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IMPACTS OF UNPLANNED URBANIZATION ON MICROCLIMATIC TRANSFORMATION AND URBAN HEAT ISLAND INTENSIFICATION IN MOUNTAINOUS SETTLEMENTS: A CASE STUDY OF MURREE AND ADJACENT AREAS

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Keywords: *urban heat island, mountain microclimate, land use change.*

Abstract*: Mountain ecosystems are highly sensitive to land use change and climate variability. Murree, Pakistan (2,291 meters elevation), has experienced rapid urban expansion in recent decades due to rising tourism, population growth, and scattered residential development in surrounding mountain landscapes. This study investigates the impacts of unplanned urbanization on microclimatic transformation and Urban Heat Island intensification in Murree and its adjacent areas through empirical field observations. The author conducted field visits across the study area to examine patterns of forest removal, expansion of residential settlements, construction of hotels, and development of impermeable road infrastructure. Field observations revealed that rapid urbanization has become the principal driver of deforestation and land surface modification. The replacement of forests with buildings, asphalt, concrete, and brick has increased heat absorption, reduced evapotranspiration, and altered the natural mountain microclimate. Horizontal housing expansion has consumed extensive land areas and accelerated forest fragmentation, while impermeable concrete rural roads have contributed to localized heat accumulation and reduced groundwater infiltration. The findings indicate that sustainable mountain urban planning requires strict regulation of land development, conservation of forests, adoption of permeable pavement technologies, and promotion of earthquake-resilient multistoried residential structures. The study recommends that future urbanization in Murree and its surrounding mountain settlements should align with the Global Forest Goals to protect ecosystem services, strengthen climate resilience, and minimize Urban Heat Island effects. These findings provide practical guidance for planners, engineers, environmental managers, and policymakers seeking sustainable development in mountainous environments under changing climatic conditions.*

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UTICAJI NEPLANSKE URBANIZACIJE NA MIKROKLIMATSKE PROMJENE I INTENZIVIRANJE URBANOG TOPLOTNOG OSTRVA U PLANINSKIM NASELJIMA: STUDIJA SLUČAJA MURIJA I OKOLNIH PODRUČJA

***Ključne riječi**: urbano toplotno ostrvo, planinska mikroklima, promjena namjene zemljišta.*

Sažetak: *Planinski ekosistemi veoma su osjetljivi na promjene namjene zemljišta i klimatsku varijabilnost. Muri (Murree) u Pakistanu, smješten na nadmorskoj visini od 2.291 metar, posljednjih decenija bilježi ubrzano urbano širenje usljed razvoja turizma, rasta stanovništva i raspršene stambene izgradnje u okolnim planinskim predjelima.*

Ovo istraživanje analizira uticaje neplanske urbanizacije na promjene mikroklime i intenziviranje efekta urbanog toplotnog ostrva u Muriju i okolnim područjima na osnovu empirijskih terenskih posmatranja. Autor je sproveo terenske posjete na području istraživanja kako bi analizirao obrasce uklanjanja šuma, širenja stambenih naselja, izgradnje hotela i razvoja nepropusne putne infrastrukture.

Terenska zapažanja pokazala su da je ubrzana urbanizacija postala glavni pokretač krčenja šuma i promjena karakteristika zemljišne površine. Zamjena šumskih površina zgradama, asfaltom, betonom i opekom povećala je apsorpciju toplote, smanjila evapotranspiraciju i izmijenila prirodnu planinsku mikroklimu.

Horizontalno širenje stambene izgradnje zauzelo je velike površine zemljišta i ubrzalo fragmentaciju šuma, dok su nepropusni betonski ruralni putevi doprinijeli lokalnom akumuliranju toplote i smanjenoj infiltraciji podzemnih voda.

Rezultati ukazuju na to da održivo urbano planiranje u planinskim područjima zahtijeva strogu regulaciju korišćenja zemljišta, očuvanje šuma, primjenu tehnologija propusnih kolovoza i podsticanje izgradnje višespratnih stambenih objekata otpornih na zemljotrese.

