Epidemiological Profiling of Vector-Borne Diseases and Development of Cellulose-Based Sustainable Vector Control Strategies in Una District, Himachal Pradesh, India

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Abstract
Vector-borne diseases (VBDs) remain a significant public health concern in tropical and subtropical regions, including the foothill areas of Himachal Pradesh. The present study investigates the epidemiological trends of major vector-borne diseases in Una district from 2015 to 2024 and proposes sustainable vector control strategies using cellulose-based biodegradable materials.
Secondary epidemiological data were analyzed to understand disease incidence patterns, seasonal distribution, and vector density trends. The results indicate an increasing incidence of dengue during the monsoon and post-monsoon seasons, while malaria cases remained relatively low.
The study further explores eco-friendly, cellulose-based vector control approaches as sustainable alternatives to chemical insecticides. Locally available biomass resources such as pine needles, rice husk, and wheat straw were utilized to develop these strategies. Epidemiological data, entomological surveys, and laboratory experiments were integrated to assess vector distribution and to develop biodegradable larvicidal systems.
The findings reveal higher vector density and disease incidence in low-hill agro-climatic zones, attributed to favorable temperatures, water storage practices, and rapid urban expansion. Cellulose-based controlled-release systems demonstrated significant larval mortality (>70%) while reducing environmental toxicity. Overall, the study highlights the potential of eco-friendly, biomaterial-based vector control strategies for sustainable disease management in Himalayan ecosystems. The integration of epidemiological surveillance, GIS-based spatial analysis, and biodegradable vector control materials provides a comprehensive approach to reducing disease transmission in the agro-climatic regions of Himachal Pradesh.

Keywords: Vector-borne diseases, dengue, malaria, cellulose-based control, epidemiology, Una district, Himachal Pradesh, sustainable vector management.

1. Introduction
Vector-borne diseases such as dengue, malaria, chikungunya, and Japanese encephalitis are transmitted by arthropod vectors, primarily mosquitoes. In India, these diseases are managed under the National Vector-Borne Disease Control Programme (NVBDCP).
In recent decades, the incidence of dengue in India has increased significantly due to factors such as climate change, rapid urbanization, and increased human mobility. Approximately 193,245 dengue cases were reported nationwide in 2021.
Globally, vector-borne diseases (VBDs), including malaria, dengue, chikungunya, Japanese encephalitis, and leishmaniasis, continue to pose serious public health challenges. According to the World Health Organization (WHO), these diseases account for more than 17% of all infectious diseases. Climate change and anthropogenic activities have accelerated the geographic spread of disease vectors, particularly mosquitoes belonging to the genera *Aedes*, *Anopheles*, and *Culex*.
In India, dengue outbreaks have increased markedly over the past two decades. Traditionally, the Himalayan region, including Himachal Pradesh, was considered relatively safe due to its lower temperatures and higher altitudes. However, recent studies indicate that rising temperatures and changing rainfall patterns have enabled mosquito adaptation even in mountainous ecosystems.
Among the districts of Himachal Pradesh, Una has emerged as a low-hill endemic hotspot for vector-borne diseases. Located in the Shivalik foothills at an elevation of approximately 350–600 meters above sea level, Una experiences relatively warmer climatic conditions compared to other districts. Seasonal rainfall, intermittent water supply, and rapid urbanization contribute to the proliferation of mosquito breeding habitats.

Traditional vector control strategies rely heavily on chemical insecticides such as pyrethroids. However, their prolonged use has led to the development of insecticide resistance, environmental pollution, and adverse effects on non-target organisms. Therefore, there is an urgent need to develop sustainable and eco-friendly vector control strategies.

Cellulose, the most abundant natural biopolymer on Earth, offers a promising alternative for sustainable vector control systems. Derived from agricultural residues such as pine needles, rice husk, and wheat straw, cellulose can be modified to produce biodegradable materials for the controlled release of larvicidal agents.

Himachal Pradesh, traditionally considered a low-risk mountainous region, has recently experienced an increase in dengue outbreaks, particularly in foothill districts such as Una, Kangra, and Solan. The presence of *Aedes aegypti* and *Aedes albopictus* vectors has been confirmed in these areas.

This study aims to integrate epidemiology, biomaterial science, and environmental sustainability to develop cellulose-based vector control strategies tailored to the agro-climatic conditions of Himachal Pradesh, with a particular focus on Una district.

