



HUMAN ECOLOGY, LAND USE CHANGE AND DISEASE VULNERABILITY IN THE IMPHAL VALLEY OF NORTHEAST INDIA: JAPANESE ENCEPHALITIS AS A SENTINEL CONDITION

Th. Manimala Devi^{1*}

^{1*}Deptt of Environmental Science, South East Manipur College, Komlathabi, Chandel District – 795135, Manipur, India.

***Corresponding Author:** Th. Manimala Devi
*Email: drmanimalthok@gmail.com

1. Abstract

Vector-borne diseases are increasingly recognised as outcomes of complex human and environment interactions, particularly in fragile ecosystems undergoing rapid transformation. Northeast India, a biodiversity hotspot marked by high population growth and shifting land-use patterns, offers critical insights into this nexus. This paper examines the links between human ecology, land use change, and disease vulnerability with a focus on Japanese Encephalitis (JE) in the Imphal districts of Manipur. Drawing upon demographic data, land-use surveys, and secondary health reports, the study situates JE as a sentinel disease whose ecology is shaped by rice-paddy cultivation, pig rearing, wetland modification, and settlement density. Rice fields create aquatic habitats conducive to the breeding of *Culex* mosquitoes, while pig husbandry amplifies viral transmission to human populations. Urban expansion and the degradation of natural wetlands further exacerbate the risk by altering ecological balances. Using a human ecology framework, the findings highlight that disease vulnerability is not merely a biomedical issue but the outcome of population pressure, resource use, and unsustainable land transformation. While JE forms the focal case, the broader insights extend to other vector-borne diseases such as dengue and malaria, which similarly thrive under conditions of ecological disruption. The paper argues for integrating One Health approaches and sustainable land management practices into regional planning, emphasising that environmental resilience is fundamental to public health security. In doing so, it contributes to interdisciplinary scholarship on environment–health linkages and offers a timeless framework for understanding how ecological change drives disease vulnerability in fragile landscapes.

Keywords: Vector-borne diseases; Japanese Encephalitis; Human ecology; Land use change; One Health; Imphal Valley; Disease vulnerability

2. Introduction

2.1 Background

Vector-borne diseases constitute one of the most pressing public health challenges of the twenty-first century, particularly in ecologically fragile and rapidly transforming regions (WHO, 2020). The World Health Organization estimates that over 80% of the global population is at risk from at least one vector-borne disease, with malaria, dengue, chikungunya, and Japanese Encephalitis (JE)

among the most widespread (Githeko *et al.*, 2000). These diseases are not merely biomedical phenomena; they are shaped by complex human and environment interactions (Odum, 1971; Patz *et al.*, 2004) that alter the ecology of vectors and pathogens. Consequently, they represent a critical intersection of environmental science, epidemiology, and sustainability studies (Haines *et al.*, 2006; Lambin *et al.*, 2010).

2.2 Human Ecology and Disease Linkages

The conceptual foundation for understanding these linkages lies in human ecology, which examines the interdependence of population, resources and environment (McDonnell & Pickett, 1993). From this perspective, disease vulnerability emerges as a systemic outcome of demographic transitions, land use practices, agricultural intensification, and settlement expansion. Examples from across the globe underscore this point: malaria in African highlands is linked to deforestation and irrigation practices; dengue in Southeast Asia is tied to unplanned urbanisation and water storage behaviours; and JE in rural Asia is embedded within rice–pig agro-ecosystems (Patz & Olson, 2006; Keiser *et al.*, 2005). These insights reinforce the relevance of the One Health paradigm, which highlights the interconnectedness of human, animal, and ecosystem health (Zinsstag *et al.*, 2011; Atlas, 2012).