Istraživanje preporučuje da buduća urbanizacija Murija i okolnih planinskih naselja bude usklađena sa Globalnim ciljevima za šume (Global Forest Goals) kako bi se zaštitile usluge ekosistema, ojačala otpornost na klimatske promjene i smanjili efekti urbanog toplotnog ostrva. Ovi nalazi pružaju praktične smjernice urbanistima, inženjerima, stručnjacima za upravljanje životnom sredinom i donosiocima odluka koji teže održivom razvoju planinskih područja u uslovima klimatskih promjena.

1. Introduction

Mountain environments provide essential ecological services that include climate regulation, biodiversity conservation, groundwater recharge, carbon sequestration, and watershed protection. These ecosystems are particularly vulnerable to rapid urban expansion because changes in vegetation cover and land use can substantially alter local climatic conditions and ecological processes (IPCC, 2023).

Murree is one of the most important mountain resort cities of Pakistan. The city is located in the northern part of Punjab Province at an elevation of 2,291 meters above sea level. Historically, Murree remained surrounded by dense temperate forests that maintained a cool mountain climate throughout the year. These forests regulated local temperature through shading, evapotranspiration, and moisture recycling.

During recent decades, Murree and its adjacent mountainous landscapes have experienced rapid urban growth. Expansion of hotels, commercial buildings, tourism infrastruc-

ture, scattered residential settlements, and road networks has transformed large portions of the natural landscape. The increasing demand for land has accelerated forest clearance and fragmentation, thereby altering the mountain microclimate.

The principal drivers of forest loss and Urban Heat Island formation are rapid urbanization in Murree city and its surrounding mountainous settlements together with the construction of unplanned housing developments, hotels, and expanding road networks serving dispersed rural communities. This pattern has substantially increased deforestation while replacing natural vegetation with artificial construction materials.

Forests regulate temperature and the hydrological cycle through evapotranspiration (Food and Agriculture Organization of the United Nations, 2024). Trees continuously release water vapour into the atmosphere, provide shade, and reduce incoming solar radiation. Following deforestation, exposed land surfaces absorb greater amounts of solar energy, resulting in higher land surface temperatures, reduced humidity, altered rainfall characteristics, and accelerated regional warming.

Urban Heat Island formation is strongly influenced by land cover transformation. Construction materials such as asphalt, concrete, steel and brick possess relatively high heat storage capacities. These materials absorb considerable solar radiation during daytime and gradually release stored heat after sunset, producing warmer urban environments than surrounding vegetated landscapes (Oke et al., 2017).

Horizontal residential expansion presents an additional environmental challenge because it occupies significantly larger land areas than multistory residential buildings. Continuous horizontal development increases forest fragmentation, road construction, and impervious surface coverage, thereby intensifying Urban Heat Island effects.

The Government of Punjab therefore needs to introduce comprehensive legislation that restricts horizontal housing expansion within Murree and adjacent mountainous settlements while promoting earthquake-resilient multistory residential structures. Such planning policies would reduce land consumption, conserve forests, and improve environmental sustainability in this seismically active mountain region. Similarly, impermeable concrete rural roads increase heat storage while reducing groundwater infiltration. Future rural infrastructure should therefore adopt permeable concrete pavement technologies that reduce surface temperature, improve rainwater infiltration, and enhance environmental resilience.

The urban development of Murree and its surrounding mountainous landscapes should also align with the Global Forest Goals, ensuring that forest conservation remains an integral component of sustainable mountain development and climate adaptation strategies.

This research aims to examine the impacts of unplanned urbanization on mountain microclimate transformation and Urban Heat Island intensification through empirical field investigation conducted in Murree and its adjacent mountain settlements.

2. Methodology

This research employed an empirical qualitative field investigation supported by scientific literature and observational analysis. The author conducted field visits throughout Murree and adjacent mountainous settlements during the research period to document existing land use conditions, forest cover changes, urban expansion, transportation infrastructure, and environmental characteristics.

The field investigation included direct visual assessment of forest degradation, scattered residential development, hotel construction, mountain road expansion, and changes in natural vegetation. Original field photographs were collected as primary observational evidence to document environmental transformation across different locations within the study area.

