

# ECOLOGICAL AND BEHAVIORAL STUDY OF SNAKE SPECIES IN KOTA, RAJASTHAN WITH REFERENCE TO VENOM CHARACTERISTICS

Vineet Mahobia<sup>1</sup>, Dr. Ram Bhajan Kumawat<sup>2</sup>

Research Scholar, Department of Zoology, University of Technology, Jaipur<sup>1</sup>

Professor, Department of Zoology, University of Technology, Jaipur<sup>2</sup>

## ABSTRACT

Snakes are a rare and even less understood, critical aspect of terrestrial ecosystems, serving as both hunter and quarry through trophic levels. Kota, a district in southeastern Rajasthan, India, in the biome of the Chambal River basin, ravines, dry deciduous forests, and semi-arid scrublands is a heterogeneous, biologically rich zone with a great diversity of snakes. The current study was on systematic field-based observational study of snake species diversity, habitat preference, behavioral traits and venom profile in Kota district. Methodology: A combination of structured transect walks, opportunistic encounter surveys, key informant interviews and synthesis of verified secondary literature were used for data collection in local communities and with forest department personnel. Fifteen snake species from seven families were recorded or confirmed from the study area. Four of them *Naja naja* (Indian Cobra), *Bungarus caeruleus* (Common Krait), *Daboia russelii* (Russell's Viper) and *Echiscarinatus* (Saw-scaled Viper) constitute medically significant venomous species of India's "Big Four". Focal follows permitted documentation and analysis of behavioral patterns like patterns of activity rhythm and foraging strategies, thermoregulatory behavior, and defensive responses. Secondary toxinological data were used to classify venom toxicities to neurotoxic, hemotoxic and cytotoxic profiles for venomous species. The study illustrates the ecological role of snake communities in gemstones of the Chambal ecosystem, conservation imperatives for these lineages and provides a first central dataset of herpeto-fauna of management relevance for the study region.

**Keywords:** *ophidian ecology*<sup>1</sup>; *Chambal ravines*<sup>2</sup>; *Rajasthan herpetofauna*<sup>3</sup>; *snake venom toxicity*<sup>4</sup>; *snakebite envenomation*<sup>5</sup>.

## 1. INTRODUCTION

With around 300 species of snakes, almost 60 of the species are medically important (Whitaker & Captain, 2004) and India is one of the most herpetologically diverse countries in the world. As a group, snakes are at an

ecologically foundational level, controlling rodent numbers, balancing prey-predator communities, and responding to environmental impacts as indicator species (Greene, 1997). In India, however, snake communities still remain insufficiently documented at district-wide or even regional scales, instead contributing critical knowledge gaps which handicap effective conservation planning despite their significant ecological roles. As the biggest state of India by area, Rajasthan has also a remarkably intriguing case for herpetological exploration. The state, possessing a heterogeneous landscape consisting of the west-Thar Desert, the central-Aravalli hill ranges and the southeastern corner-Chambal basin occupying part of the state (Sharma, 2002), harbours a high variety of microhabitats and consequently a high diversity of reptiles. This make Kota significant ecologically among the districts in Rajasthan. The surrounding habitat consists of a mosaic of riparian, scrub and rocky formations provided by the Chambal River and its long ravine systems (locally called *beehad*) which is known to harbour considerable reptile diversity (Champion & Seth, 1968). Adding to the conservation value of the region is the erstwhile Chambal Wildlife Sanctuary stretching between Kota and Sawai Madhopur districts.

There are multiple interrelated reasons why understanding the ecology and behaviour of snake species is important. First, snakes play an important role as a keystone predator in many terrestrial food webs, and declining snake populations are known to result in cascading effects – rodent population explosions and associated increased agricultural losses and risk of diseases transmission (Vitt & Caldwell, 2009). Second, India has the highest snakebite mortality burden worldwide, as established by Mohapatra et al. (2011) are that there are about 45,900 deaths per year, which is an order of magnitude higher than most estimates by the World Health Organization, which nevertheless considers snakebite a top-ten neglected tropical disease (WHO, 2019). As such, accurate recording of species ranges, behavior and venom-production is understandably of direct relevance to public health and antivenom policy. Third, snake venom systems represent an outstanding pharmacological interest. The study of snake venoms, which are complex mixtures of enzymes, peptides and non-enzymatic proteins, has led to the discovery of therapeutic agents such as captopril (from bradykinin-potentiating peptides of *Bothrops jararaca* venom) and anticoagulants (Kini, 2006). Part of doing that is knowing how the snakes vary in their venoms region by region, which will help clinical toxinology and drug discovery, too (getting things more precise).

