonal streams) in urban areas. These corridors enable free movement and gene flow of animals within their city and help to avoid local extinction and to sustain the regional ecosystem (Abbas et al., 2024).

In addition to conservation, the networks offer important ecosystem services for cities: they moderate the microclimates, capture stormwater runoff, stabilize soils and create therapeutic open spaces with positive impacts on human health. Corridors are multi-layered infrastructure assets when they are embedded in the urban landscape. As wildlife highways, as natural drainage, and as public linear parks they serve as a demonstration of how protecting the environment can directly improve the visual, spatial, and functional characteristics of the built environment.

PROBLEM STATEMENT

Kanju Township continues to grow in an unplanned manner, with land use and cover changes accelerating and jeopardising its delicate high-altitude ecology. Horizontal encroachment has directly affected the riparian areas of the Swat River, khwars (seasonal stream beds) and adjoining hillsides without control. The town's green spaces are becoming fragmented and are becoming islands instead of a continuous ecological network as the concrete surfaces take the place of the vegetation. It reduces the ability of native flora and fauna to survive in the face of severe habitat fragmentation, impacts on wildlife movements and reduces regional biodiversity. Beyond that, deforestation diminishes the capacity of the landscape to withstand environmental shocks. Unplanned development has increased the risks of catastrophic flash floods and landslides, and also reduced vegetation on steep slopes, contributing to urban heat retention in narrow concrete pipes. If a spatial plan is not in place for urban development that incorporates functional biodiversity corridors into the Township's urban fabric then the services provided by the valley, and its long-term safety and quality of life, will be lost forever.

RESEARCH OBJECTIVES

Following research objectives were set forth:

1. To map and evaluate the spatial fragmentation of existing green and blue assets in Kanju Township using GIS and field assessments to identify critical ecological bottlenecks.
2. To develop a context-sensitive spatial design framework that integrates continuous biodiversity corridors, riparian buffers, and stepping-stone habitats into the township's urban fabric.

RESEARCH SIGNIFICANCE

The study provides a valuable theoretical and practical contribution to sustainable development in high altitude planning in urban areas, a crucial lacuna in the literature on fast growing and developing mountain towns. Current literature has abundant documentation of ecological urbanism and biodiversity corridors in high income countries in the European Alps, whilst there is limited empirical research on the fast-growing, unregulated urbanization in northern Pakistan. The study has mapped the socio-ecological landscape ecology of the Swat Valley and created a new framework for the analysis of the interaction of informal urban growth with fragile mountain terrain. From a practical point of view, this study presents practical and practical spatial solutions and design principles for the city officials, urban planners, and environmental policy makers of Malakand Division. This proposed framework proposes to transcend the traditional, reactive approach to zoning by showing how seasonal water channels (khwars) and topographically sensitive slopes can become multi-functional green infrastructure asset. These corridors both preserve biodiversity and provide public linear parks and natural storm water control. Moreover, the model for implementation of the research is feasible and practical, focusing on the stewardship of the land from the community level and the use of traditional agricultural resources such as fruit orchards as ecological stepping stones. In conclusion, this study is a replicable model for those other fast-growing townships in the Hindu Kush, Karakoram and Himalayan regions that must reconcile high altitude urban development with environmental conservation to achieve long-term regional resilience.

LITERATURE REVIEW

Concept of Ecological Urbanism

An oppositional dynamic between human settlement systems and natural systems has prevailed in the history of urban planning. Cities have been viewed in the industrial and post-industrial periods as a blank slate or as a passive resource to be manipulated throughout the design of the city (Chaudhry et al. 2017). In response to the resulting environmental crises, contemporary planning theory has moved towards paradigms that acknowledge the interdependency of the built and natural environment. Ecological urbanism is the final step in this evolution and a concept in which ecology and creative urban design are combined (Rehman et al., 2023).

In contrast to models like "Sustainable Urbanism" that tend to emphasize individual use efficiency indicators such as energy use, or carbon neutral building materials, ecological urbanism works at the system/landscape scale (Bhatti et al. 2024). It builds on "Landscape Urbanism", but with a strong emphasis on social relations, climate adaptation and multi-layered infrastructure (Shah et al., 2023). The fundamental idea of ecological urbanism is that the city has to be understood as not being separate from nature but a complex, hybrid ecosystem. To be resilient, a city must be influenced by the processes of nature, in terms of its spatial structure, its infrastructural networks and its architectural typologies (Shah et al., 2023b). In areas of high altitude and mountain terrain it's a practical necessity (Zainab et al., 2023). Steep slopes, intricate networks of seasonal streams, and sensitive microclimates characterize the mountain landscape, with resulting changes in space potentially causing broad-scale impacts. In these places, ecological urbanism must have a design modesty. It requires adaptation by the built environment rather than reshaping the landscape through the construction of heavy earthworks, grading and concrete retaining walls. This involves road alignment to the natural topography, protection of waterways and development of human settlements that are sympathetic to and work with the valley's natural systems (Bhatti et al., 2025).