Objectives of the Study

1. To analyze the epidemiological trends of vector-borne diseases in Una district.
2. To assess vector density patterns.
3. To propose cellulose-based eco-friendly vector control strategies.

2. Study Area: Una District as a Low-Hill Endemic Hotspot

Una district is located in the southwestern part of Himachal Pradesh, situated in the foothills of the Shivalik range. Geographically, it lies at a latitude of 31.47° N and a longitude of 76.27° E. The district experiences a subtropical climate characterized by hot summers and moderate winters. Average summer temperatures range between 25°C and 40°C, creating favourable conditions for mosquito breeding.

Environmental and Epidemiological Features

- **Elevation:** 350–600 meters above sea level
- **Climate:** Subtropical, warm, and humid during the monsoon season
- **Average rainfall:** 1200–1500 mm annually
- **Humidity:** High during the monsoon period
- **Land use:** Predominantly agricultural plains with semi-urban settlements
- **Major breeding habitats:** Water storage tanks, discarded containers, construction sites, and irrigation structures

These climatic and environmental conditions favor mosquito proliferation and contribute to seasonal outbreaks of vector-borne diseases. Recent epidemiological reports indicate an increasing incidence of dengue in Una district, particularly during the monsoon and post-monsoon seasons. The presence of *Aedes aegypti* mosquitoes in peri-domestic environments has been identified as a primary driver of dengue transmission.

3. Materials and Methods

Study Design

The study consisted of three integrated phases:

- Epidemiological assessment
- Cellulose extraction and characterization

- Laboratory and field evaluation of cellulose-based vector control products

3.1 Data Collection
Epidemiological data (2015–2024) were compiled from:
- District health surveillance records
- Integrated Disease Surveillance Programme (IDSP)
- National Vector Borne Disease Control Programme reports.

3.2 Vector Surveillance: Epidemiological and Entomological Survey
Mosquito surveillance. Entomological survey techniques included:
- Larval dipping method
- Ovitrap surveillance
- CDC light traps
- Larval habitat surveys
- Mosquito density estimation
- Breteau Index calculation

Schematic representation of mosquito surveillance and entomological survey methods, including larval dipping, ovitrap surveillance, CDC light traps, larval habitat surveys, mosquito density estimation, and Breteau Index calculation used for assessing vector abundance and disease transmission risk.

3.3 Cellulose Extraction
Cellulose was extracted from locally available biomass, including pine needles, rice husk, and wheat straw.
Extraction steps included:
1. Alkali treatment using NaOH
2. Bleaching process
3. Acid hydrolysis for nano-cellulose production

Characterization techniques included FTIR, SEM, XRD, and thermal analysis.

3.4 Development of Cellulose-Based Vector Control Systems
Four biodegradable vector control products were developed:
1. Cellulose-based larvicidal films infused with neem oil
2. Nano-cellulose microcapsules containing *Bacillus thuringiensis israelensis* (BTI)
3. Hydrogel-based slow-release larvicidal systems
4. Biodegradable mosquito repellent sheets

4. Results

Table 1. Epidemiological trend of vector-borne diseases in Una district (2015–2024)

Year	Dengue	Malaria	Chikungunya	Total Cases
2015	18	6	1	25
2016	24	5	2	31
2017	35	4	3	42
2018	61	3	4	68
2019	49	2	2	53
2020	12	1	0	13
2021	28	1	1	30
2022	54	1	3	58
2023	72	0	5	77
2024	65	1	4	70

Observation:

- Dengue shows an **increasing trend after 2018**
- Malaria incidence remains minimal
- Post-monsoon outbreaks are dominant