### Research Objectives

The present study was guided by the following objectives:

1. To document the species diversity and taxonomic composition of snake communities in Kota district, Rajasthan.
2. To characterize habitat associations, microhabitat preferences, and seasonal activity patterns of recorded species.
3. To describe key behavioral traits including foraging strategy, thermoregulatory behavior, defensive responses, and reproductive ecology.
4. To profile the venom characteristics including toxin categories, biochemical composition, and clinical implications of medically significant species recorded from the study area.

5. To provide conservation-relevant recommendations for the protection of ophidian fauna in the Chambal ecosystem.

### Research Questions

The study addressed the following research questions:

- What is the species composition and relative abundance of snakes across different habitat types in Kota district?
- How do behavioral patterns vary across species in relation to season, habitat, and ecological niche?
- What are the primary venom categories among medically significant species, and what clinical toxidromes do they produce?
- What anthropogenic and ecological pressures threaten snake populations in the region?

## 2. REVIEW OF LITERATURE

### Snake Ecology and Habitat Use

The foundations developed by Boulenger (1890), who provided an early systematic assessment of South Asian reptiles that continues as a reference cornerstone, and further synthesized by Whitaker and Captain (2004) in their thorough field guide have created a solid literature deposit for Indian snakes. The authoritative taxonomic treatment of Indian serpents was recently published (along with subsequent species entries) by Sharma (2002) in the series *Fauna of India*, part of the Zoological Survey of India series and it details species distributions and morphological diagnostics across the subcontinent. Shifts in habitat use by snakes suggest complex species interactions related to prey availability, interspecific competition, and physiological tolerances (Greene, 1997). These habitats are broadly similar to the rocky outcrops, agricultural margins and river valleys of southeastern Rajasthan which are recognised as important ophidian microhabitats in the semi-arid and dry deciduous zones of peninsular and central India (Das, 2002) Our Investigation: Thermal environment represents one of the main drivers of reptile activity budgets (e.g., Vitt and Caldwell, 2009) and snakes in semi-arid habitat may exploit patches of optimal thermal microclimate through selection of particular substrates, aspects and/or burrow systems. According to Shine (1994), body size and thermal strategy are linked amongst snake taxa, as larger species tend to have more thermal inertia and can remain active longer under suboptimal conditions.

The hilly areas of the Chambal valley (Chambal Wildlife Sanctuary, CWS) have been described as a habitat of high reptile diversity by the Indian Forest and Wildlife Institute (1988) and are characterized by a locally endemic system of deeply dissected alluvial ravines, largely devoid of scrub vegetation, and rock outcrops in the river escarpments. Champion and Seth (1968) defined the vegetation in the Chambal basin area as tropical dry deciduous forest changing into thorn scrub, conditions that can sustain high overall species diversity, including that of snakes, through combined suitable prey communities (mainly rodents and amphibians) and habitat structural complexity.

## Behavioral Patterns of Snakes

Behavioral ecology of snakes includes a wide range of topics from foraging strategy to anti-predator behavior, reproductive behavior, and thermoregulation. A previous publication (Greene, 1997) synthesized snake behavioral diversity broadly on the basis of known foraging behaviours that are partially associated with the sit-and-wait pool of ambush predators (typical of vipers) and active foragers (typical of many colubrids and elapids). *Najana* has been extensively studied in India mostly using radio-telemetry; while the species is primarily crepuscular to nocturnal, considerable behavioral plasticity during cooler months is evident by the observable increase in time spent outside diurnal activity (Whitaker & Captain, 2004). *Bungaruscaeruleus* consists of one of the most strictly nocturnal nature of Indian snakes characterized behavior that is essentially nocturnal because the main prey of *Bungaruscaeruleus*, other small snakes and lizards, is also essentially nocturnal (Das, 2002).

They are going to find their way directly into Kota, where agriculture patches, ravines, and human settlements exist side by side, and road motion exposes an individual to potential road mortality and human persecution. Defensive behaviour in snakes is taxonomically variable and ecologically consequential. In a similar vein, *Echiscarinatus* and *Daboia russelii* are venomous species that use cryptic coloration and threat displays for the most part to deter predators and reserve venom deployment for prey capture, although defensive bites are well-studied in the literature (Warrell, 2010). An exceedingly unique form of acoustic warning signal, studied in a behavioral contexts, is characterized by stridulation produced by the rasping of serrated lateral scales of the saw-scaled viper (Whitaker & Captain, 2004).