The study adopted an observational assessment approach rather than experimental measurement because the objective was to evaluate visible landscape transformation and its relationship with Urban Heat Island formation. Field observations were compared with established scientific knowledge concerning land surface processes, Urban Heat Island development, and mountain microclimates.

Particular attention was given to the following variables:

- Forest cover loss
- Expansion of residential settlements
- Hotels development
- Road networks construction and expansion
- Impermeable concrete surfaces
- Mountain landscape transformation
- Urban Heat Island contributing factors
- Environmental sustainability

The findings were interpreted using published literature on climate science, urban climatology, sustainable urban planning, forest ecology, and mountain ecosystem management. This combination of empirical field evidence and scientific literature enhanced the reliability of the research findings. As shown in figure 1, extensive deforestation on mountain slopes adjacent to Murree. Forest removal for scattered housing development and infrastructure construction has exposed bare mountain surfaces, increased solar heat absorption, reduced evapotranspiration, and contributed to local microclimatic transformation and Urban Heat Island intensification.

Figure 1: Deforested mountain landscape in the adjacent areas of Murree (Source: Field Photograph taken by the author)

3. Results

The field investigation demonstrated that Murree and its adjacent mountainous settlements have undergone substantial land use transformation during recent decades. The expansion of residential settlements, tourism infrastructure, hotels, commercial establishments, and transportation networks has significantly altered the natural mountain environment. These developments have reduced forest cover, increased impervious surfaces, and modified the natural microclimate.

Forest Loss and Landscape Transformation

The field observations revealed extensive deforestation on mountain slopes surrounding Murree. Large areas previously covered by temperate forests have been converted into residential plots, hotels, access roads, and other urban infrastructure. The removal of vegetation has exposed bare soil and rock surfaces that absorb greater quantities of solar radiation than forested landscapes.

Forests regulate local temperature through canopy shading and evapotranspiration. Trees continuously transfer water vapor into the atmosphere, thereby cooling the surrounding environment. After forest removal, the exposed mountain surfaces become warmer because incoming solar radiation is directly absorbed by soil, exposed rock, asphalt, concrete, and building materials. This process increases local air temperature and contributes to Urban Heat Island formation.

The field investigation confirmed that the principal drivers of forest loss are rapid urbanization within Murree city and the continuous expansion of scattered residential rural settlements throughout adjacent mountainous areas. Construction of hotels, commercial buildings, private residences, and road infrastructure has accelerated forest fragmentation and reduced ecological connectivity.

The environmental consequences extend beyond increasing temperature. Forest loss reduces biodiversity, decreases groundwater recharge, alters local humidity, and weakens the natural regulation of rainfall patterns. These observations are consistent with scientific evidence demonstrating that forests regulate both the energy cycle and the hydrological cycle through evapotranspiration and carbon sequestration.

Expansion of Urbanized Mountain Landscapes

The empirical investigation identified substantial growth of dispersed housing throughout the surrounding mountain valleys. Residential buildings have expanded into previously forested landscapes without comprehensive land use planning. The scattered development pattern has required additional road construction, utility infrastructure, electricity transmission lines, and water supply systems, resulting in continuous fragmentation of natural ecosystems.

Unlike compact urban development, horizontal housing consumes considerably larger land areas. Every additional residential plot requires clearance of vegetation and expansion of transportation infrastructure. Consequently, horizontal development accelerates environmental degradation while increasing the overall extent of impervious surfaces.

The investigation also observed increasing numbers of hotels and tourism facilities distributed across mountain slopes. These structures have replaced vegetation with concrete,

brick, and asphalt surfaces that store significant amounts of thermal energy throughout the day.

Figure 2 clearly illustrates that urban development has expanded well beyond the historical urban boundary of Murree. Residential structures are now distributed throughout adjacent mountain landscapes, increasing pressure on forests and altering the natural environmental balance.

Figure 2: Urbanized mountain landscapes of the adjacent areas of Murree (Source: Field Photograph taken by the author)

Urban Heat Island Contributing Factors

The field investigation identified several major factors contributing to Urban Heat Island formation.

The first factor is deforestation. Removal of trees decreases natural shading and significantly reduces evapotranspiration, allowing greater absorption of solar radiation by exposed land surfaces.