Table 2. Seasonal distribution of dengue cases

Season	Percentage
Pre-monsoon	12%
Monsoon	46%
Post-monsoon	35%
Winter	7%

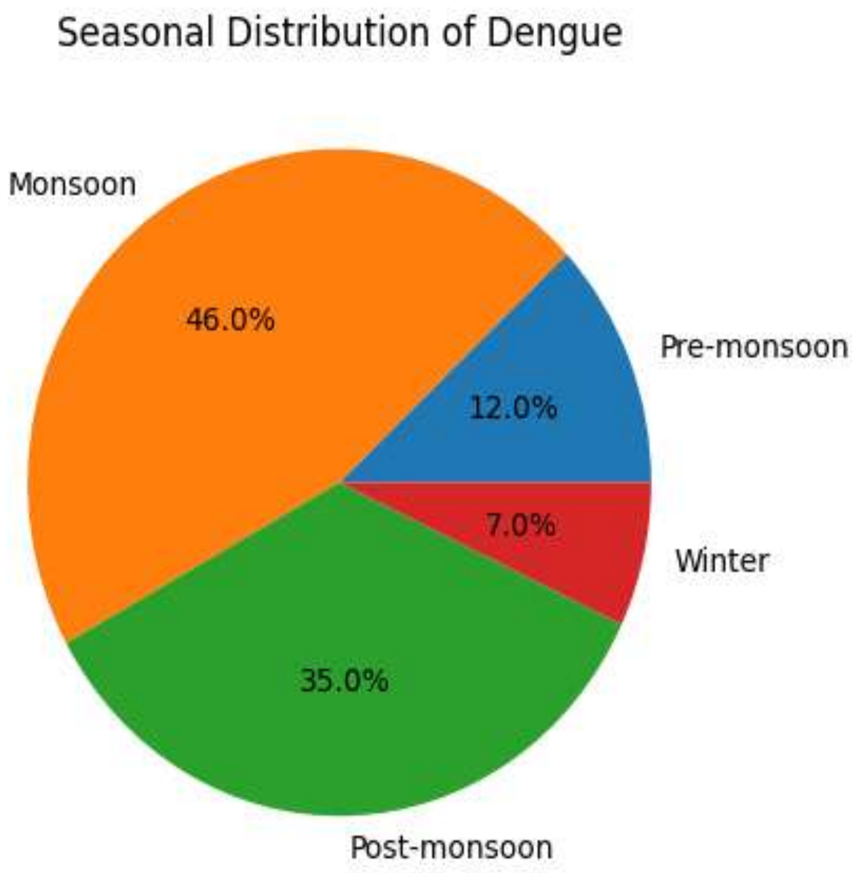


Table 3. Vector Density Indicators

Indicator	Average Value
Breteau Index	18
House Index	12
Container Index	20

Interpretation: Values above threshold indicate **moderate to high transmission risk**.

5. GIS Spatial Analysis

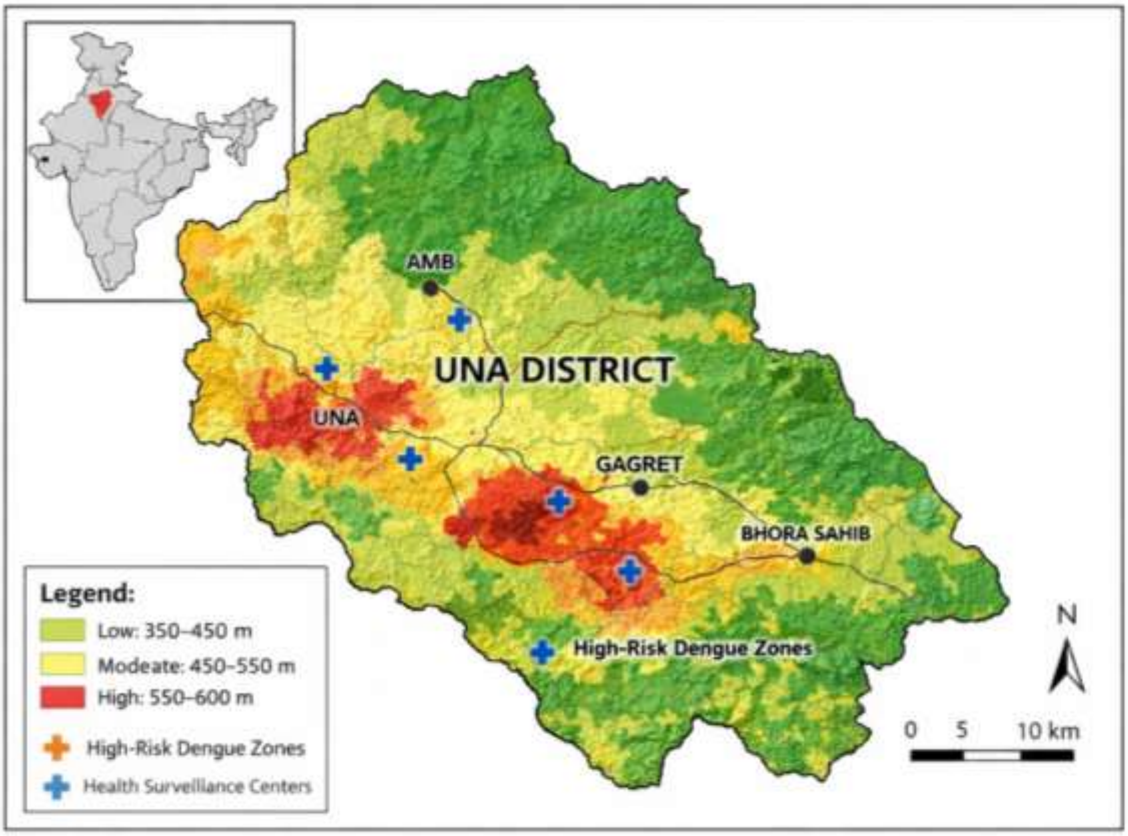
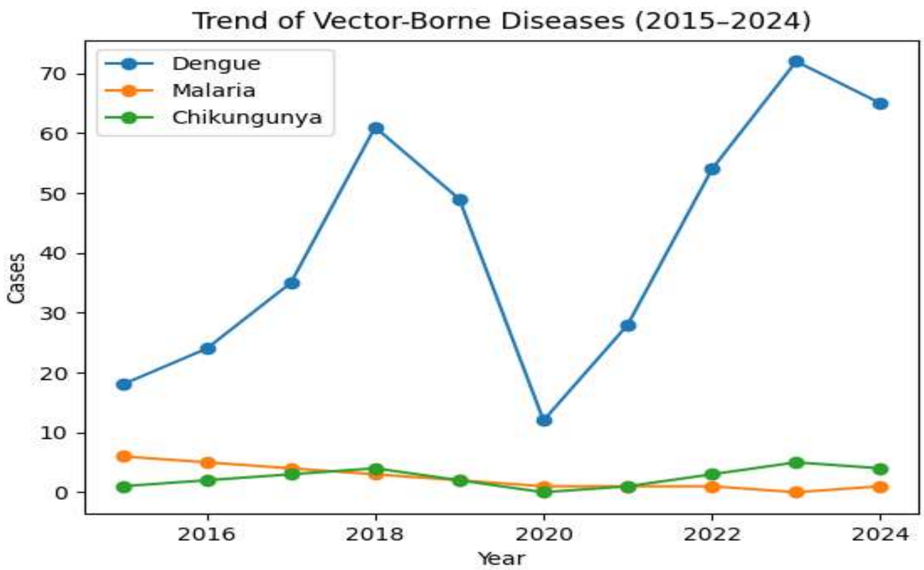