## Venom Composition and Toxicity

Snake venom is one of the most complex biochemical weaponry in the animal world and has evolved predominantly for immobilization and predigestion of prey (Fry et al., 2003). Venomics, or the use of proteomic, transcriptomic and phylogenetic methods to study molecular evolution of venom systems, has been used to great success (Calvete, 2017). Using an integrative framework, Calvete showed that venom composition represents an initial condition based on evolutionarily conserved biochemical pathways that are adapted to dietary ecology and prey-predator arms races. The major venom types among Indian medically important snakes are (i) neurotoxic venoms (*Naja* and *Bungarus* species, characteristic of elapids), acting through presynaptic and postsynaptic sites at the neuromuscular junction; (ii) hemotoxic venoms (*Daboia russelii*, characteristic of vipers), which trigger coagulation cascades and may lead to disseminated intravascular coagulation (DIC) thrombocytopenia, and hemorrhage (Gutiérrez et al., 2017); and (iii) cytotoxic venoms, which induce local tissue necrosis and may contribute to systemic toxicity. Clinical Review Following their definitive clinical review on the management of snakebites, Warrell (2010) documented that snakes self-deployed *envenomation* from *Daboia russelii* represents the most frequent cause of snakebite fatalities in South Asia, due to their potent hemotoxic venom and overlap in habitat with rural communities.

Three-finger toxins (3FTx) the most important neurotoxic components of elapid venoms, have undergone extensive diversification through gene duplication and accelerated molecular evolution among species from *Naja* and *Bungarus* (2003). In a review of antocoagulant action of viper venom proteins, Kini (2006) identified

phospholipase A2 (PLA2) enzymes, serine proteases and metalloproteinases that synergistically antagonize hemostasis via overlapping biochemical mechanisms. The aforementioned review by Aird (2005) published the taxonomic distribution of free nucleosides found in snake venoms, hypothesizing their role as putative purinergic signal modulators that could be implicated in the immobilization of the prey by causing hypotension. There has been a comprehensive review about snakebite in South Asia (2010), demonstrating that the seasonality of snakebite incidence with peaks during the monsoon and post-monsoon months (July–October) is explained by the convergence of snake activity, human agricultural activity and the problem in visibility in flooded fields. Such seasonality is most immediately pertinent to Kota district, which sees a rise in agricultural activities along the Chambal floodplain during the monsoon season. Through a national mortality survey, Mohapatra et al. (2011) directly quantified snakebite deaths in India and showed that rural, agricultural communities disproportionately contribute to rural mortality from snakebite deaths, of which Rajasthan is a large contributor.

Using multi-dimensional proteomic approaches to analyze venoms, Fox and Serrano (2008) proposed that as much as fifty or more proteins comprise the "venom proteome" for individual species, with proportions differing by sex, age, season, and geographic population. Using the relationship between diet and venom evolution, Sasa (1999) reported evidence that specialization of diet drives intraspecific variation in venom, and this has also important implications regarding the variation of venom potency and composition of different populations of *Echiscarinatus* in relation to their diet in different regions of Rajasthan. In WHO Bulletin, Chippaux (1998) is one of the few foundational studies estimating the global burden of snakebite and prompting to highlight the snakebite hotspots in India & sub-Saharan Africa as the "snakebite belt" of human mortality. The complete reference handbook on reptile venoms and toxins, which included a multitude of standardized biochemical data on the venom compositional profiles for all four of members of India "Big Four" Upendra K. G. Mackessy, 2010 (ed.) then examined the description of these new preliminary data in terms of their potential use in drug discovery.

### 3. STUDY AREA DESCRIPTION

**Geographical Location and Physical Features:** Kota district is located in the southeast of Rajasthan state, India, bounded approximately between latitudes 24°25'N to 25°32'N and longitudes 75°05'E to 76°30'E with an area of about 5,217 km<sup>2</sup> and is mainly covered by Chambal River along with its tributaries; Kalisindh River, Parwan River and Ahu River. A Ramsar-listed wetland of ecological significance, the Chambal River one of the most unpolluted large rivers in India divides the district and forms a broad alluvial corridor between deeply incised ravine systems. The topography of Kota can be basically divided into three physiographic zones which are the Chambal flood plain and active floodplain terraces, the ravine badlands (beehad) with gullied and highly dissected geography with sparse vegetation and last are the upland plateau which is the extension of Malwa Plateau to the east with topography which is relatively level and farmland and scrubland use predominates.

**Climate:** According to Köppen-Geiger climate classification, Kota has a semi-arid to sub-humid climate (BSH (hot semi-arid steppe)). The annual climate cycle encompasses four distinct seasons: (i) a hot dry long summer (March–June) characterized with maximum temperatures regularly surpassing 45°C; (ii) a monsoon season (July–September) receiving around 700–800 mm of annual rainfall; (iii) a post-monsoon transition (October–

November); and (iv) a cool dry short winter (December–February) with minimum temperatures reaching as low as 6–8°C (note 3–5). This thermal seasonality is marked and directly regulates snake activity budgets whereby thermal activity windows constrain foraging, reproduction, and dispersal behavior.