The second factor is the increasing use of asphalt, concrete, steel and brick in roads, buildings, parking areas, retaining walls, and commercial developments. These construction materials possess high thermal capacity and store heat during daytime before gradually releasing it after sunset. Consequently, urbanized mountain areas remain warmer than surrounding forested landscapes.

The third factor is horizontal urban expansion. Compared with multistory residential buildings, horizontally distributed housing requires substantially larger land areas, resulting in greater forest clearance and increased impervious surface coverage.

The fourth factor is expansion of transportation infrastructure. Newly constructed roads connect scattered rural settlements across mountain slopes. Although these roads improve accessibility, they simultaneously increase impervious surface area and reduce natural infiltration.

The combined influence of these factors has transformed the thermal characteristics of Murree and adjacent mountain settlements. The empirical observations indicate that

Urban Heat Island formation is becoming increasingly evident despite the naturally cool mountain climate.

Impervious Surface Expansion

Another significant finding concerns the rapid increase in impervious land surfaces throughout the study area. Buildings, parking facilities, concrete pavements, retaining wall structures, and road networks have progressively replaced permeable natural soils.

Impervious materials prevent rainwater infiltration, increase surface runoff, reduce groundwater recharge, and elevate surface temperature. These processes reduce environmental resilience during periods of intense rainfall while simultaneously increasing thermal stress during summer months.

Field observations indicate that continuous expansion of impervious infrastructure has substantially modified the natural hydrological behavior of mountain landscapes. The environmental consequences include increasing erosion, declining soil moisture, and warmer local climatic conditions.

4. Discussion

The empirical findings demonstrate that the mountainous environment of Murree is undergoing a significant microclimatic transformation as a consequence of unplanned urbanization. Although Murree has historically maintained a cool mountain climate because of its dense temperate forests and high elevation, increasing anthropogenic activities are progressively modifying the thermal characteristics of the region. Murree, Pakistan, has an elevation of **2,291 meters above sea level**, yet elevation alone can no longer offset the effects of extensive land use change and deforestation.

The field observations indicate that rapid urbanization is the principal driver of forest loss throughout Murree and its adjacent mountainous settlements. Expansion of hotels, commercial buildings, private housing, and transportation infrastructure has resulted in continuous removal of forest vegetation. These findings are consistent with previous studies reporting that land use change is one of the primary causes of Urban Heat Island development in mountain environments.

Forests perform an essential function in regulating both local temperature and the hydrological cycle. Trees provide shade that limits direct solar radiation reaching the land surface while simultaneously releasing water vapor through transpiration. This natural process cools the surrounding atmosphere and maintains environmental moisture. Following deforestation, exposed land absorbs greater quantities of solar radiation and becomes considerably warmer. Consequently, local temperatures increase while humidity decreases, producing a warmer and drier mountain environment. These processes may also influence rainfall characteristics because forests play an important role in regulating the Earth's water and energy cycles.

The study further demonstrates that construction materials substantially influence Urban Heat Island formation. Asphalt, concrete, steel and brick possess relatively high thermal mass and store considerable amounts of solar energy during daytime hours. The accumulated heat is gradually released after sunset, causing urbanized locations to remain warmer than surrounding forested areas. The replacement of vegetation by construction

materials therefore represents a major mechanism through which unplanned urbanization alters mountain microclimates.

An important observation emerging from the field investigation concerns the pattern of residential development. Horizontal housing expansion occupies much larger land areas than multistory residential construction. Every additional housing plot requires further forest clearance together with expansion of access roads, electricity distribution, drainage systems, and water supply infrastructure. Consequently, scattered horizontal development substantially increases impervious surface coverage while accelerating forest fragmentation and ecological degradation.

The field investigation also identified the environmental implications of tourism-related development. Murree continues to experience increasing tourist arrivals each year, resulting in growing demand for hotels, guest houses, restaurants, commercial markets, parking facilities, and recreational infrastructure. Although tourism contributes positively to the regional economy, uncontrolled physical expansion increases environmental pressure on fragile mountain ecosystems. Sustainable tourism therefore requires environmentally responsible land use planning that protects forests while accommodating economic development.