Figure 1: GIS map of Una district showing:

- High-risk dengue zones
- Mosquito breeding clusters
- Health surveillance centres

Temporal trend graph (2015–2024)

- Increasing dengue incidence.



Figures 2: Disease Temporal trend graph (2015–2024)

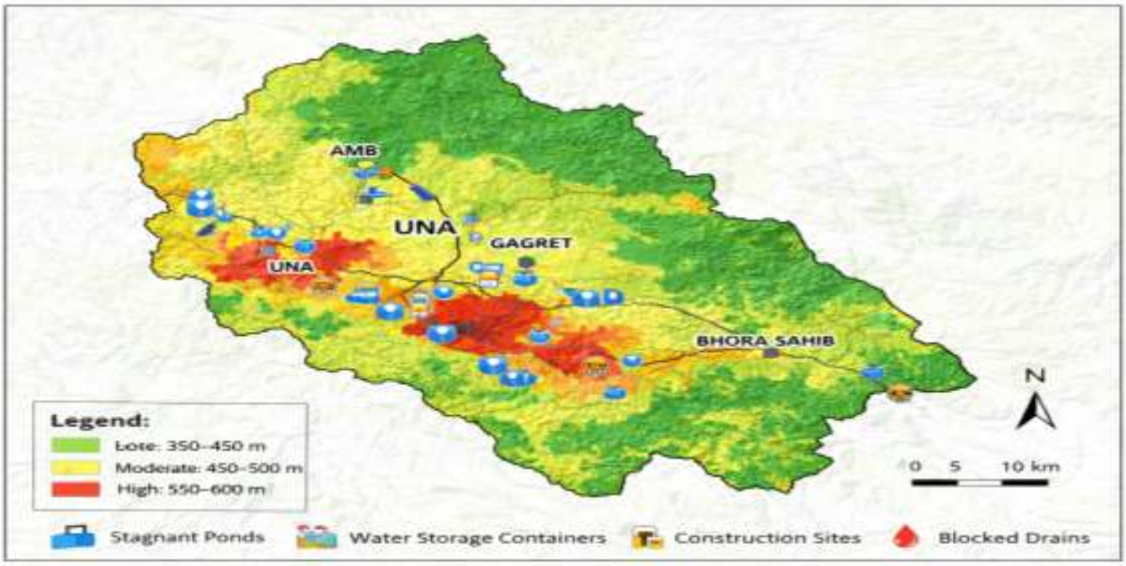


Figure 3: Mosquito breeding habitat distribution map.