**Vegetation and Land Use:** Following classification of Champion and Seth (1968), vegetation of Kota district is mainly Tropical Dry Deciduous Forest (Type 5A) in the ravine regions whereas a Tropical Thorn Forest type is present in the hotter and drier upland tract. The predominant tree species contains *Anogeissus latifolia*, *Boswelliaserrata*, *Acacia catechu*, *Ziziphus mauritiana* and *Buteamonosperma*, with the order of colonization patches of the invasive shrub *Lantana camara* in the disturbed fringes. Grass vegetation, *Prosopis juliflora* thickets in the Chambal River riparian zones Part of the Mukundra Hills Tiger Reserve, which is included in the south of Kota district, contains more perfect dry deciduous forest and is the best natural environment in the region. The district has a large amount of land under agriculture, with wheat, mustard, soybean and cotton being the main crops. The agricultural land mosaics especially fields associated with ravine scrub and village peripheries could be critical interface habitats for human-snake interactions.

**Relevance to Snake Diversity:** Both ecological inequity associated with narrow denning habitat availability and higher predation risk impose an upper limit on snake densities in the development of a snake fauna in a given geographic area. In particular, the Chambal ravines with their compacted rocky escarpments, sandy banks, and dense thorny scrub are home to high densities of snakes that find shelter, thermoregulatory sites, and foraging habitat (Rodgers&Panwar, 1988). Some steep ravine sections are also relatively inaccessible to intense human disturbance, and may have maintained refugial populations of sensitive species.

#### 4. RESEARCH METHODOLOGY

Field-based observational research design in a mixed method framework, combining primary data collection using a structured field survey with synthesis and analysis of verified secondary literature and meta-analysis design using the two-step prediction approach (we call this the two-step prediction meta-analysis design). Because differential phylogeographical effects were observed between warmer and cooler seasons, the study was set over a multi-season window that allowed for simultaneous warm-season active periods and cooler-season reduced-activity phases of behavioral variation to be captured. Study area We stratified the study area into five habitat types for the purpose of systematic sampling across ecologically distinct physiognomic zones; (i) Chambal riverine margins and active floodplain, (ii) ravine scrubland (*beehad*), (iii) dry deciduous forest patches within and adjacent to Mukundra Hills, (iv), agriculture and village peripheries, and (v) rocky upland scrub. For each habitat stratum, plots were sampled to ensure representation.

- **Visual Encounter Surveys (VES):** Transects were walked systematically in line with each habitat stratum. Two observers walked 1 km long transects slowly in the early morning (06:00–09:00), evening (17:00–20:00), and night hours to record both diurnal and nocturnal species. Observers noted every snake seen at a distance of 2 meters on both sides of the transect line producing a 2000 m<sup>2</sup> sampling corridor per transect walk.

- **Cover Object Surveys:** Potential refugia (e.g., flat rocks, fallen logs, brush piles, and sheets of tin) were systematically searched and checked to detect cryptic or sheltering organisms in daytime surveys.
- **Pitfall Trap Arrays:** Additionally, drift-fence and pitfall trap arrays were deployed at each passive habitat type during each active season to augment the visual survey dataset.
- **Key Informant Interviews:** were conducted with local villagers, and farmers, as well as snake charmers (saperas), and field staff of Rajasthan Forest Department to obtain details pertaining to historical and recent sightings, human – snake conflict incidents as well as traditional ecological knowledge (TEK) about snake behaviour and habitat use.
- **Secondary Data Compilation:** In addition, secondary data compilation using published reports of herpetofauna, ZSI survey reports, records of the state wildlife department, and validated literature for the state of Rajasthan on the reptiles were done to supplement and validate the field data collected.

### Species Identification

In situ identification of snakes was based on physical traits (i.e., scalation, color pattern, head shape, and body proportions) using Whitaker and Captain (2004) and Das (2002) as main guides. We photographed all encounters with digital cameras and verified images with herpetologists. Snake tongs and bags were used to similarly examine non-venomous species where possible and appropriate; venomous species were observed and photographed but not handled.

### Behavioral Observations

Data on behavior were collected using focal animal observation protocols when individual encounters were long enough. We documented other parameters: substrate use, body posture, locomotory mode, defensive-display, foraging activity, and behaviour that seems to be otherwise related to thermoregulation. Activity level (diurnal vs nocturnal) was determined for encounters based on encounter timing over survey sessions.

### Venom Characterization Approach

All venom characterization was performed solely through secondary analyses of peer-reviewed toxinological literature and established databases. Field trip No venom extraction from wild-caught specimens Viperid venom composition, LD50 values, and clinical toxidromes for species recorded in our study region were compiled primarily from previously published data (Mackessy 2010, Gutiérrez et al. (2017), and Warrell (2010).

### Ethical Considerations

Field activities were performed under the provisions of Wildlife Protection Act, 1972 (Government of India) and were approved by local ethical committees, where needed. No snakes were captured, slaughtered, or kept. All records of venomous species were recorded from a safe distance. To reduce stress and mortality of captured individuals, pitfall traps were emptied every 12 hours, and captured individuals were released at capture sites. The institutional ethics committee reviewed and approved the study protocol. All field personnel were trained in first aid for snakebite and provided communication devices for emergencies.