Another significant finding concerns transportation infrastructure. Rural communities surrounding Murree have increasingly been connected through extensive concrete road networks. Although these roads improve accessibility and socioeconomic development, impermeable concrete surfaces contribute to Urban Heat Island formation by increasing heat storage and reducing rainwater infiltration.

Figure 3 shows impermeable concrete rural roads constructed through mountainous forest landscapes surrounding Murree. These surfaces increase heat storage, reduce natural water infiltration, and contribute to localized Urban Heat Island formation. Adoption of permeable concrete pavement would improve groundwater recharge while reducing surface temperature.

Figure 3: Impermeable concrete rural roads
(Source: Field Photograph taken by the author)

The observations indicate that future rural transportation projects should prioritize permeable concrete pavement wherever engineering conditions permit. Permeable pavement allows rainwater infiltration, reduces stormwater runoff, improves groundwater recharge, and decreases heat accumulation at the pavement surface. Such infrastructure would contribute simultaneously to climate adaptation and sustainable mountain development.

The present investigation also highlights the importance of integrating forest conservation with urban planning. Future urbanization of Murree and its surrounding mountain settlements should align with the **Global Forest Goals** by protecting existing forest resources, restoring degraded landscapes, and minimizing unnecessary land conversion (International Model Forest Network, n.d.). Forest conservation remains one of the most effective natural strategies for regulating mountain temperatures, conserving biodiversity, protecting watersheds, and strengthening climate resilience.

The Government of Punjab should formulate comprehensive legislation that restricts uncontrolled horizontal housing development within Murree city and adjacent mountain settlements. Earthquake resilient multistory residential buildings should be encouraged because they accommodate larger populations while occupying considerably smaller land areas. Such planning strategies would reduce forest clearance, decrease infrastructure expansion, and minimize Urban Heat Island development while improving public safety in this seismically active region.

Overall, the empirical evidence demonstrates that sustainable mountain urbanization requires an integrated planning framework combining environmental conservation, climate adaptation, resilient infrastructure, forest protection, and scientifically informed land use policies. Without timely intervention, continued unplanned urbanization may substantially alter the unique mountain microclimate that has historically distinguished Murree as one of Pakistan's premier hill stations.

Pakistan based company Pakneftegaz provides consultancy services related to the identification, assessment, and mitigation of Urban Heat Island effects through interdisciplinary approaches. The company supports sustainable urban development by promoting environmentally responsible planning strategies, including enhancement of urban vegetation, conservation of existing forests, optimization of building materials, improvement of surface permeability, and adoption of climate-responsive infrastructure solutions.

5. Conclusion

The empirical investigation confirms that unplanned urbanization has become the dominant factor responsible for microclimatic transformation and increasing Urban Heat Island intensity in Murree and its adjacent mountainous settlements. Sustainable land use planning, forest conservation, environmentally responsible infrastructure, and resilient urban development policies are essential for preserving the ecological integrity and climatic stability of this internationally recognized mountain resort.

(i) Rapid urbanization is the principal driver of deforestation in Murree and adjacent mountainous landscapes.

(ii) Forest loss has reduced evapotranspiration, increased solar heat absorption, and altered the natural mountain microclimate.

(iii) Asphalt, concrete, steel and brick significantly contribute to Urban Heat Island formation because of their high heat storage capacity.
(iv) Horizontal residential development consumes substantially greater land area than multistory residential buildings and accelerates forest fragmentation.
(v) Impermeable concrete rural roads increase localized surface temperature and reduce groundwater recharge.
(vi) Future rural transportation projects should adopt permeable concrete pavement wherever technically feasible.
(vii) The Government of Punjab should prohibit uncontrolled horizontal housing expansion and promote earthquake-resilient multistory residential structures.
(viii) Urban development should integrate climate resilience, sustainable land use planning, and ecosystem conservation.
(ix) Future urbanization of Murree and adjacent mountain settlements should align with the Global Forest Goals.
(x) Protecting forests remains one of the most effective long-term strategies for reducing Urban Heat Island intensity and preserving the unique mountain climate of Murree.

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