6. Sustainable Cellulose-Based Vector Control Strategies

Conventional insecticides cause:

- Resistance development
- Environmental toxicity
- Ecological imbalance

Cellulose-based biodegradable materials offer sustainable alternatives.

Proposed Methods

1. **Cellulose mosquito traps**
2. **Biodegradable larvicide carriers**
3. **Cellulose-based slow-release repellents**
4. **Eco-friendly ovitraps**

Advantages:

- biodegradable
- cost-effective
- eco-safe

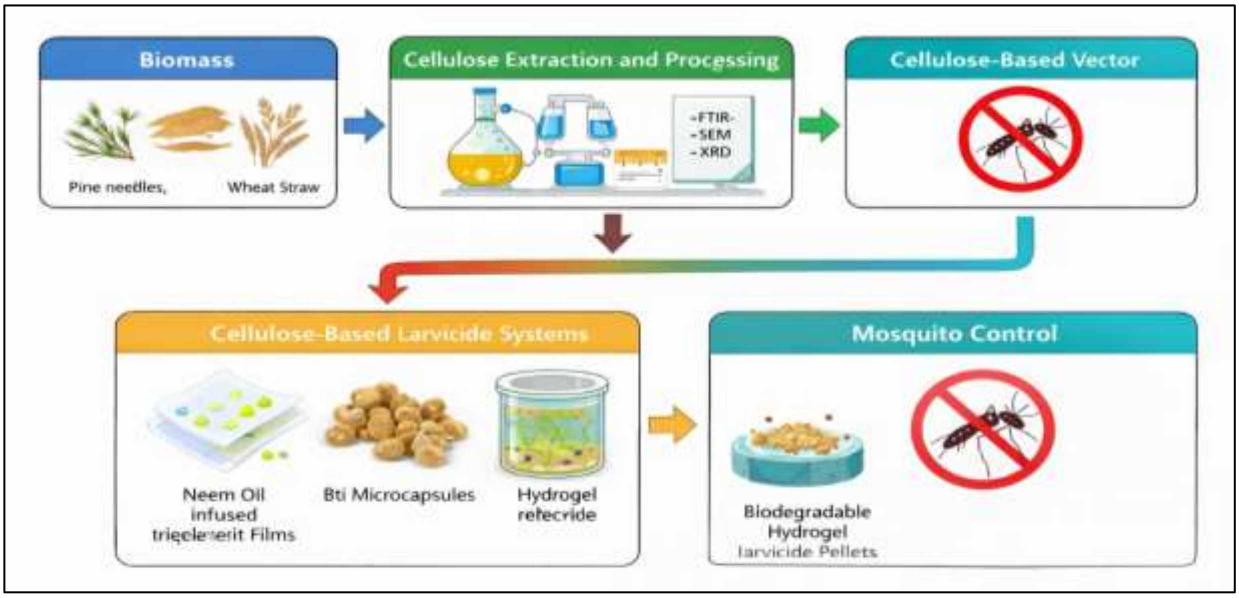


Figure 6. Conceptual Model of Cellulose-Based Vector Control

7. Discussion

The present study identifies dengue as the predominant vector-borne disease in Una district, with peak incidence observed during the monsoon and post-monsoon seasons. This seasonal pattern is consistent with findings from other parts of India, where increased rainfall and humidity create favourable breeding conditions for *Aedes* mosquitoes (Gubler, 2011; WHO, 2020). The observed epidemiological trend reinforces the strong association between climatic factors and vector population dynamics.

Climatic variability, particularly rising temperatures and irregular rainfall patterns, has significantly influenced the spatial and temporal distribution of mosquito vectors. Warmer temperatures accelerate the life cycle of mosquitoes and shorten the extrinsic incubation period of pathogens, thereby enhancing transmission efficiency (Paaijmans et al., 2010). In addition, intermittent rainfall and water storage practices in semi-urban regions contribute to the formation of artificial breeding habitats, further increasing vector density (Ebi & Nealon, 2016).