2.3 Regional Context: Northeast India and Imphal Valley

Northeast India, designated as part of the Indo-Burma biodiversity hotspot, represents an ecologically sensitive yet socio-economically vulnerable region (Myers *et al.*, 2000). The region is marked by rapid population growth, land use transitions, and livelihood shifts that have placed enormous stress on natural resources (Choudhury, 2006). The Imphal Valley of Manipur is a particularly critical case study. Encompassing about 1,843 km², it is home to over 60% of the state's population (Census of India, 2011). The valley is characterised by intensive rice cultivation, widespread pig husbandry, and rapid urban expansion (Singh & Devi, 2018). Wetlands such as Loktak Lake have been shrinking due to encroachment and land reclamation (Trisal & Manihar, 2004; LDA, 2016). These transformations collectively generate ecological niches that support vector proliferation, particularly for *Culex* mosquitoes associated with JE (Solomon *et al.*, 2000; ICMR, 2017).

2.4 Rationale and Research Gap

Existing studies on JE and other vector-borne diseases in India have largely focused on biomedical and epidemiological aspects, such as vaccination coverage, vector control, and clinical case management (WHO, 2020; ICMR, 2017). However, less emphasis has been placed on the structural ecological determinants of disease vulnerability in fragile landscapes. By situating JE within a human ecology framework, this paper addresses a critical research gap emphasising how population growth, land use transformation, and ecological resilience interact to shape long-term disease risk.

2.5 Objectives of the Study

This paper aims to:

1. Examine the relationships between human ecology, land use transformation, and disease vulnerability in Northeast India, with a case study of JE in the Imphal Valley.
2. Situate disease vulnerability within a sustainability and resilience framework, emphasising the role of population pressure and unsustainable land management.
3. Contribute to interdisciplinary scholarship by linking insights from landscape ecology, public health, and environmental planning into a generalisable framework for vector-borne disease vulnerability.

2.6 Contribution of the Paper

By adopting this interdisciplinary approach, the paper moves beyond the biomedical paradigm and demonstrates that environmental sustainability is fundamental to long-term disease risk reduction. It argues that timeless ecological drivers such as demographic pressure, agricultural intensification,

and land use change and determine the trajectory of vector-borne diseases in fragile ecosystems such as the Imphal Valley (Patz *et al.*, 2005; Zinsstag *et al.*, 2011). In doing so, the paper provides a framework that is both locally grounded and globally relevant, making it applicable to disease vulnerability research across diverse ecological and social contexts.

3. Study Area and Methods

3.1 Study Area

The Imphal Valley, located at the core of Manipur in Northeast India, represents a fragile alluvial basin encircled by hill ranges. Geographically, it lies between 23°50'–25°10'N latitude and 93°45'–94°15'E longitude, covering approximately 1,843 km² (Singh & Devi, 2018). Its elevation ranges from 790–830 m above sea level, with a subtropical monsoon climate: hot, humid summers and cool, dry winters (Trisal & Manihar, 2004). The valley is drained by the Imphal, Iril, Nambul and Thoubal rivers, which feed into Loktak Lake, the largest freshwater lake in Northeast India. These wetlands provide crucial ecological services, including flood moderation, fishery resources, and habitat for migratory birds. Yet they have undergone significant shrinkage due to reclamation, siltation, and encroachment (LDA, 2016). Demographically, the Imphal Valley accommodates over 60% of Manipur's population, concentrated in Imphal East, Imphal West, Thoubal and Bishnupur districts (Census of India, 2011). Rice paddies dominate the agricultural landscape, covering more than 70% of cultivated land. Pig rearing is both culturally and economically significant, particularly in peri-urban areas. Together, rice cultivation and pig husbandry create ecological niches ideal for *Culex* mosquitoes, the primary vector of Japanese Encephalitis (Solomon *et al.*, 2000; ICMR, 2017).

