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Original Research Article

Tracing Zoonotic Emergence through Evolution and Biodiversity of Reptiles: An Appraisal on One Health Concept from the Indian -Subcontinent

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ABSTRACT

The Indian subcontinent provides a unique natural laboratory to study the relationships between geological history, biodiversity, evolutionary diversification and zoonotic disease emergence. Subsequent to its splitting from Gondwana, the Indian Plate drifted northward and collided with Eurasia, drastically altering the landscape, temperature and biogeography of the region. The formation of the Himalaya, Indo-Gangetic plains, northeastern hill systems and prominent biogeographic barriers facilitated isolation, dispersal and diversity of reptile lineages. While the knowledge of reptile diversity continues to improve, significant gaps remain uncovered in comparing evolutionary history to pathogenic ecology. Molecular studies of Himalayan and Indo-Burmese reptiles indicate that diversification has been associated with geological and climatic changes, especially the uplift of the Himalayas and the establishment of the South Asian monsoon. These evolutionary processes lead to a diversity of reptile assemblages and possibly structured host-associated microbial ecosystems. Reptiles may harbour bacteria, viruses and parasites of zoonotic significance and their interactions with arthropod vectors could potentially contribute to the maintenance and transmission of pathogens. Established ecological systems can be disrupted by evolving stresses such as habitat fragmentation, urbanization, wildlife trade, climate change, invasive species and growing human-animal interface and might provide opportunities for pathogen spillover. A One Health paradigm that includes evolutionary biology, herpetology, microbiology, veterinary science, ecology and public health is therefore significant for the identification and mitigation of increasing zoonotic diseases associated with reptiles.

Keywords: Indian subcontinent, One Health, Pathogens, Reptile diversification, Zoonoses

1. INTRODUCTION

The One Health concept is an integrated and interdisciplinary paradigm that emphasizes a close connection of human, animal and environmental health and fosters coordinated action across multiple domains to address complex health concerns. One Health is not only about infectious diseases from the human medical point of perspective but also about the ecological and epidemiological ties by which infections pass along among wildlife, domestic animals, humans and the environment that they share. This is especially relevant in the case of zoonotic diseases, which constitute a significant portion of human infectious diseases

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and are an important driver of emerging and re-emerging infectious diseases (Rahman et al., 2020).

In this context, reptiles deserve higher priority as an often under-investigated aspect of the human-animal-environment interface. Reptiles can be observed in a wide range of terrestrial and aquatic settings and may harbour bacteria, viruses, fungi and parasites some of which have demonstrated or potential zoonotic diseases. Human exposure occurs through direct handling, bites and scratches, contact with faecally contaminated surfaces, consumption of reptile-derived goods, wildlife commerce, keeping captive animals and occupational activities (Tennakoon et al., 2023; WHO, 2020). Therefore, a One Health approach to reptile-associated zoonoses is necessary to integrate with pathogen surveillance, animal ecology, veterinary practice, environmental health, human epidemiology, and public-health management (Liu et al., 2025). This unifying paradigm should increase understanding of transmission pathways, susceptible populations, and early detection and prevention of developing zoonotic risks.

The enormous diversity of reptiles, and the diversity of pathogens they carry, can be best explained by their ancient evolutionary history, their broad ecological spectrum, and their extensive geographical distribution (Mendoza-Roldan et al., 2020). Reptiles are among the oldest groups of animals on Earth, with ancestors dating back over 300 million years, and have adapted to almost every continent and biotope (Mitchell, 2011). This long-term adaptation and diversification has made them important hosts for wide range pathogens.

2. OVERVIEW OF REPTILIAN DIVERSITY AND ASSOCIATED PATHOGENS

Reptiles are one of the most taxonomically diverse groups of vertebrates worldwide with over 11,000 identified species in at least 1,200 genera and a broad range of terrestrial, freshwater and marine environments around the world (Turkozan & Escoriza, 2026). Reptiles are a highly varied category of vertebrates with an evolutionary lineage that dates back to the Paleozoic era, around 320 million years ago (Buffa & Laurin, 2024). Reptiles, distinguished by keratinized scales, ectothermic metabolism, and primarily three-chambered hearts-except for crocodilians which have four-chambered hearts-inhabit a wide range of terrestrial and aquatic environments. Their population is almost distributed globally, with a notable absence of Polar Regions. The class is represented by four extant orders: Squamata (lizards, snakes and amphisbaenians), Testudines (turtles and tortoises), Crocodylia and Rhynchocephalia; encompassing a great evolutionary and ecological diversity (Gill, et al., 2024). Reptiles, with their wide geographical distribution and ecological adaptability, are natural reservoirs for a wide range of microorganisms and parasites, including a number of viral, bacterial, protozoan and helminth pathogens, several of which have recognized zoonotic potential (Roll et al., 2017; Gilbert et al., 2014).

Reptiles are known to harbour a variety of parasites including trematodes (Alaria), cestodes (Spirometra), nematodes (*Anisakis, Eustrongylides, Angiostrongylus, Gnathostoma and Trichinella*), pentastomids (Armillifer), mites (*Ophionyssus natricis*) and protozoans such as Trypanosoma, Sarcocystis and Cryptosporidium (Mendoza-Roldan et al., 2020; Reboredo-Fernández et al., 2017). As per the latest Fauna of India checklist of the Zoological Survey of India (2025), up to December 2024, 833 species and subspecies of reptiles were documented in India, including 3 Crocodylia, 44 Testudines, 786 squamata (419 Sauria and 367 Serpentes). Of these taxa 472 are endemic to India, with the Western Ghats, Andaman and Nicobar Islands, and northeastern India being the primary regions of reptile endemism (**Table 1**).

Substantial increases in human–reptile interactions have been driven by habitat overlap,

the exotic pet trade, ecotourism and the use of reptiles for food, traditional medicine and leather production. Therefore, reptiles have been increasingly included within the One Health concept, as they can contribute to the maintenance and spread of zoonotic infections at the wildlife–human interface (Magnino et al., 2009). This highlights the significance of studying host-parasite associations to better understand the biodiversity of reptiles and their possible role in the ecology of zoonotic diseases.

3. METHODOLOGY

For this review, we searched PubMed- Medline, Google Scholar, Web of Science, ScienceDirect and Scopus. The search was based on keyword was based on: ((biodiversity of reptiles) AND (pathogens)) AND (zoonoses). The filters were used as Meta-Analysis and English. The detailed search in PubMed is as follows: biodiversity: ”biodiverse”[All Fields] OR ”biodiversities”[All Fields] OR ”biodiversity”[MeSH Terms] OR ”biodiversity”[All Fields] OR ”biodiversity's”[All Fields];reptiles: ”reptiles”[MeSH Terms] OR ”reptiles”[All Fields] OR ”reptile”[All Fields]; pathogens: ”pathogen”[All Fields] OR ”pathogen's”[All Fields] OR ”pathogene”[All Fields] OR ”pathogenes”[All Fields] OR ”pathogenic”[All Fields] OR ”pathogenically”[All Fields] OR ”pathogenicities”[All Fields] OR ”pathogenicity”[Subheading] OR ”pathogenicity”[All Fields] OR ”virulence”[MeSH Terms] OR ”virulence”[All Fields] OR ”pathogenity”[All Fields] OR ”pathogenous”[All Fields] OR ”pathogens”[All Fields]; zoonoses: ”zoonoses”[MeSH Terms] OR ”zoonoses”[All Fields] OR ”zoonose”[All Fields]. For Scopus the search strategy was: TITLE-ABS-KEY (“reptiles”, “zoonoses”, “pathogens”).