## 5. RESULTS AND ANALYSIS

### Species Composition and Diversity

Methods: The study area is a district in Rajasthan, India, where snake fauna was documented or confirmed from a total of fifteen snake species represented by seven families. These include four species which are of medical importance (part of "Big Four" venomous species complex of India), three species that are mildly venomous or rear-fanged (*opisthoglyphous*) and eight that are non-venomous. Total species richness recorded is similar to that from well-documented *herpetofaunal* inventories from ecologically comparable areas of semi-arid peninsular India (Whitaker & Captain 2004; Sharma 2002). The species most encountered overall were *Ptyas mucosa* (Indian Rat Snake), *Xenochrophis piscator* (Checkered Keelback), and *Eryx johnii* (Indian Sand Boa) and were generalists with high encounter rates across habitat types. The commonly met medically important venomous species were *Najanaja*.

**Table 1: Snake Species Recorded in Kota District, Rajasthan: Taxonomy, Venom Status, and IUCN Conservation Status**

S. No.	Common Name	Scientific Name	Family	Venom Status	IUCN Status
1	Indian Cobra	<i>Najanaja</i> (Linnaeus, 1758)	Elapidae	Venomous (Neurotoxic + Cytotoxic)	Least Concern
2	Common Krait	<i>Bungarus caeruleus</i> (Schneider, 1801)	Elapidae	Venomous (Neurotoxic)	Least Concern
3	Russell's Viper	<i>Daboia russelii</i> (Shaw & Nodder, 1797)	Viperidae	Venomous (Hemotoxic + Cytotoxic)	Least Concern
4	Saw-scaled Viper	<i>Echiscarinatus</i> (Schneider, 1801)	Viperidae	Venomous (Hemotoxic + Cytotoxic)	Least Concern
5	Indian Rock Python	<i>Python molurus</i> (Linnaeus, 1758)	Pythonidae	Non-venomous (Constrictor)	Vulnerable
6	Indian Rat Snake	<i>Ptyas mucosa</i> (Linnaeus, 1758)	Colubridae	Non-venomous	Least Concern

7	Checkered Keelback	<i>Xenochrophispiscator</i> (Schneider, 1799)	Natricidae	Mildly venomous (Rear-fanged)	Least Concern
8	Indian Sand Boa	<i>Eryxjohnii</i> (Russell, 1801)	Erycidae	Non- venomous	Least Concern
9	Common Sand Boa	<i>Eryxconicus</i> (Schneider, 1801)	Erycidae	Non- venomous	Least Concern
10	Indian Wolf Snake	<i>Lycodonaulicus</i> (Linnaeus, 1758)	Colubridae	Non- venomous	Least Concern
11	Indian Egg-eating Snake	<i>Boigatriginata</i> (Schneider, 1802)	Colubridae	Mildly venomous (Rear-fanged)	Least Concern
12	Buff-striped Keelback	<i>Amphiesmastolata</i> (Linnaeus, 1758)	Natricidae	Non- venomous	Least Concern
13	Bronze-back Tree Snake	<i>Dendrelaphistris</i> (Daudin, 1803)	Colubridae	Non- venomous	Least Concern
14	Green Vine Snake	<i>Ahaetullanasuta</i> (Lacépède, 1789)	Colubridae	Mildly venomous (Rear-fanged)	Least Concern
15	Diadem Snake	<i>Spalerosophisdiadema</i> (Schlegel, 1837)	Colubridae	Non- venomous	Least Concern

Source: Compiled from Whitaker and Captain (2004), Sharma (2002), Das (2002), and IUCN (2023).

Table 1 Taxonomic classification, venom status and conservation status of all the fifteen snake species recorded and confirmed from Kota district, Rajasthan during the study period. Species are categorized based on modern herpetological taxonomy after Whitaker and Captain (2004) and Sharma (2002). Venom status types based on fange placement: Venom status, corresponding types based on fange placement (of teeth): Used in frontally-fanged highly venomous species (medically significant) in rear-fanged mildly venomous species opostoglyphous, generally not medically significant as for medline Non-venomous species in aglyphous. The conservation status was adapted from the most recent assessments in the IUCN Red List with only the Indian Rock Python (*Python molurus*) identified in this assemblage of comprising the sole Vulnerable-listed species.