3.2 Data Sources

The study synthesises data from multiple secondary sources:

1. Demographic Data : Population growth, density, and settlement distribution from the Census of India (2001, 2011); district-level health and disease surveillance data from the Directorate of Health Services, Manipur.
2. Land Use and Agriculture : Agricultural census data for cropped area, cropping intensity, and livestock (pig) populations; state reports on agricultural practices and rural development; remote sensing and GIS-based land cover analyses.
3. Disease Data: Epidemiological records of JE incidence in Manipur, collated from ICMR and WHO surveillance bulletins (ICMR, 2017; WHO, 2020); comparative data on dengue and malaria from state health departments and published regional studies.
4. Ecological and Environmental Data : Research on wetlands, agro-ecosystem changes and deforestation (Trisal & Manihar, 2004; Choudhury, 2006); theoretical frameworks from landscape ecology and resilience science (Turner *et al.*, 2003; Lambin *et al.*, 2010).

3.3 Analytical Framework and Methods

The methodological design applies a human ecology framework (Odum, 1971), integrating population, resource, and environmental variables to examine disease vulnerability. Three steps were followed:

1. Trend Analysis of Land Use and Demography – Comparative evaluation of land use change (expansion of rice paddies, pig rearing growth, wetland loss); assessment of demographic growth rates and urbanisation patterns relative to disease hotspots; triangulation with remote-sensing interpretations to validate spatial change.
2. Disease Ecology Assessment – Mapping ecological correlates of JE outbreaks, with attention to *Culex* breeding in paddy fields, pig density clusters, and settlement distribution; contextualization with other vector-borne diseases (malaria, dengue, chikungunya) to demonstrate generalisable prin-

ciples (Keiser *et al.*, 2005; Patz & Olson, 2006); use of secondary entomological studies and health reports to connect land use drivers with epidemiological outcomes.

3. Conceptual Modelling of Vulnerability – Development of a causal pathway model linking land use transformation → ecological disruption → vector ecology → human exposure → disease vulnerability (Fig 1); application of resilience theory (Turner *et al.*, 2003) to evaluate the capacity of wetlands and agro-ecosystems to buffer disease risk; integration of One Health perspectives (Zinsstag *et al.*, 2011) to highlight cross-sectoral implications.

3.4 Ethical Considerations

This study is based exclusively on secondary data from published sources, government records and international databases. No human participants or direct field experiments were involved. Ethical approval was therefore not required.

4. Results and Discussion:

Between 2001 and 2011, Imphal Valley districts recorded a moderate rise in population. Imphal East grew from about 411,000 people in 2001 to 456,000 in 2011, representing an overall growth rate of 10.9 %. Population density also increased, reaching approximately 1,005 persons per km², indicating rising demographic pressure on land resources (Table 1 and Fig.2).

Table 1: Population Growth and Density in Imphal Valley Districts (2001–2011)

District	Population 2001	Population 2011	Growth Rate (%)	Density (per km ²)
Imphal East	411,000	456,000	10.9	1,005

The Imphal Valley has experienced a dual transformation over the past two decades: rapid demographic growth and intensified land use. According to the Census of India (2011), population density in Imphal East and West exceeds 1,000 persons per km², among the highest in Northeast India. Urban settlements have expanded into erstwhile agricultural and wetland areas, accelerating land conversion (Singh & Devi, 2018). Despite urbanisation, rice remains the dominant crop, accounting for over 70% of cultivated land. Agricultural intensification has been accompanied by the proliferation of pig husbandry, particularly in peri-urban settlements. The co-location of rice paddies and pig rearing creates a high risk agro-ecosystem for *Culex* mosquito breeding and JE transmission (Solomon *et al.*, 2000; ICMR, 2017).

Livestock numbers, particularly pigs, the recognised amplifying host for Japanese encephalitis (JE) were sizeable at the start of the decade. In 2001, the valley was estimated to have 120,000 pigs, while rice, the dominant crop, covered nearly 150,000 ha. The coexistence of large pig populations with extensive paddy cultivation reflects an agro-ecosystem that can sustain vector breeding and JE virus circulation (Table 2 and Fig 3).