3.1 Inclusion and Exclusion Criteria

All the data from the selected databases, including research article details like author names, titles, journals, keywords, institutional affiliations, citations and abstracts, were downloaded based on biodiversity of reptiles and the pathogens they harbour. All this data was subsequently converted to an ‘.xls file’ (Microsoft Excel) to identify any data errors. Thereafter, all the downloaded data were filtered by exclusions, which were (a) nonrelevance to the aims and objectives of the research questions, (b) incomplete key information, and (c) in vitro and non- human groups as research subjects.

No specific timeline was entered during the search strategy; nonetheless, the first report was available in 1998 (**Figure 1a**). Out of 147 articles, 69.4% are articles and 22.4% are reviews, rest are book chapters and surveys (**Figure 1b**). Most papers were found in the journal (Animals) followed by BMC Veterinary research, one health and Plos One (**Figure 1c**). The subject area of the said pathogens mainly centered around medicine, immunology and veterinary **(Figure 1d**). Studies considering reptiles and zoonoses were found to be very rare. Out of those available, most were related to other animals, predominantly poultry; food contamination and transmission of pathogens through pets; and among the countries, maximum work has been published from United States followed by other European nations (**Figure 1e**).

Ironically, no article has been found from Asea-Oceania region which has the most diverse reptilian population and had undergone many folds of evolution due to reasons explained in detail in the following sections of this review. In this review, the focus is mainly on the biodiversity of Geckos that are used as ornamental pets and harbour pathogens that may spread to humans.

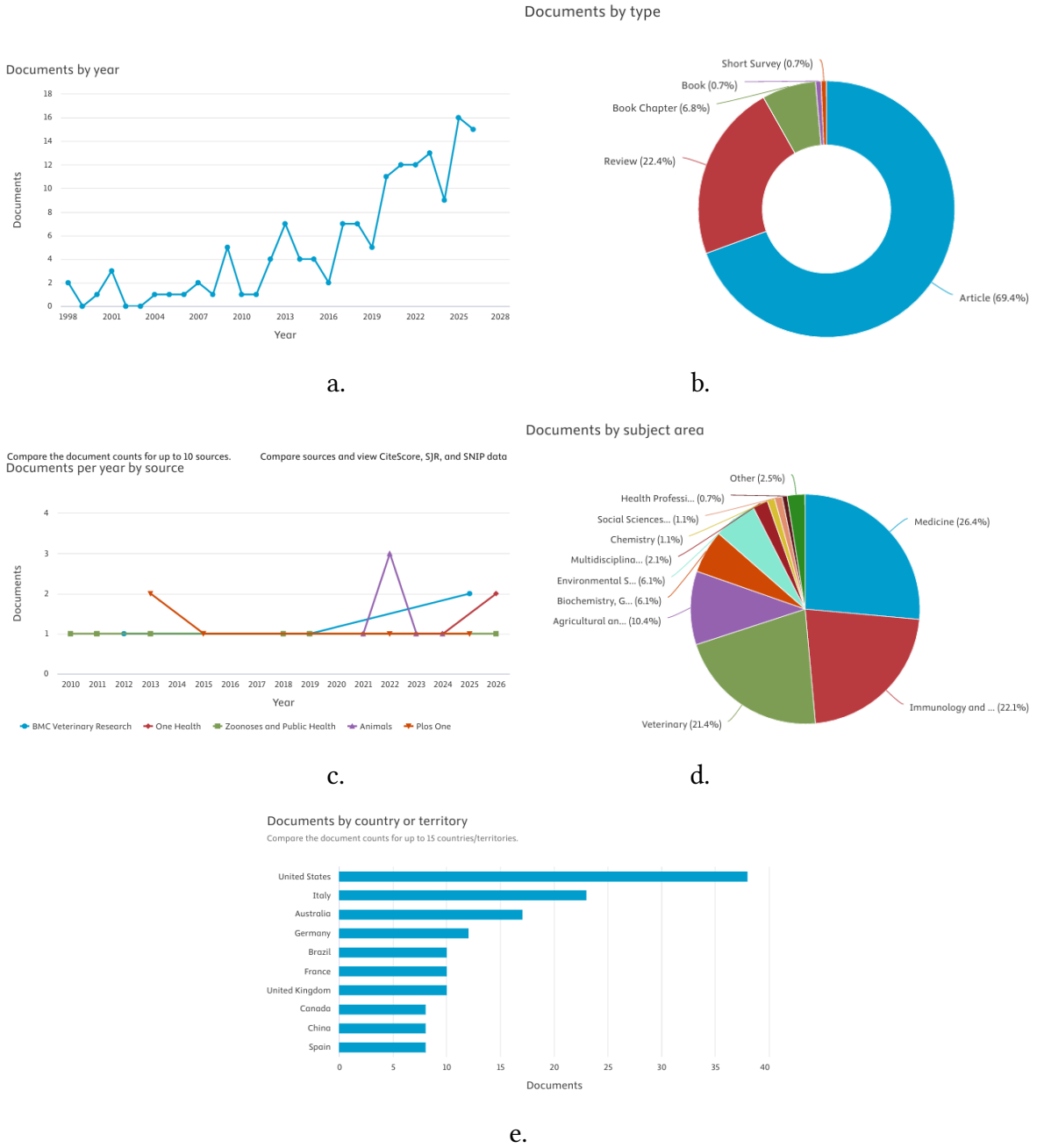


Figure 1: Detailed graphs showing search strategy with year-wise distribution (a); types of documents (b); Journals with most publication (c); the subject area (d) and the country or territory which had the maximum work regarding reptiles and zoonoses (e).

4. BIOGEOGRAPHIC AND EVOLUTIONARY PERSPECTIVES ON REPTILE DIVERSITY IN INDIA

In India, the existing reptile fauna consists of 3 major orders: Crocodylia, Testudines, and Squamata, which comprise crocodiles, turtles and tortoises, as well as lizards and snakes. India's diversified landscapes and climatic conditions enable significant reptilian variety, especially in biodiversity-rich areas like the Western Ghats and the Himalayan foothills (Mohapatra et al., 2024). The identification of previously unidentified diversity has significantly advanced through the use of integrative taxonomy, which combines morphological, molecular, and various other forms of data. Nevertheless, the relatively uneven geographic distributions and specific microhabitat

Table 1: Comparative assessment of reptile diversity and conservation status across Indian States and Union Territories.

State/UT	Species	SIS	ES	CR	EN	VU	NT	T/NT	SA
Andhra Pradesh	118	119	8	2	3	5	8	18	103
Arunachal Pradesh	111	111	7	1	7	5	7	20	99
Assam	147	149	4	6	9	10	7	32	136
Bihar	63	64	0	4	7	3	4	18	56
Chhattisgarh	84	85	2	1	7	5	4	17	82
Goa	81	82	1	1	2	4	5	12	76
Gujarat	124	125	5	1	5	8	4	18	115
Haryana	31	31	1	0	1	2	2	5	27
Himachal Pradesh	62	62	3	1	1	1	7	10	50
Jharkhand	57	58	0	0	6	3	3	12	41
Karnataka	142	143	23	4	6	8	6	24	114
Kerala	225	226	32	5	11	12	14	42	177
Madhya Pradesh	95	97	1	3	6	6	4	19	86
Maharashtra	145	148	26	3	5	6	6	20	129
Manipur	39	39	1	1	5	1	1	8	27
Meghalaya	81	81	8	2	6	4	4	16	65
Mizoram	112	112	11	4	5	5	6	20	97
Nagaland	55	56	1	2	3	2	2	9	47
Odisha	130	132	3	7	8	8	5	28	118
Punjab	44	44	0	0	2	2	4	8	40
Rajasthan	69	69	0	3	3	2	4	12	49
Sikkim	67	67	0	0	1	3	3	7	63
Tamil Nadu	259	260	63	9	16	14	15	54	208
Telangana	66	66	4	0	1	3	6	10	58
Tripura	50	50	1	4	3	2	2	11	39
Uttarakhand	58	59	0	2	4	4	5	15	48
Uttar Pradesh	69	70	0	3	5	6	5	19	61
West Bengal	153	155	3	5	9	8	7	29	132
Andaman & Nicobar Islands	90	90	43	2	9	5	2	18	80
Chandigarh	15	15	0	0	0	0	2	2	15
Dadra & Nagar Haveli and Daman & Diu	26	26	0	0	0	2	2	4	22
NCT of Delhi	37	37	0	1	2	2	4	9	37
Jammu & Kashmir	61	61	2	0	1	0	5	6	55
Ladakh	11	11	0	0	0	0	0	0	11
Lakshadweep	13	13	0	1	1	2	0	4	13
Puducherry	42	42	0	0	0	2	2	4	18

Abbreviations: CR – Critically Endangered; EN – Endangered; ES–Endemic species; VU – Vulnerable; NT – Near Threatened; SA–Species assessed; SIS– Species incl. subspecies; T/NT–Threatened/NT ; Threatened /NT total – Combined number of species categorized as CR + EN + VU + NT. (sources: Mohapatra et al., 2025)

necessities of numerous reptile species make them susceptible to habitat alteration, fragmentation, pollution, illegal trade, and climate change.