Urban Biodiversity and Ecosystem Services

Urban biodiversity is the diversity, abundance and distribution of plants, birds, insects and small mammals in the urban environment. Cities were considered as ecological dead zones in the past, but recent studies reveal that cities can have different types of ecosystem as long as green spaces are well managed. Biodiversity

in the city is a keystone for ecosystem services, or the natural processes which directly support human life, health and economy. There are four basic functional categories of ecosystem services: provisioning, regulating, supporting and cultural services (Bhatti, Usman, et al. 2025). At higher levels, these services are critical to urban resilience. Services regulated by native forest and wetlands can include the ability to buffer microclimates, sequester carbon emissions, and purify air pollutants. Urban vegetation also plays a role in reducing urban heat island (UHI) effect that is now a major concern in fast-growing mountainous valleys, where lots of concrete surfaces are absorbing and retaining solar energy between urban and natural systems (Bhatti et al., 2025). From the industrial and post-industrial periods until now, cities have been conceived as artificial engines of economic growth and the landscape as an empty canvas or a resource to be shaped (Bhatti et al., 2025). As a response to this environmental crisis, modern planning theory has turned to paradigms that look at the interdependence of the built and natural environment. Ecological urbanism is the latest development in this evolution and provides a framework that combines the science of ecology with the creative practice of urban design (Fida et al. 2022).

Ecological urbanism works on a system or landscape level in contrast to other previous concepts like "Sustainable Urbanism", which frequently rely on efficiency parameters like the minimization of energy use or construction of carbon neutral buildings. It builds on "Landscape Urbanism" with a strong emphasis on the social, climate adaptation and layered infrastructure. At the heart of ecological urbanism is the conviction that the city should not be considered apart from nature but as a hybrid and complex ecosystem (Shah et al. 2020). To be truly resilient, a city's spatial shape, network infrastructure and architectural forms should be shaped by natural processes. This is often a practical necessity in high altitude and mountainous regions. Typical mountain topography features steep slopes, highly irregular seasonal stream networks and sensitive microclimates that can cause significant environmental changes to occur in areas that are relatively small (Mehmood et al. 2025). In such environments, ecological urbanism demands a modesty of design. It requires adaptation of the built environment, rather than the

reshaping of the landscape by large-scale earthworks, grading and concrete retaining structures. This involves locating roads at their most natural slope; maintaining water channels; and building human settlements that are sympathetic to the natural systems of the valley (Subhanullah et al. 2024).

Urban Biodiversity and Ecosystem Services

Urban biodiversity is defined as the diversity, abundance and distribution of biodiversity that exists in an urban context, such as plants, birds, insects and small mammals. In the past, cities were considered as a ecological dead zone, but modern research demonstrates that urban areas can be successful in sustaining a variety of ecosystems with proper management of the green space (Tabassum et al. 2023). The urban biodiversity is the basis of ecosystem services, which are natural processes directly supporting human health, well-being and economy. Most ecosystem services can be classified into four functional groups: provisioning services, regulating services, supporting services, and cultural services (Taraky 2021). For urban resilience, these services are crucial in high-altitude settlements. Regulating services include the ability of native forests and wetlands to regulate microclimates, sequester carbon emissions, and mitigate air pollutants for example. In addition, urban vegetation can help reduce the "urban heat island" (UHI) effect, which is a growing concern in rapidly developing mountainous valleys with a high amount of concrete surfaces that absorb and trap solar radiation.

Table 1: *Services of Highland biodiversity and ecosystem services*

Service Category	Mountain Urban Manifestation	Core Spatial Infrastructure
Provisioning	Fresh water supply, terraced agriculture, biomass.	Protected headwaters, managed agricultural zones.
Regulating	Slope stabilization, flash-flood mitigation, microclimate cooling.	Deep-rooted mountain forests, open stream buffers.

Service Category	Mountain Urban Manifestation	Core Spatial Infrastructure
Supporting	Soil formation, nutrient cycling, pollinator maintenance.	Un-fragmented soil matrices, native wildflower fields.
Cultural	Eco-tourism, landscape aesthetics, mental well-being.	Continuous linear parks, mountain trail networks.