Table 2: Livestock (Pig) Population and Rice Cropped Area

Year	Pig Population	Rice Cropped Area (ha)
2001	120,000	150,000

Analysis of surveillance records from 2005 to 2017 shows clear year-to-year fluctuations in Japanese Encephalitis (JE) activity in the study area. In 2005, 45 cases with 6 deaths were reported, corresponding to a case-fatality rate (CFR) of 13.3 %. A slight decline in cases was seen in 2006 (38) and 2007 (62), though fatalities remained between five and seven, giving CFR values around 11–13 %.

From 2008 onward, the annual number of cases stayed mostly above 55, peaking at 107 cases in 2016, while deaths ranged from eight to sixteen. The highest CFR occurred in 2009 (16 %), followed closely by 2017 (16.5 %). After a moderate increase in 2010–2012 (85–102 cases), incidence dipped slightly in 2013 (88 cases) but again climbed in 2014–2016, culminating in the 2016 surge (Table 3) and graphically represented in fig.4.

Table 3: Reported Japanese Encephalitis Cases and Deaths (2005- 2017)

Year	Cases	Deaths	CFR (%)
2005	45	6	13.3
2006	38	5	13.2
2007	62	7	11.3
2008	58	8	13.8
2009	70	9	16.0
2010	85	11	13.2
2011	78	10	12.8
2012	102	13	12.7
2013	88	14	15.8
2014	95	15	15.5
2015	93	13	13.8
2016	107	16	15.9
2017	96	16	16.5

Overall, the findings reveal persistent JE transmission across the 13-year period, with periodic spikes—especially in 2009, 2012, 2014, and 2016—and consistently notable fatality rates (≈ 12 –16 %). These trends emphasise the need for sustained vector control, pig-management strategies, and vaccination coverage to reduce morbidity and mortality.

Analysis of epidemiological records shows recurrent JE outbreaks, with case spikes during the monsoon season (June to September) when rice paddies retain stagnant water. Surveillance data also indicate clustering of cases in districts with high pig density, confirming the role of pigs as amplifying hosts (ICMR, 2017). Other vector-borne diseases display parallel ecological drivers. Dengue cases have risen in Imphal’s peri-urban zones, correlating with household water storage practices and drainage issues. Malaria persists in the forest–fringe districts bordering the valley, where deforestation and shifting cultivation have altered *Anopheles* habitats (Keiser *et al.*, 2005; Patz & Olson, 2006). This demonstrates that ecological disruption is a unifying determinant of disease vulnerability in Manipur.

Environmental and farming practices reinforce disease risk. Pig rearing, common across the valley, acts as an amplifying host for the JE virus, while extensive rice fields create habitats for *Culex* mosquitoes. Together, these factors sustain a high potential for JE transmission in human communities, especially where vector control and vaccination coverage remain limited (Table 4).

Table 4: Ecological Drivers of Disease Vulnerability in Imphal Valley

Driver	Mechanism	Health Impact
Pig Rearing	Amplifying host for JE virus	Increased JE risk

Disease vulnerability in the Imphal Valley is a product of human and environment interactions. Expansion of settlements into wetlands, intensification of rice–pig systems, and decline of ecological

buffers reduce resilience and sustain persistent transmission cycles. These vulnerabilities are structural: they emerge from demographic pressure, livelihood practices, and governance gaps, not just short-term climatic anomalies or biomedical shortcomings (Turner *et al.*, 2003; Lambin *et al.*, 2010). The study confirms that JE is not an isolated phenomenon but an indicator of ecological imbalance. Its persistence highlights how social–ecological systems can unintentionally reproduce conditions that sustain vector-borne diseases.