In the context of phylogeography, understanding historical plate movements enables the correlation of lineage divergence with geological events such as the Himalayan Orogeny and associated tectonic reorganizations. The existence

of faunal characteristic on the Indian subcontinent before the Himalayan–Tibetan collision in the Paleogene (Yin & Harrison, 2000) does not definitively suggest an indigenous origin within the subcontinent. These tectonic processes have directly influenced patterns of species dispersal, isolation, and diversification by altering habitat connectivity and creating physical barriers such as mountain ranges, fault systems, and major river basins (Chatterjee et al., 2017). This viewpoint emphasizes the necessity of combining tectonic reconstructions with evolutionary timeframes to precisely deduce the genesis and diversification of lineages in the Indian subcontinent. Numerous hypotheses linking Cenozoic global cooling, atmospheric CO_2 reduction, and monsoon intensification to early Himalayan uplift may have been responsible to have significant topographic development impact that emerged later in the Oligocene (Molnar et al., 2010).

The study of past plate motions provides a robust framework for interpreting present-day phylogeographic patterns and understanding the historical processes that has shaped current biodiversity distributions.

The **figure 2** demonstrates Late Cretaceous biogeographic and geological reconstructions (~65–66 Ma) and suggested the dispersal patterns of terrestrial animals. Panel (a) shows inferred faunal interchange including reptile across the main land masses, including Africa (Af), India (Ind) Madagascar (Mad), Europe (Eu), South America and Antarctica (An). Arrows are the probable migration paths. The distribution of animals such as frogs, caecilians, turtles, anguids, iguanian lizards, boid snakes, dinosaurs and mammals points to ancient biotic links between Gondwanan and Laurasian regions. Panel (b) indicates a paleogeographic reconstruction depicting India as an isolated continental fragment surrounded by the Neotethys Ocean and hypothesized dispersal pathways for Maastrichtian terrestrial tetrapods. Indian Maastrichtian fossils include various snake lineages, such as madtsoiids and Indophis. Maastrichtian snakes from several Indian sites reaffirm their palaeobiogeographical importance and Gondwanan affinities (Rage et al., 2004). The overall figure highlights the role of continental drift, plate movements and episodic land bridges in triggering historical dispersal and biogeographic distribution of vertebrate lineages, including the exchange of taxa among India, Africa, Madagascar, Eurasia and other Gondwanan fragment.

Historical events such as tectonic collisions and land bridge links that introduce new faunal elements and episodic turnover of continental faunas may have influenced modern faunal diversity. The acrodont lizards exhibit primary vicariance as a consequence of the plate separations. The anguid lizards exhibit secondary contact of the Southeast Asian plates with Eurasia, resulting in dispersion from Eurasia (Macey et al., 2000). Furthermore, the presence of taxa in pre-collision India should not be construed as indication of autochthonous evolution; rather, it requires a thorough assessment utilizing phylogenetic, molecular, and biogeographic data to differentiate between vicariance, dispersal, and ancestral conservation broadly in consistent with geological history. Molecular phylogenetic studies consistently predict divergence periods that precede the collision, suggesting that certain lineages inhabited the Indian plate either before its isolation or during intermittent association episodes (Macey et al., 1999).

5. DRIVERS OF REPTILE DIVERSITY

The collision of Indian and Eurasian plates has had huge impacts on the biogeography and evolutionary diversification of reptiles in the Indian subcontinent. The subsequent shifts in geology and climate, including the uplift of the Himalayas, the creation of complex topography, the beginning of new ecological gradients and changes in the monsoonal trend, resulting in

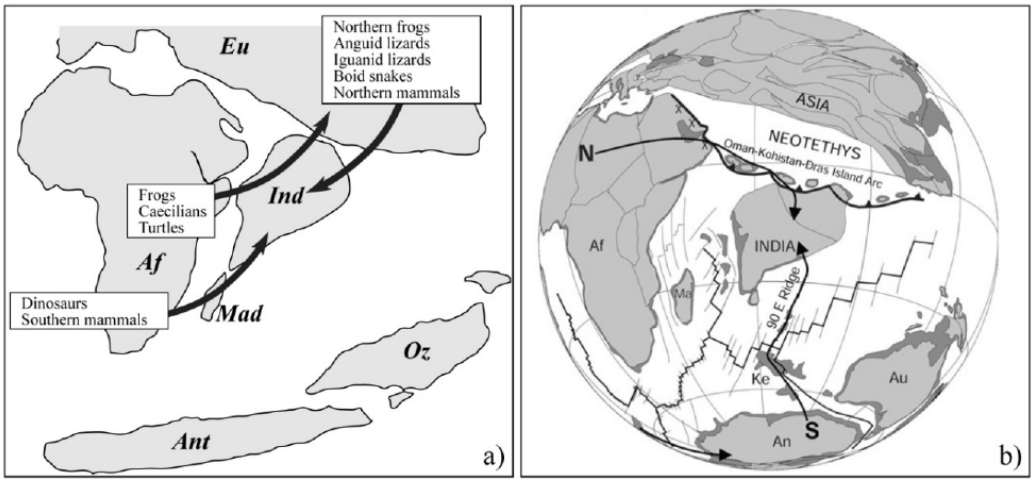


Figure 2: Late Cretaceous Paleogeography of the Indian Plate and Proposed Vertebrate Dispersal Routes including reptile. a) Late Cretaceous (~65 Ma) and b) Late Cretaceous (~66 Ma)(Source: Vérard et al., 2017).

diverse ecosystems and geographical barriers. Habitat variability, isolation, possibilities for migration and subsequent variations in the climate undoubtedly shaped reptile diversity, distribution, range expansion and population differentiation across the subcontinent. The Indian subcontinent is therefore the primary site for studying the relationships between tectonic history, environmental change and reptile diversity.

5.1 Evolutionary Adaptation and Plasticity

Species distributions are dynamic and are influenced by the combined effects of environmental conditions, phenotypic plasticity, and evolutionary adaptation. Traditionally, range shifts were considered passive responses to environmental changes such as climate change or geological events. However, temperature is now recognized as another major determinant of species distributions in both terrestrial and marine ecosystems (Parmesan et al., 2000). Increasing evidence suggests that evolutionary processes can also facilitate range expansion independent of environmental change. Long-term studies further demonstrate that species respond through both phenotypic plasticity and genetic adaptation (Urban et al., 2014).

Recent studies on the Indian rock python (*Python molurus*) comparing body temperature in relation to air temperature and relative humidity in wild Indian rock pythons offered insights into thermoregulation of a tropical Indian reptile (Vishnu et al., 2025). In reptiles with temperature-dependent sex determination (TSD), the sex phenotype depends on the ambient temperature during embryonic development. Thus, the same genotype may produce distinct sex phenotypes under various temperature circumstances (Martínez-Juárez 2019)

These findings highlight that species' responses to environmental change are shaped by interactions among climate, evolutionary adaptation, and phenotypic plasticity, ultimately influencing their distribution, persistence, and ecological success.