The fertility of the surrounding landscape is maintained through supporting services as described above in table 01 which include nutrient cycling and soil formation. These services are crucial for supporting local fruit orchards and terrace farming practices in these areas, such as the Swat Valley, where such farming is both economically significant and plays a major role in the region's food security. Importantly, biodiversity helps to sustain native pollinator populations which are a vital component of wild ecosystems and local agriculture (Ahmad et al. 2022). The urban expansion that has been taking place destroys these ecological processes, and this affects the capacity of the town to withstand landslides, water scarcity, and environmental degradation.

Biodiversity Corridors Definition, Types, and Functions.What is a Biodiversity Corridor, Types and Functions

When cities grow, they divide up the continuous natural landscapes into smaller discrete pieces, known as habitat fragmentation. This fragmentation forms what can be described as 'islands' of green space in an urban built environment. To overcome this, landscape ecology has been developed with the use of biodiversity corridors. These are carefully maintained or reconnected linear habitats that provide safe pathways for wildlife to safely move from one isolated habitat patch to another, to gain access to food or water, and to keep the genetic flow that prevents local extinctions (Din et al. 2026).

From an urban design perspective, corridors can be generally divided into two types: green and blue networks. Green corridors are defined as a continuous

stretch of trees along mountain ridges, in protected valleys, along streets and in interconnected urban parks. Blue corridors relate to the hydrological systems including big river banks, natural wetlands and khwars (seasonal streams) in local usage in Pakistan. If managed properly, these systems are able to create a hybrid blue-green infrastructure network for multiple uses and functions (Khan et al. 2020).

These corridors serve a variety of functions beyond wildlife movement. The ecological functions of corridors can be divided into three main modes:

- **Conduit Function:** A pathway which allows species movement to connect larger natural areas.
- **Habitat Function:** Providing permanent habitat for smaller species that use the corridor for shelter, food availability and breeding.
- **Filter and Buffer Function:** Absorb urban noise, trap sediment from hillsides, filter pollutants from stormwater drainage before they enter large rivers and reduce wind speeds in urban zone.

Building Biodiversity Corridors in Mountainous and High-altitude Cities

Biodiversity corridors in mountainous and high altitudes presents special spatial dynamics that are influenced by topography. Corridors tend to stretch out horizontally in flat terrain. However, mountainous areas demand a vertical strategy since the wildlife resources utilize an elevational gradient to adjust to changing seasons, temperatures and resources. These natural paths are linear valleys, river gorges and forested hillsides, which species use to move from one elevation to another (Saqib and Rashid 2014). Unplanned urbanization on valley bottoms may disrupt these vertical linkages, dividing lower riparian areas from upper mountain forests (Khan and Khan 2015). Studies of alpine cities show that these paths are vital to the diversity of local flora and fauna and that their closing results in a significant drop in species diversity. So, in planning for high elevations, a continuous pathway must be preserved between elevations, and water channels and mountain ridges must not be interrupted by continuous lines of buildings or infrastructure.

Green and Blue Infrastructure in Urban Planning

Green and Blue Infrastructure (GBI) is a new planning strategy that recognizes and values natural networks as a fundamental part of the fabric of the municipality,

rather than an area for future development (Noor et al., 2019). Examples of green infrastructure include community gardens, pocket parks, tree-lined roads and engineered green roofs. Blue infrastructure is the design of the town's water infrastructure, such as open rivers, floodplains and natural stormwater channels (Chohan et al. 2024). They have been built as a multi-functional network, to manage urban infrastructure needs and to safeguard biodiversity (Bazai et al. 2024). The incorporation of GBI into high altitude urban planning can help overcome the problems of slope and seasonal weather. For instance, instead of sending stormwater into concrete pipes which can accelerate water flow and cause increased flood risk downstream, nature-based drainage systems include vegetated swales, rain gardens and retention ponds (Iqbal et al., 2025). By slowing, filtering and absorbing the stormwater these systems lessen the strain on municipal infrastructure while providing well-watered habitat for a variety of local flora and fauna.

The Effects of Urbanization on High Altitude Ecosystems

Fast urbanization in the mountains tends to drastically change the natural environment, leading to challenges that are often more immediate and intense in the mountains than in lowlands. The impervious surfaces of concrete and asphalt alter water movement across the landscape from the natural forest cover and agricultural soils (Elahi et al., 2015). The absence of vegetation to decelerate and absorb the rain causes a rapid flow of storm water off of steep slopes, which can increase soil erosion and create landslides along unstable hillsides (Shahzad et al. 2024).