### Habitat Preferences and Microhabitat Use

Analysis of habitat showed evident interspecific variation in microhabitat preference, in accordance with the ecological principle of niche partitioning that has been documented to operate for various snake assemblages in

tropical and subtropical systems (Greene, 1997; Vitt & Caldwell, 2009). The highest species richness (nine out of fifteen) was along Chambal margins of riparian habitats. High encounter rates of *Najana*, *Ptyas mucosa*, and *Bungarus caeruleus*, was characterized in agricultural margin-ravine interface habitats. *Echiscarinatus*, *Spalerosophis diadema* and the two sand boa species were supported as distinct assemblages in the rocky ravine scrub. Encounters of *Python molurus* were only within Mukundra Hills in forest patches.

**Table 2: Habitat Association, Activity Pattern, and Feeding Guild of Snake Species Recorded in Kota District**

Species	Primary Habitat	Secondary Habitat	Activity Pattern	Primary Prey
<i>Najana</i>	Agricultural margins, village peripheries	Ravine scrub, forest edge	Crepuscular/Nocturnal (diurnal in winter)	Rodents, frogs, lizards, other snakes
<i>Bungarus caeruleus</i>	Agricultural fields, village peripheries	Riparian scrub	Strictly Nocturnal	Snakes, lizards, small rodents
<i>Daboia russelii</i>	Agricultural land, grassland	Scrub forest margins	Nocturnal (crepuscular)	Rodents, frogs, lizards
<i>Echiscarinatus</i>	Rocky scrub, ravines	Sandy soil habitats	Nocturnal	Scorpions, insects, lizards, small rodents
<i>Python molurus</i>	Forest patches, riparian areas	Rocky ravines with cover	Nocturnal	Medium-large mammals, birds
<i>Ptyas mucosa</i>	Agricultural margins, open scrub	Riparian zones	Diurnal	Frogs, rodents, lizards
<i>Xenochrophis piscator</i>	Chambal riparian zone, wetlands	Irrigation canals	Diurnal	Frogs, fish, tadpoles
<i>Eryx johnii</i>	Sandy soils, agricultural fields	Open scrubland	Nocturnal / Fossorial	Rodents, lizards

<i>Eryxconicus</i>	Sandy ravine margins, open scrub	Agricultural margins	Nocturnal / Fossorial	Lizards, small rodents
<i>Lycodonaulicus</i>	Village peripheries, rock crevices	Scrub forest	Nocturnal	Lizards, geckos
<i>Boigatrigonata</i>	Scrub forest, bushes, rocky areas	Agricultural hedgerows	Nocturnal / Arboreal	Lizards, small birds, eggs
<i>Amphiesmastolata</i>	Riparian grassland, paddy margins	Moist scrub	Diurnal	Frogs, toads, earthworms
<i>Dendrelaphistris</i>	Forest edge, shrubby vegetation	Open scrub	Diurnal / Arboreal	Lizards, frogs, small birds
<i>Ahaetullanasuta</i>	Dense scrub, forest edge, bushes	Riparian woodland	Diurnal / Arboreal	Lizards, frogs
<i>Spalerosophisdiadema</i>	Rocky ravines, dry scrub	Sandy desert margin	Diurnal / Crepuscular	Rodents, lizards

Source: Compiled from Whitaker and Captain (2004), Das (2002), Greene (1997), and field observations.

The following table summarizes the habitat associations, timing of activity, and main dietary guilds for each of the fifteen snake species documented in the Kota district. Habitats are classed according to the most frequently used microhabitat, determined from the encounter site characteristics recorded during field surveys, and compared with literature data. The patterns of activity are diurnal (active mainly in the daytime), nocturnal (active mainly at night), crepuscular (active at dusk and in the dawn), and fossorial (subterranean). Literature records and feeding observations were compiled for primary prey items. This table further highlights resource partitioning within the Kota assemblage at the habitat, temporal, and dietary axes to illustrate ecological niche diversity.

### Behavioral Observations

**Thermoregulatory Behavior:** Thermoregulation was one of the few behaviours with consistent documentation. In the mornings (09:00–11:00), *Najana* and *Ptyas mucosa* were often seen basking on south-facing rock faces and dark soil, which is consistent with the use of these surfaces in winter months to raise the body temperature over its minimum thermal threshold (see Vitt & Caldwell, 2009). Because *Echiscarinatus* and species of sand

boa are primarily nocturnal, they were found using warmed rock undersurfaces and rodent burrow entrances during the day.

**Defensive Behavior:** *Najanaja* displayed the entire suite of documented defensive behaviors such as hood spreading, threat posture elevating, hissing, and mock-strike behavior. None of the unprovoked strikes were recorded at distances greater than 1 meter in the observation sessions. All of the above behavior is consistent with the aggressive defensive reputation of this species documented by Whitaker and Captain (2004), as *E. carinatus* consistently stridulated its warning when approached, coiled defensively, and struck quickly when further disturbed. *Ptyas mucosa* had fast flight response as main *antipredator* tactic, while neck flattening and striking only occurred when cornered.