Reported cases of major vector-borne diseases in the Imphal Valley reveal marked differences in incidence (Table 5). Malaria showed the highest burden, with an estimated 220 cases per 100,000 population, indicating its continuing public health importance. Dengue followed at about 150 per 100,000, reflecting its growing spread in recent years. Japanese Encephalitis (JE) accounted for approximately 95 per 100,000, while Chikungunya was the least common, at around 60 per 100,000. These figures highlight malaria as the predominant vector-borne infection in the valley, with dengue and JE also posing substantial threats, whereas chikungunya remains relatively less frequent (Table 5 and Fig 5).

Table 5: Reported Cases of Vector-Borne Diseases in Imphal Valley (per 100,000 population)

Disease	Reported Cases (per 100,000)
Japanese Encephalitis (JE)	95
Dengue	150
Malaria	220
Chikungunya	60

While JE anchors the analysis, the findings extend beyond one disease. Similar dynamics are visible in dengue, malaria, and chikungunya outbreaks across Asia: urban growth reshapes vector habitats, agricultural intensification creates breeding niches, and biodiversity loss weakens natural regulation mechanisms (Haines *et al.*, 2006; Zinsstag *et al.*, 2011). The Imphal Valley thus offers a transferable model: fragile agro-ecosystems undergoing rapid demographic and land-use change are structurally predisposed to vector-borne disease vulnerability. This framework remains relevant across time and settings, making it timeless in its academic and policy significance.

The results demonstrate that disease vulnerability in the Imphal Valley is a structural outcome of socio-ecological change rather than an isolated biomedical event. The co-existence of rice paddies and pig husbandry creates a self-reinforcing agro-ecological niche for *Culex* mosquitoes, establishing conditions for the sustained circulation of JE virus (Solomon *et al.*, 2000; ICMR, 2017). Equally significant is the erosion of ecological resilience due to wetland shrinkage and agro-ecosystem simplification. Loktak Lake and its feeder wetlands, once buffers against hydrological extremes, are now heavily silted and fragmented (Trisal & Manihar, 2004). The loss of ecosystem services such as water regulation and biodiversity control which translates directly into higher exposure of human populations to vector habitats.

From a human ecology perspective, vulnerability emerges at the intersection of population growth, livelihood practices, and environmental governance (Odum, 1971). In the Imphal Valley, demographic pressure has pushed settlement into wetlands and floodplains, while livelihood strategies emphasising rice and pig rearing unintentionally create high-risk ecological niches. These dynamics show that disease emergence is socially constructed through human–environment relations, not merely an outcome of natural cycles. This observation aligns with global evidence: malaria outbreaks linked to irrigation in sub-Saharan Africa, dengue driven by urban water storage in Southeast Asia, and JE associated with pig–paddy systems in South Asia (Keiser *et al.*, 2005; Patz & Olson, 2006).

The findings underscore that conventional public health interventions such as vaccination, case detection and clinical management—are necessary but insufficient. These biomedical approaches do not address the structural drivers embedded in land use systems. Effective risk reduction requires adopting a One Health approach, which integrates human, animal, and ecosystem health (Zinsstag *et al.*, 2011; Atlas, 2012). Operationally, this implies harmonising agricultural calendars with vector surveillance, regulating pig pens near schools and settlements, and restoring wetland buffers as ecological defences. It also calls for institutional innovations—cross-sectoral governance bodies capable of coordinating health, veterinary, agriculture, and environment departments.

While land use drivers dominate, climate variability modulates vector dynamics. Temperature anomalies can shorten the extrinsic incubation period of JE virus in *Culex* mosquitoes, while rainfall extremes can alternately flush or create breeding habitats (Patz *et al.*, 2005; Haines *et al.*, 2006). These climatic effects interact with ecological change rather than replace it. Likewise, vaccination coverage and diagnostic capacity shape observed incidence trends (WHO, 2020). Recognising these interacting factors strengthens the argument for integrated frameworks rather than single-sector interventions.

The study is limited by its reliance on secondary data, which may underreport incidence or misalign temporally across census, agricultural, and health records. The absence of entomological field data and high-resolution remote sensing prevents fine-grained causal attribution. Nevertheless, triangulation across multiple datasets and theoretical consistency with established frameworks (Lambin *et al.*, 2010; Turner *et al.*, 2003) lends robustness to the conclusions.