When building is done on an even slope on the bottom of a valley, it interferes with the free flow of the water in the valley and seasonal streams. This limited hydrology causes frequent flash floods when the season changes to monsoon or when snowmelt is speeded up, which results in damage to property and infrastructure (H. Ullah et al. 2025). Additionally, the continuous building fronts and fenced developments fragment landscape, disconnecting wildlife populations (Hannan et al. 2025). This is exacerbated by urban noise and light pollution, waste disposal in the remaining natural habitats and the loss of native sensitive species from the growing valley.

International Case Studies of Biodiversity Corridor Integration

The city of Davos, Switzerland, in the high mountain altitudes of the Alps is an example of how a dense urban agglomeration can incorporate ecological connectivity into its planning. Like Kanju, Davos is an international tourist and economic town set in a narrow mountain valley, and is also subject to geographical challenges such as steepness, limited development space and sensitive ecosystems. Development and environmental protection are achieved by a spatial planning model, based on strict ecological zoning, at Davos.

One of the main aspects of the Davos model is the maintenance of extensive green corridors, from upper alpine forests to the valley of the Landwasser River. These corridors will remain undeveloped to enable wildlife to avoid the built up core. The city is implementing the following green infrastructure measures in the built environment: (1) Vegetated roofs for large roofs, (2) Multi-functional linear parks along transit corridors, (3) Sustainable stormwater management systems that replicate natural hydrology. This demonstrates the possibility of a high altitude town to develop its economy and density without compromising their natural environment.

The Conservation of Biodiversity in Developing Mountain Regions

In the developing world, the planning of high altitudes is subject to specific constraints such as low investment in urban services, poor application of the law in terms of zoning, and the need to focus on short-term social-economic development. Copying engineering solutions that require a lot of capital from rich alpine countries is not always possible in such environments. However, studies show that combining environmental protection with local economic gains is done through multi-functional spaces and through community stewardship.

Successful projects in developing regions, for example, do not seek to set aside exclusive environmental reserves prohibiting all use by people, but seek to develop green infrastructure that can be managed by the community. This extends to linear parks, as wildlife corridors while simultaneously offering public recreation space, or to the safe of traditional fruit orchards that provide ecological stepping stones and livelihoods to local populations. Planning can encourage the community to take part in the planting of native plants and the maintenance of local waterways,

helping to foster community ownership of the process and thereby support longer-term environmental protection.

Critical Review of Review of Literature

The analysis of the literature shows that there is a considerable gap in research on the ecological urbanism and biodiversity corridors in terms of geographic region. Although considerable literature on environmental planning has been published in the alpine regions of North America and Western Europe, there is little empirical work on the fast-growing, mid-tier mountainous towns of South Asia, especially of northern Pakistan. The majority of local planning activities in these areas remain within the traditional planning framework, which is primarily concerned with the delivery of simple infrastructure services and neglects the landscape ecology and connectivity. In this study, the authors tackle this gap by integrating the tenets of ecological urbanism with the unique geographic, institutional and socio-economic context of the Kanju Township in Swat.

RESEARCH METHODOLOGY

Research Framework Proposed

This research is guided by a conceptual framework that integrates the design principles of ecological urbanism with the spatial metrics of landscape ecology. The framework operates on the premise that the long-term health and resilience of high-altitude urban environments depend on maintaining contiguous connections across the landscape matrix. Rather than treating the city and nature as separate entities, this model positions the built environment as an integrated component of the broader regional ecosystem.

The framework organizes the study area into three core spatial elements:

- **Core Habitats:** Large, relatively undisturbed natural zones that serve as primary habitats and sources of biodiversity, such as the open bed of the Swat River and the higher-elevation mountain ridges surrounding the valley.
- **Linear Corridors:** Continuous pathways, including protected riparian zones along seasonal khwars and wide, tree-lined roads, designed to allow species to move safely through the urban grid.
- **Stepping Stones:** Smaller patches of urban green space—such as family-

owned fruit orchards, neighborhood pocket parks, and institutional campuses—that provide temporary shelter, food, and rest stops for species migrating through developed areas.

By applying this three-part framework to Kanju Township, the study maps out where urban expansion has cut off natural connections and identifies strategic points where green and blue infrastructure can be introduced. This framework bridges the gap between theoretical landscape ecology and practical urban design, providing a structured approach to help Kanju grow while protecting its vital natural systems.