5.2 Anthropogenic climate Change

Anthropogenic climate change has emerged as one of the most significant threats to global biodiversity. Although climate has long been recognized as a key determinant of species distribution and ecosystem functioning, earlier ecological studies considered the biological impacts of greenhouse gas-driven climate change to be largely a future concern, with greater emphasis placed on land-use change, nitrogen enrichment, and elevated atmospheric CO_2 (Vitousek, 1992). However,

extensive evidence accumulated over the past few decades demonstrates that anthropogenic climate change has already affected biodiversity across all continents, oceans, and major taxonomic groups (IPCC, 2001a; Walther et al., 2002; Root et al., 2003; Le Galliard et al, 2012).

Three factors of climate change are of concern to turtles and crocodilians. First, climate change can fragment and shift habitats of aquatic animals (Mulhall et al., 2022). Second, turtles and alligators have temperature-sensitive sex determination: cooler temperatures create male nests, higher temperatures create female nests (Olson & Saenz, 2013). It can alter the sex ratios of a population. This will have an effect on future reproduction and lower the evolutionary fitness. Thirdly, warmer ocean temperatures may result in more frequent and intense storms, threatening coastal animals like the American alligator and crocodile (Schriever et al., 2009). These impacts include alterations in species distributions, phenology, abundance, and ecological interactions.

5.3 Environmental Change, Range Dynamics, and Reptilian Responses

Reptiles, particularly squamates, are highly sensitive to environmental changes because of their ectothermic physiology. Their distribution and demographic dynamics are therefore strongly influenced by climatic conditions, while physiological and behavioural adaptations can determine their ability to tolerate changing thermal environments (Doody & Moore, 2010; Frishkoff et al., 2015; Kearney et al., 2009). Historical reconstructions indicate that climatic fluctuations during the Quaternary, strongly influenced reptile distributions, with range expansions and contractions further constrained by geographical barriers and species-specific life-history traits. Mountain systems, for example, have restricted dispersal routes, whereas traits such as viviparity and enhanced performance at low temperatures may facilitate expansion into colder regions (Araújo et a., 2008). Consequently, some reptile species may potentially extend their geographical ranges under future warming scenarios. In particular, comparing their microbiome composition and functional profiles could help explore whether microbial associations contribute to physiological flexibility, habitat utilization, and potentially the establishment or persistence of particular species under changing environmental conditions.

Despite this potential for range expansion, reptile populations are increasingly threatened by habitat loss and fragmentation, land-use change, overexploitation, illegal collection, and invasive species. These pressures may interact synergistically with climate change, increasing the risk of population decline and local extinction (Nagar, 2025; Acharya & Chettri, 2012; Harikrishnan et al., 2022). Therefore, understanding how reptiles respond to changing climatic conditions is essential for predicting future distributional shifts and developing effective conservation strategies.

5.4 Endemism, Ecological Significance and Conservation Aspects

As mentioned earlier, India records very high reptile endemism with 427 endemic taxa among 833 species and subspecies recorded till July, 2025 (Mohapatra et al., 2025). Western Ghats has the maximum number of endemic reptiles, followed by Andaman and Nicobar Islands and Northeast India. Reptiles occupy diverse ecological niches, including terrestrial, arboreal, fossorial, rupicolous, fresh and marine water habitats, indicating a high degree of ecological specialization (Skeels et al., 2020).

Ecologically, reptiles play a vital role in regulating food webs as predators and prey, and some species influence ecological mechanisms by regulating prey populations. Their ecological services consequently go beyond their intrinsic biodiversity status. Conservation challenges, especially for species with restricted distributions and specialized habitat requirements, are significant,

driven by anthropogenic pressures like habitat degradation and fragmentation, exploitation, illegal collection and trade, pollution, and climate-related environmental change. The fundamental statute for conservation of wild life in India is the Wild Life (Protection) Act, 1972 which regulates both hunting and wild life trade.

For human, reptiles are also very important for their contributions to food systems, traditional practices, the pet trade and biomedical research. In the past, and in fact still in some parts of India, exhibiting live snakes has been the only income for snake charmers. At present, many reptiles, especially exotic species, are being traded more as pets. Venomous snakes are an important public-health concern (Habib, 2013). The "Big Four" responsible for almost 90% of snakebites in India include the Indian cobra, common krait, Russell's viper and saw-scaled viper. Snake venom is also a valuable resource for antivenom development and scientific research (Simpson, 2007). These ecological, conservation and public-health aspects emphasize the demand for integrated research and One Health-oriented management of the reptile diversity across India.

6. ZOONOTIC DISEASES ASSOCIATED WITH REPTILES

Reptiles are increasingly recognized to be hosts, asymptomatic carriers and, in some pathogen–host systems, potential reservoir or amplifying hosts. These roles must be differentiated epidemiologically, as the detection of a pathogen in a single reptile does not prove reservoir competence. The most documented example is reptile-associated carriage of *Salmonella spp.,* which is often colonized in the gastrointestinal tract of apparently healthy snakes, lizards and chelonians and can be shed in feces providing opportunities for environmental contamination and zoonotic transmission (Waltenburg et al., 2022). Reptiles may possibly play a role in transmission cycles of arboviruses (Burkett-Cadena et al., 2008). Bacterial infections are the most often observed zoonotic diseases associated with reptiles, but parasitic, viral and fungal agents may also be a concern to human health (Mitchell, 2011). Of special significance is the zoonotic potential of reptiles, as apparently healthy animals can transmit and frequently shed pathogens without developing symptoms (Whiley, et al., 2017) as described in **Table 2**.

Additionally, the finding of Eastern equine encephalitis virus (EEEV) RNA and antibodies in wild snakes in the field supports their role in the ecology of the virus, but the quantitative contribution of snakes to transmission is unknown (Graham et al., 2012). Thus, reptiles should be considered not just as passive hosts, but also as potentially critical components in pathogen transmission networks, their epidemiological relevance depending on pathogen biology, host competence, vector feeding behavior and environmental factors.

6.1 Bacterial zoonoses

Salmonella spp. is the most known and significant reptile bacterial zoonosis. Reptiles may contain salmonella in their gut microbiome and not show symptoms since they excrete the bacterium in their feces. Contamination can be transferred to the animal's cage, substrate, water, feeding supplies, and other surfaces. Humans are typically infected by fecal-oral transmission by touching reptiles or contaminated environments **(**Satharasinghe et al., 2026**).**

A Long History of Salmonella was first isolated from a lizard in the 1940s and later from snakes and chelonians, which suggests that both wild and captive reptiles can carry it **(**Hinshaw & McNeil, 1947**).** Analysis of reptile-associated salmonellosis indicated that direct or indirect reptile exposure could account for 6% of sporadic occurrences in humans depending on the region and study design. Reptiles can have serotypes of Salmonella that are

Table 2: Reptile-Associated Zoonotic Pathogens along with its host associations, human clinical manifestations, antimicrobial resistance mechanisms, and public health implications