**Foraging Behavior:** Foraging *Behavior* *Ptyas mucosa* and *Dendrelaphistristis* were seen as active foragers, wandering through habitat with regular tongue-flicking and methodical examination of burrow openings, cracks in rocks, and margins of vegetation. This active foraging mode is in stark contrast to the sit-and-wait ambush foraging position, in which *Daboiarusselii* and *Echiscarinatus* were commonly documented, remaining still for hours or days at a time whilst they waited for prey to pass (Greene, 1997).

### Venom Characteristics

**Table 3: Venom Characteristics of Medically Significant Snake Species in Kota District, Rajasthan**

Species	Primary Venom Type	Key Toxic Components	Subcutaneous LD50 (mg/kg, mice)	Principal Clinical Syndrome	Antivenom Availability
<i>Najanaja</i>	Neurotoxic + Cytotoxic	$\alpha$ -neurotoxins, phospholipase A2 (PLA2), cytotoxins (cardiotoxins)	0.40–0.45	Neuromuscular blockade, ptosis, respiratory paralysis, local necrosis	Indian Polyvalent Antivenom (VINS, Bharat Serums)
<i>Bungaruscaeruleus</i>	Neurotoxic	$\beta$ -bungarotoxin (pre-synaptic), $\alpha$ -bungarotoxin (post-synaptic), PLA2	0.09–0.10	Ascending flaccid paralysis, respiratory failure, minimal local effect	Indian Polyvalent Antivenom
<i>Daboiarusselii</i>	Hemotoxic + Cytotoxic	Serine proteases (ancrod-like), PLA2, metalloproteinases,	0.40–0.75	Coagulopathy, DIC, hemorrhage, AKI, thrombocytopenia,	Indian Polyvalent Antivenom

		PSPA		local necrosis	
<i>Echiscarinatus</i>	Hemotoxic + Cytotoxic	Echistatin (RGD disintegrin), PLA2, thrombin-like enzymes, metalloproteinases	0.44–2.30	Spontaneous systemic bleeding, incoagulable blood, local swelling and necrosis	Indian Polyvalent Antivenom

Source: Compiled from Warrell (2010), Gutiérrez et al. (2017), Mackessy (2010), and Kini (2006).

The venom properties of four main medically important snake species of ("Big Four") found in Kota district, Rajasthan are presented in the table. Values of the lethal dose for 50% of test mice (LD50) were taken from published toxicological databases and are expressed to quantify venom potency per unit mass (toxicity). The predominant clinical syndrome is represented by primary venom types, although there is considerable overlap between them, (for example, both cobra and Russell's viper venoms contain significant cytotoxic components that act locally to destroy tissue in a manner independent of systemic neurotoxic or hemotoxic outcomes). DIC: disseminated intravascular coagulation; AKI: acute kidney injury; PSPA: phospholipase A2-stimulating protein A; PLA2: phospholipase A2. The Indian Polyvalent Antivenom is indicated for all four species, but clinical efficacy vary depending on geographic venom variant.

**Neurotoxic Venoms:** *Najanaja* venom combines post-synaptic  $\alpha$ -neurotoxins that bind competitively and irreversibly to acetylcholine nicotinic receptors at the neuromuscular junction and phospholipase A2 enzymes with direct myotoxic and membrane-disrupting activity (Fry et al., 2003). Venum of *Bungaruscaeruleus* is known to contain a pre-synaptic neurotoxin known as  $\beta$ -bungarotoxin that obstructs the release of acetylcholine by destroying phospholipids in the presynaptic membrane via PLA2 activity. Krait postsynaptic blockade is pre- and postsynaptic in nature, and therefore causes significant resistance to antivenom treatment after clinical symptoms establish (Warrell, 2010).

**Hemotoxic Venoms:** Venom of *Daboiarusselii* activates several stages in the coagulation cascade, whereby specific serine proteases cleave fibrinogen and activate factor X and prothrombin, thus leading to consumption coagulopathy and DIC (Kini, 2006). Russell's viper bite is the commonest reason for acute kidney injury (AKI) amongst snakebite victims from South Asia, a pathological outcome of not only hypotension and DIC but also of direct tubular toxicity (Gutiérrez et al., 2017). In addition to thrombin-like enzymes responsible for the clinically significant defibrination syndrome (Calvete, 2017), the venom of *Echiscarinatus* contains echistatin, a potent RGD-domain disintegrin which inhibits platelet aggregation by blocking fibrinogen binding to glycoprotein IIb/IIIa).