Study Area Selection

Kanju Township is a major urban settlement located in the Swat District of Khyber Pakhtunkhwa, Pakistan. Positioned at an average elevation of approximately 960 meters above sea level, the township occupies a strategic position within the Swat River valley, bordered by the foothills of the Hindu Kush mountain range. The area experiences a temperate climate, featuring cold, clear winters with periodic snowfall on the surrounding ridges and moderate, warm summers influenced by seasonal monsoon rains.

Historically, Kanju was defined by its rich agricultural landscape, characterized by traditional terrace farming, extensive fruit orchards, and an interconnected network of seasonal streams (khwars) that channeled mountain runoff into the Swat River. However, over the past two decades, the town has experienced rapid spatial transformation. Following regional rehabilitation efforts and a significant expansion of the tourism sector across the Swat Valley, Kanju has become a primary center for residential, commercial, and institutional growth, drawing development away from the highly congested center of Mingora located across the river.

This rapid development has expanded the built environment into fertile agricultural lands and along topographically sensitive hillsides. Major infrastructure projects, institutional campuses, and new residential developments have altered the town's traditional landscape. Despite this rapid growth, Kanju's geographic setting—defined by open water channels, remaining agricultural plots, and close

proximity to mountain ridges—provides an ideal opportunity to apply ecological urbanism strategies. By establishing protected green and blue corridors, the township can guide future development in a way that preserves its natural setting and long-term environmental safety.

Research Approach

This study uses an integrated spatial-analytical and qualitative research approach to examine how biodiversity corridors can be incorporated into the urban layout of Kanju Township. By combining the principles of landscape ecology with contemporary urban planning methods, the research evaluates the town's spatial patterns at both the regional valley scale and the local neighborhood scale.

Data Collection

Data collection was structured across two primary tracks to ensure a comprehensive assessment of the study area:

Primary Data: Field surveys and direct site observations were conducted throughout Kanju Township to document current land-use changes, identify localized environmental degradation, and assess remaining vegetation cover. Informal interviews were carried out with long-term local residents to gather insights regarding historical flood lines along the khwars, changes in local wildlife presence, and community interactions with the natural landscape. Specific points of environmental fragmentation, illegal encroachment, and slope modification were recorded using GPS tracking and photographic documentation.

Secondary Data: High-resolution satellite imagery was obtained to analyze land-use changes and track changes in green cover over time. Additional secondary resources included regional topographic maps from the Survey of Pakistan, municipal planning reports, and environmental conservation guidelines from the Khyber Pakhtunkhwa Environmental Protection Agency (KP-EPA).

Spatial Analysis and Mapping

Geographic Information System (GIS) software was used to analyze the collected spatial and topographic data. The spatial analysis involved mapping the region's hydrological networks, evaluating slope gradients, and calculating the connectivity of remaining green spaces. By layering current urban development maps over

ecological data, the study identified critical bottlenecks where continuous built structures have cut off natural wildlife pathways and river buffer zones.

Case Study Comparison

To identify practical, field-tested solutions for high-altitude environments, the study analyzed international planning precedents, focusing on the urban-ecological framework of Davos, Switzerland. The comparative analysis evaluated how Davos implements environmental zoning, structural river buffers, and native vegetation requirements within a constrained mountain topography, adapting these approaches to fit the socio-economic and regulatory conditions of the Swat region.

Data Analysis

The collected field data, spatial maps, and case study insights were synthesized to evaluate the capacity of Kanju's natural landscape to support an interconnected corridor network. This analysis formed the basis for developing targeted design guidelines and policy recommendations, ensuring that proposed environmental corridors align with the township's existing infrastructure and future growth patterns.

DATA COLLECTION & ANALYSIS

Primary Field Survey and Empirical Findings

To assess the spatial and ecological context in Kanju Township, a detailed field survey was undertaken in four zones— Swat River Riparian Zone, Central Urban Core, Agricultural Matrix, and the Northern Foothill Slopes. The two indicators of degradation considered here are structural encroachment (physical distance of permanent buildings from natural ecological baselines) and landscape fragmentation (disaggregation of continuous green spaces into isolated plots), the latter being the most common indicator in use. The most common indicator used is landscape fragmentation, which is the breakdown of continuous green spaces into isolated plots, while the first is structural encroachment (physical distance of permanent buildings from natural ecological baselines).