Zoonotic Disease	Etiological Agent	Specific Reptile Host	Major Symptoms in Humans	Antimicrobial Resistance Mechanisms	Reference
Salmonellosis (Non-typhoidal)	Salmonella species (including S.*enterica, S. bongori , S. Cotham, S. Pomona, S. Poona, S. Agbeni ,S. Offa, S. Apapa, S. Braenderup , S. Paratyphi B Var. L (+) tartrate+*,and *S. Mbandaka*)	Lizards (Bearded dragon, Pogona vitticeps),snakes, and turtles (including species < 4 inches)	Gastroenteritis, fever, abdominal pain, diarrhea (sometimes bloody), septicaemia, meningitis, and bloodstream infection	Resistance to ampicillin, chloramphenicol, streptomycin, sulfisoxazole, tetracycline, ceftriaxone, cefoxitin, ciprofloxacin, gentamicin, amoxicillin-clavulanic acid, nalidixic acid, trimethoprim-sulfamethoxazole, and fosfomycin. Genes: aac(3)-II , aph(3")-Ib , aph(6)-Id , blaCMY-2 , floR , qnrS1 , qnrB19 , sul1 , sul2 , sul3 , tet(A) , tet(B) , blaTEM-1 , blaTEM-1B , blaTEM-1C , gyrA(83) , gyrA(87) , aadA1 , aadA2 , dfrA12 , and fosA7 .	Waltenburg et al., 2022; Nichols et a., 2024; Mermin et al., 2004
Campylobacteriosis	Campylobacter species (*including C. fetus subsp. testudinum , C. fetus subsp. fetus , C. jejuni ,* and *C. iguaniorum*)	Snakes (*Heterodon nasicus , Morelia amethistina , Python reticulatus , Boa constrictor*), lizards (Blotched blue-tongued skink *Tiliqua nigrolutea* , Bearded dragon	Gastroenteritis (fever, nausea, vomiting, abdominal pains, watery or bloody diarrhea), bacteremia, infectious spondylitis, productive cough, general body weakness, and infective aneurysm	Multi-drug resistance; specific genetic markers such as sap insertion PCR/SapD sequencing; KatA enzyme for intracellular survival; potential for lateral gene transfer; resistance to critically important human antibiotics linked to unregulated use.	Miller et al., 2017; Gilbert et al., 2014

Table 2 (continued)

Zoonotic Disease	Etiological Agent	Specific Reptile Host	Major Symptoms in Humans	Antimicrobial Resistance Mechanisms	Reference
		Pogona vitticeps , Sailfin lizard *Hydrosaurus pustulatus*), and Green iguana (*Iguana iguana*)			
COVID-19	SARS-CoV-2	Snake	Fever, dry cough, headache, dyspnea, myalgia, respiratory distress, renal impairment, diarrhea, and multiple organ failure	Mutations during RNA replication can lead to newer strains that may be more resistant to antibiotics (inferred for bacterial counterparts).	Kononova et al., 2023; Chen et al., 2021; Huang et al., 2020
Leptospirosis	Leptospira	Reptiles inhabiting urban environments	High fever, headache, chills, muscle aches, vomiting, and jaundice	Not in source	
West Nile fever	West Nile virus	Reptiles	Headache, skin rash, swollen lymph nodes, stiff neck, disorientation, coma, tremors, convulsions, and paralysis	Not in source	Dahlin et al., 2016; Habarugira et al., 2020

Table 2 (continued)

Zoonotic Disease	Etiological Agent	Specific Reptile Host	Major Symptoms in Humans	Antimicrobial Resistance Mechanisms	Reference
Salmonellosis	*Salmonella* spp. (e.g., *S. Typhimurium, S. Enteritidis, S. Typhi*)	California Kingsnake (*Lampropeltis californiae*), Royal python, Green iguana, Red-eared slider, and various tortoises	Acute gastroenteritis with diarrhea, vomiting, fever, and abdominal cramps; severe cases can lead to septicemia, bone marrow, and nervous system infections	Resistance to cephalosporins, penicillins, sulfonamide-trimethoprim, and tigecycline; acts as a reservoir for resistance genes that can be transferred via horizontal gene transfer	Pedersen et al., 2009; Austin & Wilkins, 1998
Mycobacteriosis	Non-tuberculous mycobacteria (NTM) (e.g., *M. chelonae*, *M. fortuitum*, *M. marinum*)	Turtles, tortoises, saurians (lizards), and snakes (e.g., Pythons)	Lung disease, osteomyelitis, joint infections, and disseminated skin and soft tissue lesions	Infections are often diagnosed in advanced stages; therapy is expensive and long-lasting, with high potential for environmental persistence	Hernandez-Divers et al., 2002; Ebani et al., 2012
Chlamydiosis	*Chlamydia pneumoniae*, *Chlamydia psittaci*	Nile and Indopacific crocodiles, Moorish tortoises, Puff adders, and Burmese pythons	Acute and chronic respiratory disease; potentially implicated in atherosclerosis and Alzheimer's disease	Tetracycline has been used successfully; marbofloxacin shows incomplete efficacy against *C. pneumoniae* in captive snakes	”Domestic reptiles as source of zoonotic bacteria”
Leptospirosis	*Leptospira interrogans* serovars (e.g., Ballum, Pomona, Grippotyphosa, Copenhageni)	Snakes (e.g., Hog-nosed), lizards, turtles (*Phrynops geoffroanus*), and crocodilians	Typically transmitted via contact with urine-contaminated water or soil; symptoms include systemic illness similar to mammalian leptospirosis	Data on specific therapy for reptiles is limited; penicillins and streptomycin are effective in mammals and assumed to apply	Pérez-Flores et al., 2017; Lindtner-Knific et al., 2013; Paz et al., 2019

Table 2 (continued)

Zoonotic Disease	Etiological Agent	Specific Reptile Host	Major Symptoms in Humans	Antimicrobial Resistance Mechanisms	Reference
Yersiniosis	*Yersinia enterocolitica*	California Kingsnake (*Lampropeltis californiae*) and European pond turtle	Diarrhea, fever, and abdominal pain; systemic forms can lead to sepsis, particularly in the elderly or immunocompromised	Identification of pathogenic strains is linked to the *ail* gene; specific resistance mechanisms in reptile-derived strains are less documented in the provided sources	Pino-Verae et al., 2025; Pino-Vera et al., 2023; Schirò et al., 2026
Sparganosis	*Spirometra* spp.	Snakes (acting as intermediate or paratenic hosts)	Human infection occurs via ingestion of raw/undercooked meat; larvae migrate through tissues causing various localized symptoms	Not explicitly detailed for reptile hosts; generally involves surgical removal or supportive care for migrating larvae	Rahman et al., 2025; Kavitha et al., 2014
Pentastomiasis	*Armillifer* spp.	Snakes (specifically Pythonidae)	Zoonotic transmission via consumption of contaminated wild snake meat	Not explicitly detailed in the sources	Kelehear et al., 2014; Walden et al., 2020;
***E. coli* Infection**	*Escherichia coli* (carrying *stx1*, *stx2* genes)	California Kingsnake (*Lampropeltis californiae*), European pond turtle, and Green iguana	Epidemic dysentery, neonatal meningitis, or hemolytic uremic syndrome	Primarily identified via virulence genes (Shiga-like toxins); resistance mechanisms often overlap with other enteric bacteria	Pino-Verae et al., 2025; Ramos et al., 2019; Abba et al., 2017

specific to reptiles as well as serotypes that can infect humans, and there are more than 2,400 serotypes recognized (Mitchell, 2011). Young toddlers, older individuals and immunocompromised people can get serious sickness (Mermin et al., 2004). Salmonella infection in reptiles is typically clinically undetectable, but disease may occur under certain conditions. Salmonella in a healthy reptile does not suggest clinical salmonellosis, but can be a reservoir for transmission (Diemert & Yan, 2019).

Other opportunist bacteria such as *Mycobacterium, Campylobacter, Aeromonas, Yersinia, Edwardsiella, Klebsiella, Serratia, Escherichia coli* have also been associated with reptiles. *Mycobacterium marinum*, *M. fortuitum,* and *M. chelonae* are critical because mycobacteria associated with reptiles can cause cutaneous, soft tissue, osteoarticular, or other diseases in humans, especially people with compromised immunity (Lazarkevich et al., 2024).