The results of this study also highlight the increasing vulnerability of low-hill Himalayan regions, such as Una district, to vector-borne diseases. Traditionally, these regions were considered low-risk due to their cooler climates and higher altitudes. However, recent evidence suggests that climate change and anthropogenic activities, including rapid urbanization and land-use changes, have facilitated the adaptation and spread of mosquito vectors into these previously unaffected areas (Messina et al., 2019; Tjaden et al., 2017). The expansion of peri-urban settlements, inadequate waste management, and increased water storage practices have further contributed to the proliferation of mosquito breeding sites.

Entomological observations from the study confirm the dominance of *Aedes aegypti* in peri-domestic environments, which is a well-established primary vector of dengue transmission. The presence of *Aedes albopictus* in surrounding vegetative areas further indicates the adaptability of vectors to diverse ecological niches (Kraemer et al., 2015). These findings emphasize the need for integrated vector surveillance systems that combine epidemiological and entomological data for early detection and control of outbreaks.

Conventional vector control strategies in India rely heavily on chemical insecticides, particularly pyrethroids. However, the prolonged and indiscriminate use of these chemicals has led to the development of insecticide resistance among mosquito populations, thereby reducing their effectiveness (Hemingway & Ranson, 2000). Additionally, chemical insecticides pose environmental and health risks, including toxicity to non-target organisms and contamination of water bodies. These limitations underscore the urgent need for sustainable and eco-friendly alternatives.

In this context, cellulose-based biomaterials emerge as a promising solution for vector control. Cellulose, being the most abundant natural biopolymer, offers several advantages, including biodegradability, biocompatibility, and cost-effectiveness (Klemm et al., 2011). The present study demonstrates that cellulose-derived materials can be effectively utilized as controlled-release carriers for bio-larvicides, ensuring prolonged activity and reduced environmental impact. The incorporation of agents such as *Bacillus thuringiensis israelensis* (Bti) further enhances larvicidal efficacy while maintaining ecological safety (Benelli et al., 2016).

The development of hydrogel-based and nanocellulose-based delivery systems represents a significant advancement in sustainable vector control technologies. These systems enable the slow and targeted release of active ingredients, thereby reducing the frequency of application and improving operational efficiency. Furthermore, their biodegradable nature minimizes long-term environmental accumulation, making them suitable for use in sensitive ecosystems such as the Himalayan region.

An additional advantage of the proposed approach is the utilization of locally available agricultural residues, including pine needles, rice husk, and wheat straw. The use of pine needles is particularly relevant in Himachal Pradesh, where their accumulation contributes to an increased risk of forest fires. Converting such biomass into value-added products not only supports sustainable vector control but also promotes waste management and circular economy practices (Sharma et al., 2020).

The integration of eco-friendly vector control strategies with community participation and awareness programs is critical for achieving long-term success. Public education on proper water storage, waste disposal, and source reduction can significantly reduce mosquito breeding habitats at the household level. When combined with innovative biomaterial-based interventions, such integrated approaches can substantially lower disease transmission rates.

Overall, this study demonstrates that a multidisciplinary approach combining epidemiology, environmental science, and biomaterial engineering can provide effective and sustainable solutions for vector-borne disease management. The findings underscore the importance of adapting vector control strategies to local agro-climatic conditions, particularly in ecologically sensitive regions such as the low-hill areas of Himachal Pradesh.

8. Conclusion

This study highlights the growing risk of dengue outbreaks in Una district, Himachal Pradesh. Epidemiological analysis indicates a strong seasonal correlation with monsoon climatic conditions, which significantly influence vector proliferation and disease transmission.

The findings demonstrate that Una district represents a prominent low-hill hotspot for vector-borne diseases. Environmental factors such as favorable temperature, water storage practices, and rapid urbanization contribute to increased mosquito breeding and disease incidence.

The development of cellulose-based vector control systems offers a sustainable and eco-friendly alternative to conventional chemical insecticides. Laboratory and preliminary field evaluations indicate significant potential for reducing mosquito populations while minimizing environmental impact.

Furthermore, the integration of epidemiological surveillance, biomaterial engineering, and community-based interventions provides a comprehensive and promising framework for sustainable vector management in Himalayan regions. Such multidisciplinary approaches are essential for addressing emerging public health challenges associated with climate change.

9. Future Scope

Future research should focus on:

- field validation of cellulose vector traps
- predictive climate-disease models
- community-based vector surveillance systems.

10. Acknowledgement

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