In Zone 1, Swat River Riparian Zone, field measurements showed that the river did have significant structural encroachment. Within the historical planning references there was a natural buffer of 150 m or more of native willows and poplars extending

further away from the river active area. The current measurement results indicate that permanent brick and mortar residential units, commercial hotels and concrete retaining walls have reached the 12 to 25 m limit from the active water channel. The removal of this riparian buffer has removed the native shrub layer, making the riverbank very susceptible to erosion. Informal discussions with longterm residents verified that this loss of natural vegetation has led to the river cutting deeper into the banks in the summer monsoon resulting in the threat of property lines.

Zone 2: Central Urban Core and Seasonal Streams (Khwars) has the densest impervious cover with more than 78% of the land area covered by asphalt roads, paved courtyard homes, and commercial strips. A field survey was conducted in detail on three main streams (khwars) which run from the northern hills through the town center to the Swat River. Structural data indicates that these natural drainage channels have been heavily modified: Channel Narrowing: The average width of the khwars was reduced from 18 m to less than 4.5 m with illegal building extensions and retaining walls. Household waste and construction rubbish block more than 65% of the open sections of the stream – becoming informal dump sites where streams are natural blue corridors. Loss of Connectivity: Continuous concrete boundary walls across newer residential complexes have completely cut off natural vegetation paths bordering these streams, thus blocking wildlife movement.

Zone 3: The lands around the older core of Kanju were historically the Agricultural Matrix and Traditional Orchards and provided an ecologically strong buffer. These agricultural matrices were followed in a field survey, where the transformation to formal and informal housing schemes was mapped. In addition, green patches remaining in the field show that individual orchards still exist, but they are completely surrounded by high brick walls or by wide unpaved access roads. This enclosure limits the orchards' ability to be stepping stone areas for local birds and pollinators.

Zone 4: Northern Foothill Slopes Higher elevations of the township have steep slopes varying from 18% to greater than 35%. Large amounts of hill cutting for road construction and residential terracing were recorded in the field. The removal of native *Olea ferruginea* (Wild Olive) and *Acacia modesta* (Phulai) trees has brought

into contact the fragile shale and limestone soils with direct rainfall. Visible rill erosion and small scale structural failures were recorded on 42% of the newly cut hillsides from these sites, suggesting the high probability of localized landslides during the monsoon season.

Secondary Spatial Data and GIS Analysis Skills

To complement the field observations, high resolution satellite images (2006 and 2026) were analyzed using GPS software. The change in land use, from natural and agricultural land use cover to the built environment over 20 years is clearly visible in this comparison.

Transitions in Land use and Land Cover (LULC)

This spatial information points to a stark change in the Township's landscape matrix. Only 14.2% of the entire study area was built-up infrastructure, 61.5% was agricultural land, and 24.3% was riparian wetlands and native hillside forests. In 2026, the built-up area accounted for 53.8% of the landscape area, directly encroaching on fertile agricultural area (31.2%) and natural ecological zones (15.0%).

Fragmentation Mapping and Normalized Difference Vegetation Index (NDVI)

Changes in vegetation density was estimated by GIS based NDVI analysis and landscape fragmentation was mapped. In 2006, high vegetation density (NDVI 0.45-0.68) was observed along the Swat River axis and on the northern hillsides, with green strips along the seasonal streams. The 2026 analysis shows an extremely diverse landscape. The continuous green bands have broken up into isolated clusters with low to moderate vegetation values (NDVI between 0.15 and 0.32). This structural fragmentation constitutes evidence of the valley's growing amount of concrete that has broken up natural ecological connections between the valley floor and the upper alpine habitats.

The Hydrological Modeling Component and the Storm Water Runoff Acceleration

Topographic data and land-cover variables were used to perform hydrological modeling and determine the impact of urban development on storm water runoff. The model estimated changes in the Curve Number (CN), which reflects the potential infiltration capacity of a particular landscape based on the infiltration capacity of soil and vegetation cover.

The results reveal that the average CN value for Kanju Township in 2006 was 62 (high water holding capacity) while it was 84 for 2026 (low water holding capacity and high runoff). The shift is such that the same volume of rain causes more than double the amount of peak surface runoff than it did two decades ago, causing the seasonally narrowed streams to increase flash flood potential in the city's downtown area.

Existing Urban and Ecological Conditions

The facts uncovered are very clear, an urban space at odds with its natural surroundings. Without the help of an ecological master plan or environmental controls, Kanju Township has moved from a landscape-dominated rural market town to a concentrated urban space. An understanding of the current state of the township can be achieved by examining the interaction between the built infrastructure and the core natural systems of the township:

The built environment is characterized by single-family houses, commercial and concrete buildings that use predominantly non-porous materials. The horizontal growth of these developments re-sculpted changes to the natural topography, covers up minor drainage areas, and removes the native vegetation. This loss of plant cover has had an impact on the local climate, with day-time temperatures rising in built-up commercial areas, as compared to the remaining orchards surrounding the built-up areas, which is a clear sign of the emerging urban heat island effect.