7. ZOONOTIC TRANSMISSION PATHWAYS

Zoonotic diseases are infections naturally transmissible between vertebrate animals and humans through multiple, often interconnected pathways. Transmission may occur through direct contact, indirect environmental exposure, vector-mediated transmission, foodborne or waterborne ingestion, and respiratory or aerosol exposure (Rahman, 2020). The relative importance of each pathway depends on the biology of the pathogen, reservoir host, environmental persistence, and frequency and intensity of human–animal interactions.

7.1 Direct contact transmission

Direct transmission takes place when individuals engage in physical contact with infected animals or their biological substances, such as saliva, blood, urine, feces, mucous secretions, or tissues (Rahman, 2020). Injuries such as bites and scratches can serve as a direct pathway for pathogens to enter via damaged skin or mucous membranes. Professional activities involving animal handling, veterinary interventions, wildlife rehabilitation, and contact with carcasses may potentially heighten exposure risk (Loh et al., 2015). Seemingly healthy animals can function as asymptomatic carriers and shed zoonotic pathogens, further complicating the identification of direct-contact transmission without thorough monitoring.

7.2 Indirect and environmental transmission

Indirect transmission happens when individuals come into contact with contaminated formites or environment-related factors instead of the infected animal directly. Animal enclosures, cages, bedding materials, feeding equipment, soil, debris, and water can get contaminated with pathogens and hence act as reservoirs of infectious diseases (Loh et al., 2015). This route is especially applicable to infections that can endure in the environment for extended periods. *Salmonella* associated with reptiles can contaminate enclosure surfaces, water, and various objects, thus potentially facilitating transmission through human contact (Pedersen et al., 2009). The contamination of soil and water with animal waste is a significant environmental pathway to multiple zoonotic diseases.

7.3 Vector-borne transmission

Understanding arthropod vectors and their interactions with vertebrate hosts is crucial to better comprehend the nature of ecology, maintenance and emergence of zoonotic diseases. Arthropods can be biological vectors, in which the disease undergoes replication or stages of development within the vector, or mechanical vectors, in which the pathogen is carried without any biological development before being transmitted to a susceptible host (Di Giovanni et al., 2021). While the interactions between mammals, birds and hematophagous ectoparasites such as ticks, mites, mosquitoes and other dipterans have

been well studied, surprisingly little is known about the associations between reptiles and hematophagous ectoparasites (Mendoza-Roldan et al., 2020b, 2021a). However, for a reptile to be a competent reservoir host, a disease must be retained in the host population, and in sufficient prevalence or intensity to infect competent vectors and allow continued transmission. Reptiles are parasitized by ticks and mites, some carrier parasites. Reptile-associated vector-borne bacteria such *Anaplasma, Borrelia, Coxiella, Ehrlichia, Rickettsia,* and *Aeromonas* vary in epidemiology by region (Eren & Açıcı, 2025). Reptile-associated vector-borne zoonoses also consist of protozoans. Sand flies and other vectors feed on reptile blood, which can transmit *Leishmania* and *Trypanosoma* (Alvaro, 2025).

The evolutionary relationship between reptiles and arthropods is remarkably ancient, with evidence for ectoparasitic arthropods linked with vertebrates stretching deep into the Mesozoic fossil record (Peñalver et al., 2017). Ticks are thought to have evolved in the Paleozoic, although the exact timing is unclear, and their early evolutionary history may have included associations with early terrestrial vertebrates, including reptile and amphibian lineages (Jeyaprakash & Hoy, 2009; Mans, 2023). Contemporary ectoparasitic arthropods can acquire and propagate different microbes when feeding on blood, while reptiles may serve as hosts where vector-associated bacteria, protozoa, and viruses are maintained or increased (Mendoza-Roldan et al., 2021).

Reptiles may potentially be part of cycles with mosquito-borne pathogens. In the southern United States, reptiles are blood-meal hosts for Culex mosquitoes, and host availability can influence mosquito feeding patterns and arbovirus transmission dynamics (Burkett-Cadena et al., 2008). Anopheles mosquitoes are also opportunistic feeders and their host selection is regulated by host availability, host abundance, anthropophily, behavioral patterns and environmental variables (Bashar et al., 2012). Furthermore, the distribution and abundance of *Culex peccator* and *Culex territans* mosquitoes, blood feeders of reptiles and amphibians, is strongly affected by host richness and environment (Burkett-Cadena et al., 2013). Evidence of arbovirus infection in repiles further supports the hypothesis that particular reptile-vector interactions, may be involved in the maintenance or overwintering of pathogens, however the reservoir competence must be shown experimentally or by means of field transmission investigations. Thus, arthropod-mediated disease transmission is a significant but relatively understudied aspect of reptile-associated zoonotic risk.

7.4 Foodborne and waterborne transmission

Foodborne and waterborne pathways are primary channels of human exposure to reptile- and amphibian-associated zoonotic bacteria, especially as many reptile species can harbor enteric infections asymptomatically and release them by fecal shedding.

Foodborne transmission may occur in the harvesting, slaughtering, processing, handling and consumption of products from reptiles. *Salmonella spp.* is of public-health concern because reptiles can carry and occasionally shed these bacteria and contaminate meat, food, utensils, surfaces and human hands (Masila et al, 2020). Wildlife or bushmeat trade may provide more opportunities for transmission, owing to poor hygiene and biosecurity during capture, transport, processing and consumption.

Waterborne transmission is particularly crucial in aquatic and semi-aquatic reptiles, which are capable to transmit enteric and opportunistic bacteria into water system. Pathogens that are associated with aquatic systems such as *Aeromonas spp.* and some *Vibrio spp.* may result in gastrointestinal disorders in susceptible persons or in some cases, systemic infections (Scheelings, 2026). Thus, fecal contamination associated

with reptiles can affect surface waterways, soil, enclosures, agricultural settings and recreational waters and therefore indirect human exposure pathways. However, the isolation of a bacterium from reptile does not necessarily imply reservoir competency or direct zoonotic transmission, highlighting the significance of integrated One Health surveillance.

7.5 Respiratory and aerosol transmission

For the majority of reptile-associated zoonoses, respiratory or aerosol transmission is not thought to be a significant or well-established route; nonetheless, under certain occupational and husbandry contexts, it may represent a possible route. The aerosolization of respiratory secretions, fecal matter, contaminated water, or environmental particulates while cleaning and managing diseased reptiles or their habitats could lead to inhalational exposure to vulnerable individuals (Schumacher, 2011). Reptiles can host a variety of bacterial and other zoonotic pathogens, although the proof of direct airborne transmission from reptiles to people is rather scarce in comparison to fecal–oral and environmental routes. Consequently, pulmonary exposure must be taken into account, especially in veterinary clinics, laboratories, wildlife rehabilitation centers, breeding facilities, and inadequately ventilated captive housing settings, where frequent animal handling and aerosol-producing activities could elevate exposure (Paphitis et al., 2025). Adequate ventilation, personal protective gear, and sanitary enclosure management are thus vital components of a One Health strategy targeted at limiting possible workplace exposure.

8. DRIVERS OF REPTILE ASSOCIATED ZOONOTIC DISEASES

Reptile-associated zoonotic diseases are exacerbated by the complex interplay of factors such as wildlife trade, a higher rate of human-animal interactions, urbanization, invasive species, and climate change. These variables may promote pathogen transmission by increasing interaction between reptiles, humans, and other animal hosts, but environmental change can influence pathogen distribution, host susceptibility, and disease dynamics.

8.1 Wildlife Trade as a Driver of Emerging Infectious Diseases

International wildlife trade is increasingly accepted as a key avenue for the emergence and transmission of infectious illnesses via the transport of sick animals, vectors, and contaminated materials across natural and political borders (Benabdallah et. al., 2025). The trade in reptiles is particularly relevant because of the close confinement, repeated handling, mixing of species from different geographical origins and trans-boundary transit of live animals which may allow pathogen transmission and introduction into new host populations (Pienaar et.al., 2022).