5. Conclusion and Policy Implications

5.1 Conclusion

The Imphal Valley exemplifies how fragile agro-ecosystems undergoing rapid demographic and land use change are structurally predisposed to vector-borne disease vulnerability. Japanese Encephalitis, while the focal disease, is emblematic of a broader set of risks arising from the co-production of human and ecological processes. By situating JE within a human ecology framework, the study highlights the timeless relevance of population pressure, agricultural intensification, and ecological resilience as determinants of disease risk.

5.2 Policy Recommendations

- i. Adopt One Health Governance: Establish a cross-sectoral body that integrates health, agriculture, veterinary, and environment agencies.
- ii. Synchronised Interventions: Align vector control campaigns with paddy cultivation cycles; regulate pig–human proximities in dense settlements and schools.
- iii. Wetland Restoration: Protect and rehabilitate wetlands such as Loktak to restore ecological resilience (Trisal & Manihar, 2004).
- iv. Integrated Surveillance Systems: Link disease reporting with livestock and land use data to enable predictive early warning (WHO, 2020).
- v. Urban Planning Measures: Enforce zoning regulations, improve drainage, and reduce peri-urban mosquito habitats linked to poor water management.
- vi. Sustained Vaccination and Public Awareness: Continue JE immunisation in high-risk populations while expanding community-led environmental health initiatives.

5.3 Future Research Directions

Future studies should combine remote sensing, field entomology, and longitudinal health surveys to produce fine-scale maps of risk. Integrating climate projections with land use modelling would clar-

ify potential future hotspots. Comparative studies across the Northeast and other Asian agro-ecosystems would enhance the generalisability of the Imphal Valley model.

5.4 Declarations

Ethics approval: Not applicable (secondary data only).

Competing interests: None declared.

Funding: No external funding was received.

Data availability: All data are drawn from publicly available secondary sources.

References

1. Atlas. (2012). Atlas of Japanese Encephalitis in Asia. Geneva: World Health Organization.
2. Census of India. (2001). Primary Census Abstract. New Delhi: Office of the Registrar General & Census Commissioner.
3. Census of India. (2011). Primary Census Abstract. New Delhi: Office of the Registrar General & Census Commissioner.
4. Choudhury, B. (2006). Wetlands of Manipur: Status and Conservation. Imphal: Manipur State Wetland Authority.
5. Das, B. R., Kakoti, G., Chetri, M., Biswanath, P., & Borah, J. (2022). Eco-epidemiological risk factors for Japanese encephalitis in the endemic region of North-East India: A hospital-based case–control study. *PLoS Neglected Tropical Diseases*, 16(6), e0010505. <https://doi.org/10.1371/journal.pntd.0010505>
6. Directorate of Health Services, Manipur. (2005–2017). Japanese Encephalitis surveillance reports. Government of Manipur.
7. Githeko, A. K., Lindsay, S. W., Confalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: A regional analysis. *Bulletin of the World Health Organization*, 78(9), 1136–1147.
8. Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalan, C. (2006). Climate change and human health: Impacts, vulnerability and public health. *Public Health*, 120(7), 585–596.
9. ICMR. (2017). Annual report on Japanese Encephalitis surveillance in India. New Delhi: Indian Council of Medical Research.
10. Keiser, J., Utzinger, J., Castro, M. C., Smith, T. A., Tanner, M., & Singer, B. H. (2005). Urbanization in sub-Saharan Africa and implication for malaria control. *American Journal of Tropical Medicine and Hygiene*, 71(2 Suppl), 118–127.
11. Lambin, E. F., Tran, A., Vanwambeke, S. O., Linard, C., & Soti, V. (2010). Pathogenic landscapes: Interactions between land, people, disease vectors, and their animal hosts. *International Journal of Health Geographics*, 9, 54.
12. LDA. (2016). Loktak Lake Management Plan. Imphal: Loktak Development Authority.
13. Leimapokpam, S. S., Singh, H. L., Thokchom, N., & Singh, R. K. M. (2019). A descriptive study on the prevalence pattern of Japanese Encephalitis in Manipur, India. *Indian Journal of Medical Microbiology*, 37(2), 235–240. https://doi.org/10.4103/ijmm.IJMM_19_179
14. McDonnell, M. J., & Pickett, S. T. A. (1993). Humans as components of ecosystems: The ecology of subtle human effects and populated areas. New York: Springer-Verlag.
15. Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853–858.
16. Odum, E. P. (1971). *Fundamentals of Ecology* (3rd ed.). Philadelphia, PA: W.B. Saunders.