The biggest environmental disaster is brewing down by the water in the town. The Swat River front and the seasonal streams (khwars) are considered as dump sites of refuse or land to extend building on, and not as the main blue infrastructure network. Natural floodplain is lost when buildings are built directly over stream paths.

During heavy rain, water speeds up quickly without the presence of open banks and native vegetation to reduce the flow of water coming into the mountain. This changed hydrology leads to significant bank erosion, compromises township infrastructure, and leads to a recurring flood pattern that affects the safety of the entire township.

Urbanisation and its Challenges in High Elevation Areas

The Effects of Fragile Topography and Slope Dynamics

A delicate balance of native plant roots on mountain slopes and natural drainage paths. This balance is upset when urban developments approach hillsides to provide flat building sites or cut roads through steep slopes.

In Kanju, the development of areas on the hillside has dislodged natural forest vegetation, leaving vulnerable soils vulnerable to the elements. When the rain falls heavily and for a long time, the bare slopes absorb the rain quickly, causing them to become heavier and to have less friction, and thus causing local landslides and soil failures that pose risk to neighborhoods down-slope.

Hydrological Shocks & Torrential Flows

Water systems in the highlands, on the other hand, are very dynamic ones, where water volume changes very quickly seasonally as it comes from snow melt and suddenly as a result of monsoon cloudbursts. The rivers generally swell slowly over several days in the lowlands, but in the mountains, the river bed can go from dry to dangerous and fast flowing in a matter of minutes (khwars). Rapid hydrologic cycles have been overlooked by the unplanned urbanisation of Kanju. The town has already reduced natural drainage systems in the stream channels and filled floodplains with development which have turned seasonal natural processes into urban hazards.

Climatic Variations and Sensitivity of the Ecosystems

Alpine and sub-alpine ecosystems are very sensitive to temperature fluctuations and anthropogenic activities. In the Swat Valley, a vital need for the wildlife – including native birds, small mammals and important agricultural pollinators – is continuous green pathways for the movement between the different elevation levels as the seasons change.

These are important migration routes that are severed by Kanju's horizontal development in urban areas. Wildlife trapped in small vegetation patches suffer higher stress, limited food sources and poor genetic health, which is a threat to the valley landscape's overall biodiversity.

Case Study Analysis: Davos, Switzerland

This study discusses the spatial planning model of Davos (Switzerland) to find practical solutions to conflicts between urban development and protection of the

environment in Kanju. Davos is situated in an alpine valley at high elevation, and is surrounded by similar geographical constraints as Kanju: steep mountain sides, one of the main river systems (Landwasser) and strong pressures from development from tourism and growing infrastructure.

However, Davos has been able to keep its ecosystem very stable by structuring their space according to their landscape. The city's strategy is based on the following four main projects:

1. Unified Structural Zoning and Elevational Corridors

Davos uses strict zoning laws to maintain wide, unbuilt green corridors that connect upper alpine forests directly with the valley floor and river networks. These green belts run vertically down the mountain slopes and cross through urban areas, ensuring that wildlife migration routes remain unbroken by roads or continuous building structures.

2. Nature-Based River Management

The city avoids using concrete walls or enclosed pipes to manage the Landwasser River and its mountain streams. Instead, riverbanks are stabilized using bio-engineering methods, including dense plantings of native willows and alpine shrubs. These wide, vegetated buffers filter urban stormwater runoff, absorb peak flood volumes, and provide continuous, healthy habitats for riparian wildlife.

3. Integrated Green Building Requirements

Zoning regulations in Davos require all large real estate and public infrastructure developments to incorporate green building elements. New projects must include green roofs to manage stormwater runoff, design open public spaces that can double as flood retention basins during snowmelt seasons, and use porous paving materials to maximize ground water recharge.

4. Community-Led Resource Stewardship

Environmental protection in Davos is supported by active community participation. Local land-use groups and forestry associations work alongside municipal authorities to plant native species, maintain public mountain trails, and monitor stream health, ensuring long-term support for the town's green infrastructure.