The Indian setting is especially important considering the rise in trading of exotic reptiles. A study of the exotic reptile pet trade in India found 84 species of exotic reptiles in commerce and identified major differences between observed trade and CITES records, revealing major gaps in monitoring and regulation (Pragatheesh et. al., 2021). Repeated captures of illegally imported exotic reptiles, especially from Southeast Asia, have also been recorded by Indian authorities (Customs department), indicating active transboundary migration into the country (Koch, et. al., 2013). The conditions of the live animal trade also facilitate the transmission of pathogens. High-density animal transport causes physiological stress and immunosuppression which increases pathogen shedding and transmission among animals. Furthermore, pathogen prevalence has been shown to grow in the months following importation, demonstrating that the dangers of disease can escalate when animals are introduced to domestic trade networks (Nijman, 2021).

Antimicrobial-resistant strains of *Salmonella* have been found in captive animals and associated environmental samples in India, which highlights the need for pathogen surveillance at animal–human interfaces (Milton et al., 2018). Taken together, these highlight demand for pre-import health screening, quarantine, pathogen surveillance, traceability, enhanced biosecurity and responsible control of the herpetofaunal trade including reptiles within a One Health context (Yap et al., 2025).

8.2 Urbanization and the Zoonotic Risks of Invasive Species

Urban environments are highly dynamic ecosystems that impose novel selective pressures and provide diverse ecological opportunities, potentially accelerating evolutionary change in both native and non-native species. Cities can also function as important entry points and establishment sites for invasive species because of intense human-mediated transport, habitat modification, and the availability of novel resources (Borden & Flory, 2021). Recent research suggests that evolutionary responses of non-native species to urban conditions may enhance their ability to establish, persist, spread, and exert ecological impacts within urban landscapes (Rivkin et al., 2019). Such rapid adaptation may subsequently increase their capacity to respond to broader environmental changes, including climate change and other anthropogenic disturbances.

Evidences from India include the research undertaken which observed snakes for 41 months (January 2019-May 2022) and recorded 372 individuals belonging to 15 species in heavily urbanized Delhi. Encounters occurred not only in forests and parks but also in homes, drainage systems, roadways, offices, and educational institutions (Barhadiya et al., 2024). Another recent 2026 study, investigating a decade of snake-rescue data identified that snake rescues have increased during a period of urban expansion, with hotspots located within fast urbanizing areas. The recovered species were predominantly *Naja naja* and *Ptyas mucosa* (Visvanathan et al., 2026). Urbanization alters habitat, enhances reptile-human encounters, establishes new interfaces, and may promote exposure to pathogens through pets, captive reptiles, contaminated surroundings, vectors and animal transportation.

These studies in India, focused on human-wildlife interactions rather than on zoonotic transmission, however it suggests increasing possibilities for pathogen exchange at the urban reptile-human interface. Nonetheless, in 2025–26, CDC examined multistate *Salmonella* outbreaks connected with pet geckos in U.S. There were 113 outbreak-associated cases reported across 36 states of U.S. and 31 hospitalizations. Epidemiologic, laboratory and traceback evidence connected illnesses to exposure to geckos and various suppliers. (January 9, 2026, CDC investigation update)

Nevertheless, there is limited direct epidemiological evidence that urbanization has led to increasing reptile-derived zoonotic illnesses in India while studies in the U.S. indicates the possibility. Thus, integrating urban wildlife surveillance with pathogen screening of reptiles, vectors and exposed human populations would be an important One Health paradigm to examine this growing interface.

8.3 Climate Change and Zoonotic Disease Transmission

Climate change can substantially influence human and animal health by altering environmental conditions that regulate the distribution, abundance, seasonal activity, and ecological competence of vectors and reservoir hosts. Changes in temperature, precipitation, humidity, and other climatic variables can modify vector and host suitability, potentially expand the geographical range and extend the seasonal transmission periods of infectious diseases. Consequently,

climate change is increasingly recognized as an important environmental determinant of zoonotic disease dynamics (Caminade et al., 2019; IPCC, 2022).

The relationship between climate change and zoonotic disease emergence is complex and is mediated by interactions among climatic conditions, host and vector mobility, land-use change, human–animal contact, healthcare accessibility, and disease-control practices. Changes in the distribution and movement of wildlife and domestic animals may alter pathogen transmission pathways between wildlife reservoirs, vectors, livestock, and human populations, thereby increasing opportunities for pathogen spillover at the human–animal–environment interface (Patz et al., 2004; Jones et al., 2008). Thus, climate-driven ecological changes may influence both the spatial distribution of pathogens and the frequency of interactions among susceptible hosts.

From a One Health perspective, climate change should therefore be considered an important ecological driver capable of reshaping pathogen–host–vector interactions and modifying zoonotic disease risks. Understanding these interconnected processes is essential for developing predictive surveillance systems and effective prevention and control strategies for emerging infectious diseases (IPCC, 2022; Singh, 2011).

8.4 Animal Human Interface

Globalization, urbanization, habitat alterations, and the exotic pet trade have increased the frequency of interactions at the human-animal-environment interface and have greatly increased the risk for introduction of zoonotic diseases (Jones et al., 2008). As reported, 60-75% of human infectious diseases originate from pathogens that initially spread in non-human animal species (Ellwanger & Chies, 2021), underscoring the significance of the One Health strategy to address zoonotic risks through the integration of human, animal and environmental health (WHO Zoonoses, 2020).

Zoonotic spillover from reptiles is particularly possible in the animal-human interface, where wildlife, domestic animals and contaminated habitats come into close contact. In India, such linkages occur through urban wildlife encounters, occupational handling, wildlife rescue, captive reptile keeper, traditional activities and trade and transport of live reptiles. Urban expansion may further improve opportunities for interaction. For example, in a 41-month survey in Delhi 372 snakes were identified belonging to 15 species, with encounters happening in urban set up (Barhadiya et al., 2024). A fatal case of *Salmonella enterica* subsp. *arizonae* infection in a newborn in New Delhi from a snake handling family was a significant clinical Indian example emphasizing the potential role of occupational and household reptile exposure in zoonotic transmission (Mahajan et al., 2003). Reptiles can be asymptomatic carriers of pathogens and pollute the residential environment via fecal shedding, providing opportunities for direct and indirect human exposure. Transmission of reptile-associated arboviruses and vector-mediated spillover are less well described, although under appropriate ecological conditions, reptiles may also interface with mosquito and tick transmission cycles.

Importantly, no species should be destroyed or stigmatized considering the potential risks to humans. In the wild, each species has an ecological significance that should be valued. The spread of infections from non-human animals to humans is mostly facilitated by human activity. Thus, the prevention of developing illnesses should be directed at human activities and human interactions with other species. Public health emergencies have occurred many times in the history of humankind and have been found hard to totally prevent, but it is feasible to lessen the danger of such incidents. Each pandemic's intensity will be a mirror to the health system. The researchers and health authorities should

work along with society to identify the main risk factors for spillover events, using efforts to prevent them and strengthening the actions to promptly restrict disease emergence after a spillover situation.

9. PUBLIC HEALTH IMPLICATIONS

Zoonoses pose a serious public health concern with significant morbidity and mortality, especially among vulnerable populations in low- and middle-income nations. Zoonotic outbreaks have health implications beyond the immediate ones, putting pressure on health systems, challenging food security and livelihoods, and impacting economies a great deal. The rise of antimicrobials resistance (AMR) to zoonotic pathogens further complicates disease management, increases treatment challenges and the burdens on healthcare.

9.1 Health, Environmental and Socioeconomic Implications

Reptile-associated zoonoses have significant impact on human health, AMR and public health systems. The risks involved are augmented by the fact that reptiles are often asymptomatic carriers of pathogens, intermittently shed pathogens, rising reptile pets, and lack of public awareness of standard hygiene and biosecurity norms (Ebani, 2017).