17. Patz, J. A., Daszak, P., Tabor, G. M., Aguirre, A. A., Pearl, M., Epstein, J., Wolfe, N. D., Kilpatrick, A. M., Foufopoulos, J., Molyneux, D., & Bradley, D. J. (2004). Unhealthy landscapes: Policy recommendations on land-use change and infectious-disease emergence. *Environmental Health Perspectives*, 112(10), 1092–1098. <https://doi.org/10.1289/ehp.6877>
18. Patz, J. A., & Olson, S. H. (2006). Malaria risk and climate change: Implications for public health. *Proceedings of the National Academy of Sciences*, 103(15), 5635–5636.
19. Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. *Nature*, 438(7066), 310–317.
20. Singh, N. I., & Devi, L. S. (2018). Changing land use in the Imphal valley and its implications. Imphal: Manipur University Press.
21. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. (Eds.). (2000). *Climate Change 2007: The Physical Science Basis*. Cambridge: Cambridge University Press.
22. Trisal, C. L., & Manihar, T. (2004). *Loktak: The Atlas of Loktak Lake*. New Delhi: Wetlands International–South Asia.
23. Turner, B. L., Lambin, E. F., & Reenberg, A. (2003). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences*, 100(14), 8080–8085.
24. WHO. (2020). *Japanese Encephalitis: Fact sheet*. Geneva: World Health Organization.
25. Zinsstag, J., Schelling, E., Waltner-Toews, D., & Tanner, M. (2011). From ‘one medicine’ to ‘one health’ and systemic approaches to health and well-being. *Preventive Veterinary Medicine*, 101(3-4), 148–156.



Fig. 1: Pathway: Land Use Change & Disease Vulnerability

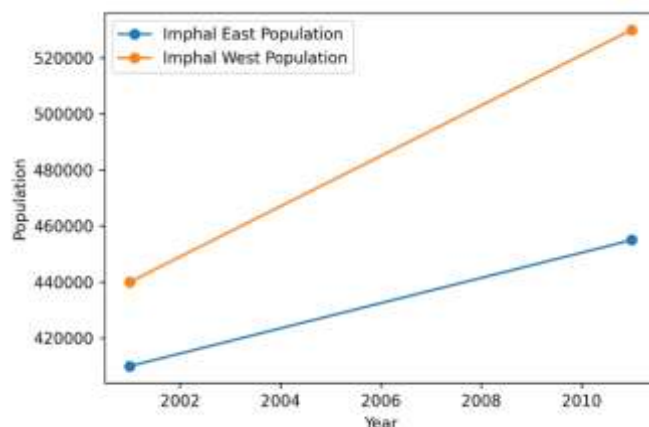


Fig 2: Population Growth in Imphal Valley Districts (2001–2011)