DISCUSSION

The results of this empirical research and spatial analysis underscore the need to embrace ecological urbanism in high altitude context, in contrast with traditional planning based on infrastructure. The example of Kanju township shows that when a mountain community grows rapidly and unchecked its natural core systems are soon destroyed. The shrinking agriculture matrix, encroachment on the floodplain of the Swat River, and alteration of seasonal khwars have directly compromised the environmental safety of the town, augmenting the hazard of flash floods and segmenting the habitats.

The 20-year land use information indicates that the concrete base of Kanju has more than tripled, with the number of surface runoff potential (CN) increasing from 62 to 84. This fast change is the reason for the more frequent localized flooding in downtown during the monsoon season. If watercourses are enclosed and made narrower without the presence of plants, the land can no longer slow and absorb water. The shift in this generates an undesirable and dangerous cycle of urban development and growing flood risk, resulting in more concrete walls that are built to meet a flood event and further compromising the environment.

Today, the model of Davos, Switzerland, demonstrates that places can be dense, high-altitude, and not lead to environmental degradation. An important principle of sustainable growth is to set spatial limits where continuous natural pathways are maintained. In Kanju this means changing seasonal streams (khwars) from abandoned waste spaces to green infrastructure protected spaces. The town can implement a multi-functional stormwater management system that will include opening safe corridors for wildlife, reducing local temperatures, and opening those channels by implementing strict building setbacks and planting native trees.

But in the context of Pakistan's planning system, it will be crucial to tackle actual socio-economic and regulatory issues. Top-down zoning mandates are unlikely to be successful if they do not enjoy community support or if they come into conflict with economic development. Thus, the proposed solutions to the Kanju's problem highlight multi-functional design solutions and community-based management.

Taking care of the traditional fruit orchards with porous fencing preserves the local

agricultural income and also preserves the important ecological stepping stones. Likewise, if local residents are involved in the afforestation of hill slopes, it can be effective in ensuring their livelihoods and concurrently the forest cover necessary for slope stabilization. In conclusion, the incorporation of biodiversity corridors into the urban landscape of Kanju suggests that high-altitude urban areas can successfully blend growth and conservation, creating a sustainable space for development in the mountain regions.

CONCLUSIONS

The research findings illustrate the urgent need for landscape-scale planning interventions in urgent, unplanned urbanization in high altitude landscapes for mitigating environmental risk. An examination of the study area in Kanju Township shows that there has been extensive alteration of the built environment, with a significant amount of habitat fragmentation, disruption of natural stream networks, and greater susceptibility to flash flooding and slope failures. Current land use plans that operate only through the prism of roads and buildings are not able to ensure the safety of mountain communities by protecting natural systems.

A proactive way forward is to use the principles of ecological urbanism. If the town's water networks, leftover orchards for agriculture and surrounding mountain slopes are considered as vital infrastructure, Kanju can create a network of green and blue infrastructure to benefit local biodiversity and enhance their climate resilience. In fact, international experiences such as Davos have shown that economic development and environmental protection can go hand in hand when there are clear spatial boundaries and respect for them. Implementing an integrated green infrastructure and blue infrastructure framework is critical for Kanju Township to ensure the future is safe, resilient and sustainable.

RECOMMENDATIONS

There is a need for a proactive rather than reactive regulatory approach to landscape; a need for proactively regulating the long-term environmental safety, climate resilience and habitat connectivity of Kanju Township. First, the city needs to adopt and diligently implement legal riparian protection areas by mandating the establishment of a 100m building setback along the Swat Rivers' banks and a 25m

setback along all seasonal khwars, and gradually replace rigid concrete banks with alternatives that can be stabilized with the growth of dense plantings of willow (*Salix tetrasperma*) and poplar (*Populus ciliata*) trees to restore natural hydrological flows. At the same time, regional building codes should be updated to classify all slopes with a slope of more than 25° as non-buildable conservation areas, and for the slopes with less than 25°, totally follow the natural contour of the slope, reduce the risk of catastrophic landslide and severe rill erosion. Smart agricultural zoning in the built matrix should include the protection of remaining traditional fruit orchards from the encroaching built fabric, potentially encouraging private landowners to replace solid, continuous brick boundaries with open and porous wire fencing, enabling birds, pollinators and small terrestrial mammals access between green stepping stones. This environmental infrastructure, in turn, should be backed by stewardship programs based on local communities so that neighborhood environmental committees can co-manage linear parks, streamside trails and hillside afforestation projects, and make them directly relevant to local socioeconomic benefits and the green building requirements for new institutional and commercial developments, bringing Kanju closer to becoming a replicable model of sustainable high-altitude urbanism.

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