9.1.1 Human health impacts and clinical severity

Reptile-associated pathogens, especially with non-typhoidal Salmonella spp, can cause serious clinical illness. During 2009–2018, United States surveillance data revealed 1,465 reptile-associated salmonellosis cases, of whom ≈30.8% were hospitalized. The frequency of bloodstream infection was also rather high in reptile-associated cases (8.8%) with invasive consequences including septicemia and meningitis in severe cases (Waltenburg et al., 2022).

Reptiles, in particular squamates, may also be a source of *Campylobacter spp.* that cause gastroenteritis in humans (Gilbert et al., 2014). Although gastrointestinal symptoms are common with infection. Complications such as Guillain-BarrÃ syndrome, Miller-Fisher syndrome and reactive arthritis may develop, suggesting that reptile-associated exposure can have repercussions beyond acute gastrointestinal disease (Olvera-Ramírez et al., 2023).

9.1.2 Vulnerable populations

Young children, older adults, and immunocompromised persons are more susceptible to adverse health effects from reptile-associated zoonoses. Children under five years old have been overrepresented in reported reptile-associated outbreaks and are at increased risk for invasive Salmonella infections. Older persons, over 65 years of age, likewise have greater rates of hospitalization and are at increased risk for severe or systemic disease (Mitchell, 2011). Such results underscore the demand for targeted education and prevention strategies for families with high-risk individuals.

9.2 Antimicrobial resistances (AMR)

Another underlying One Health concern is the emergence and spreading of antibiotic resistance bacteria in reptiles. The emergence of antimicrobial resistance (AMR) in reptiles is of particular concern, as reptiles can be reservoirs and vectors for antimicrobial resistant zoonotic pathogens, especially *Salmonella* (Marin et al., 2021), however the evidence base for India remains very low. The authors promoted the possibility of pet reptiles being a source of human MDR *Salmonella* infection. The study further linked the danger of AMR with the use of antimicrobials in the breeding of reptiles, crowded conditions, transit of animals and potentially contaminated feed – an example of the applicability of the One Health concept. However, species-specific evidence on AMR in free-ranging reptiles is not available from India.

A recent study on captive gharials from in

Chitwan National Park, Nepal detected *E. coli, Staphylococcus spp.* and *Salmonella* with a high level of antimicrobial resistance; notably, 92.31% (12/13) of Staphylococcus isolates demonstrated phenotypic resistance to cefoxitin (Adhikari et. al., 2025). These findings suggest that reptiles can be sentinels and possible carriers of AMR in aquatic ecosystems, however, evidence in Indian reptiles is low. This high incidence of AMR underscores the need for routine bacteriological surveillance to keep a watch on evolving resistance trend. Major limitations are small and geographically limited sample sizes, inconsistent sampling of wild versus captive reptiles, limited longitudinal surveillance, variation in antimicrobial susceptibility testing methods, and limited genomic characterization of resistance genes and mobile genetic elements. Future Indian studies should therefore integrate reptile monitoring with culture-based susceptibility testing and whole genome/metagenomic analysis to establish resistance determinants, transmission pathways and possible interchange of AMR between reptiles, humans, livestock and environment.

9.3 Socioeconomic, Regulatory and Legal Implications

Reptile-associated zoonoses pose not only public health risk but also economic cost in terms of medical treatment, hospitalization, loss of production, laboratory testing, outbreak surveillance, and preventative care. Despite legal prohibitions, continued occurrence of turtle-associated *Salmonellosis* highlights the complexity of dealing with zoonotic threat of reptile trade (Walters et al., 2016).

Perhaps one of the primary challenges is the poor understanding of zoonotic risks associated with reptiles. Many people may not realize that clinically healthy reptiles might be carriers of Salmonella or other diseases. Such knowledge gap may jeopardize compliance with hygiene and biosecurity procedures and, thus, ease home transmission. Thus, the effective eradication of reptile-associated zoonoses requires an integrated One Health approach that encompasses pathogen surveillance, AMR surveillance, responsible trading of reptiles, veterinary supervision, household cleanliness, and targeted public-health education.

Health care professionals, veterinarians have a responsibility to uphold human health. A recent paper describes numerous situations where a veterinarian can be blamed for a breach of professional responsibility and face legal action. Examples include: (1) not advising animals owners with zoonotic diseases (2) not advising clients of the dangers associated with exotic pets, and (3) not advising customers to seek care from a physician where necessary. Veterinarians are part of any community's health care team, and they have a responsibility in the prevention of zoonoses. Pet owners should be educated and counseled about zoonoses and the prevention of their transmission.

10. LIMITATIONS, KNOWLEDGE GAPS, AND FUTURE DIRECTIONS

India is home to remarkable reptile diversity, but integrated studies on the biogeography of reptiles and the distribution of zoonotic pathogens and public-health risk are limited. Existing research is predominantly taxonomic, ecological or pathogen-specific, with very few investigations integrating species distribution, host phylogeography, pathogen diversity, environmental factors and human exposure into a One Health paradigm (Singh et al., 2014) This gap is essential, to understand particularly as changing land uses, habitat fragmentation, urbanization and wildlife trade is increasing the wildlife–human interfaces in India. In addition, there is a dearth of region-specific resolved surveillance of infections and antimicrobial resistance in wild and captive reptile populations, restricting the ability to assess if geographic or phylogenetic

variations among reptile hosts affect disease propagation and transmission (Cardoso-Freitas et al., 2025). Other significant shortcomings of reptile-associated AMR research identified in recent literature include geographically unequal sample, methodological variation and limited genetic characterization.

Another major knowledge gap is the wildlife–trade interface. India has reported traffic in exotic reptiles and a lack of monitoring and regulation that can provide possible avenues to facilitate the entry of pathogens and invasive species (Pragatheesh et al., 2021). Moreover, systematic mapping of reptile-associated illnesses, human healthcare surveillance, and wildlife-health databases remains insufficiently established. Future study should thus combine biogeography, phylogeography, pathogen metagenomics, AMR surveillance, vector ecology and epidemiological data based on GIS.

11. CONCLUSION

India's high reptile diversity driven by complex biogeographic histories, climate variations, geological processes and habitat heterogeneity provide a significant yet insufficiently researched framework for understanding pathogen diversity and zoonotic risk. Reptiles host a variety of bacterial, viral, fungal and parasitic agents, including some species with established or potential risks to human and animal health. However, a detection of a pathogen in reptiles is not necessarily indicative of zoonotic transmission and the exact extent of many implicated potential risks is unclear. Evidences available from India are fragmented, geographically inconsistent, and frequently restricted to pathogen detection or isolated clinical reports, with very few investigations integrating host ecology, biogeography, pathogen genomes, transmission pathways and human interface. Important gaps exist in the surveillance of wild reptiles, emerging and invasive species, antimicrobial resistance, climate-driven range shifts, wildlife trade, and disease spillover at human-reptile interfaces. This underscores the need to enhance integrated One Health surveillance integrating herpetology, molecular epidemiology, ecology, veterinary medicine and public health. Standardized sampling, genetic characterization, longitudinal monitoring and risk assessment across different biogeographic regions could shed light on whether reptile-associated infections are true public-health concerns. This research is especially relevant as environmental change, urbanization, habitat fragmentation and increased contact between wildlife and humans may affect the dynamics of transmission of pathogens. By filling these knowledge gaps, India would be able to create evidence-based preparedness programs and add to the worldwide awareness and prevention of new zoonotic diseases.

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During the preparation of this manuscript, the authors used OpenAI for language editing, grammatical correction, and improvement of clarity and readability. The authors critically reviewed and revised the AI-assisted content and take full responsibility for the accuracy, integrity, originality, and final content of the manuscript. No AI tool was used to generate, fabricate, or manipulate experimental data, results, or scientific conclusions

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Conflict of Interest

Authors have no conflict of interest to declare.

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