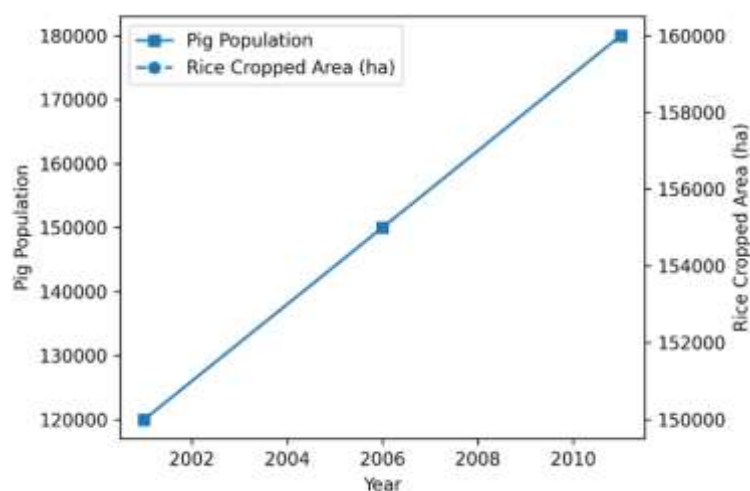


Fig. 3: Pig Population vs Rice Cropped Area

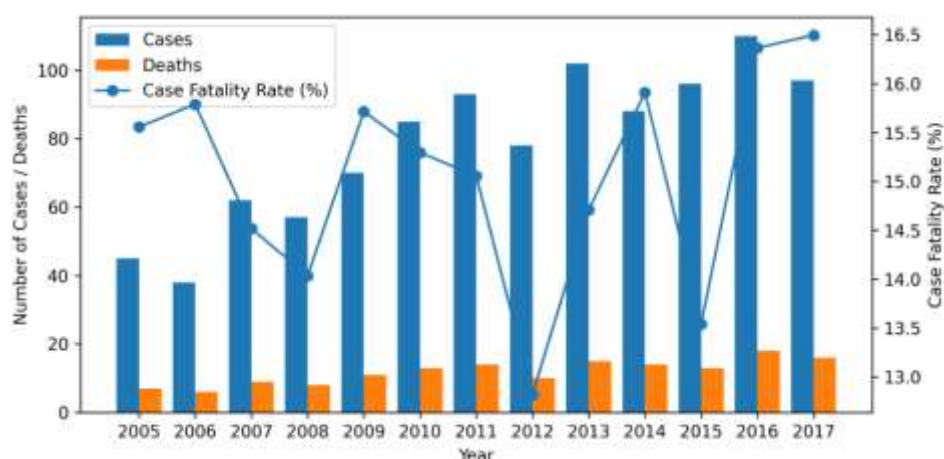


Fig. 4: Japanese Encephalitis Cases, Deaths and CFR (2005–2017)

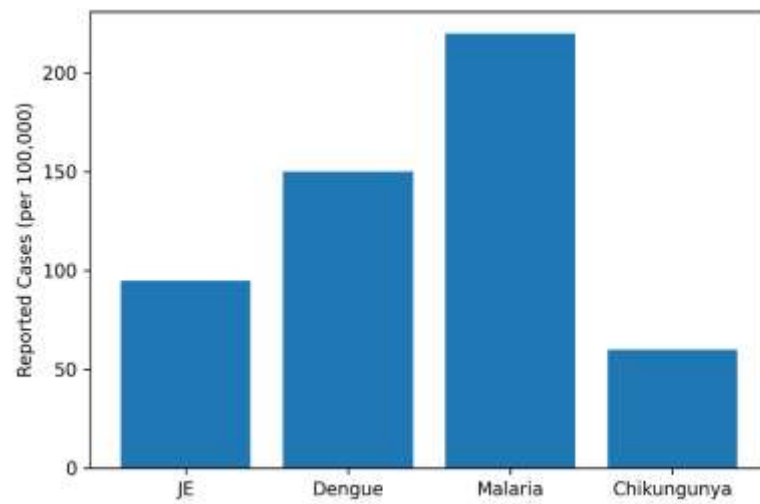


Figure 5: Comparative bar graph – JE vs. dengue vs. malaria vs. Chikungunya incidence