## 6. DISCUSSION

### Species Diversity in Ecological Context

The record of fifteen snake species from Kota district represents the true biological heterogeneity of the Chambal basin zone, in relation to similar semi-arid to dry deciduous habitat types in central and peninsular India (Whitaker & Captain, 2004; Sharma, 2002). Colubrids (five species) dominate the assemblage composition, which follows a global pattern of colubrid dominance in snake communities from temperate and tropical regions (Vitt & Caldwell, 2009). The inclusion of four medically important species (all Four "Big" species documented for India) emphasizes the public health significance of the Kota assemblage and is consistent with the geographic range details in Warrell (2010) and Alirol et al. (2010). The clustering of species diversity within riparian and agricultural interface habitats corresponds well with resource availability theory since these interface habitats provide abundant prey assemblages (frogs along river margins, rodents within agricultural fields), a relative abundance of structural complexity, and the maintenance of a relatively high soil moisture that alleviates thermoregulatory stress for ectotherms (Greene, 1997; Bonnet et al., 1999). This relative paucity of species in upland rocky scrub habitats is likely a result of limited prey abundance and extreme thermoregulatory conditions during the pre-monsoon season.

### Behavioral Patterns and Ecological Significance

Most snakes that are medically significant such as *Naja naja*, *Bungarus caeruleus*, *Daboia russelii* and *Echis carinatus* are nocturnal, which also has important consequences for the epidemiology of snakebite. This is well documented (Alirol et al., 2015). (2010) and Mohapatra et al. According to a study (2011), the highest number of fatal snakebite cases in rural India occur at night when visibility is poor and without proper footwear, which exactly aligns with the peaks of activity of the most dangerous species. Wide awareness about the nocturnal movement patterns of snakes among the community is thus an important part of snakebite prevention. The classic dichotomy described by Greene (1997) between active foragers (e.g. *Ptyas mucosa*, *Dendrelaphis tristis*) and sit-and-wait ambush predators (e.g. *Daboia russelii*, *Echis carinatus*) parallels the behavioral partitioning between active foragers that primarily rely upon chemosensory (vomeronasal) detection of prey chemical trails for prey detection and ambush predators that emphasize infrared-sensitive pit organs (in vipers) and visual detection of moving prey. The differences in foraging mode correlate broadly with body plan morphology stout-bodied vipers adapted for energetically efficient ambush exploitation versus slender, elongate active foragers (e.g. Shine, 1994), a similarity clearly evident in the Kota assemblage.

### Venom Variation and Its Ecological Role

The different types of venoms proved to be recorded across the four human affected species in Kota are suggestive of adaptive radiation of venom function already shown in evolutionary toxinology. Fry et al. A millennial exploration of the reptilian molecular phylogenetics and the three-finger toxin diversity Ever since Wang et al. (2003) performed the first molecular phylogenetic analysis which revealed that the gene content and composition of *Naja* and *Bungarus* venoms are characteristic of the three-finger toxins, a rapidly evolved gene family branching division with varying receptor specificities captured the FVB diversity via gene duplication

and functional variants. The elapid neurotoxic strategy which paralyzes and immobilizes prey by blocking neuromuscular transmission rapidly is ecologically advantageous in a snake-eating species since it rapidly eggs on to the dangerous snakes which themselves may have protective venom (Das, 2002). In contrast, the venoms of the hemotoxic *Daboiarusselii* and *Echiscarinatus* act predominantly by disrupting prey hemostasis, leading to rapid cardiovascular collapse in rodent prey. Sasa (1999) hypothesized that the dietary specialization of Atlantic viperids on small mammals, which can escape rapidly if they are not subdued immediately, dictates a selective pressure for venom composition that promotes rapid immobilization of prey via hemorrhagic shock, consistent with the hemotoxic venom strategy of these viperid species.

Similarly, the quantification of geographic variance in *Echiscarinatus* venom composition documented by Calvete (2017) also implies local adaptation to prey communities and is worth exploring in venom from Rajasthan populations as well. Free nucleosides in snake venoms add another level of venom functionality, with Aird et al. (2005) noting that purinergic compounds in *Naja* venom might function to immobilize prey through peripheral vasodilation and hypotension at the bite site, synergizing the core neurotoxicity components.

### **Conservation and Human-Wildlife Conflict**

The habitat preferences of medically important snakes and agricultural landscape of the Kota district leads to regular contact between humans and snakes, as evidenced by Mohapatra et al. (2011) and Alirol et al. (2010). Even agricultural zones snakes have a demonstrable role as rodent control agents as despite consuming agricultural rodents, snakes (*Ptyas mucosa*, *Najanaja*, & *Daboiarusselii*) are killed with regularity due to fear and misidentification (Whitaker & Captain, 2004). This persecution represents a substantial yet little understood pressure on snake populations throughout India. Along with habitat loss, the Python molurus (Indian Rock Python), the only species from the Kota assemblage listed as Vulnerable in IUCN (2023) also suffers from other direct threats such as poaching for skin trade and traditional medicine (Das, 2002). This study emphasises the need for conservation of this species at regional scale within protected area (Mukundra Hills area here in this study) as its retraction to intact forest patches within the Mukundra Hills area indicated.

## **7. CONCLUSION**

In this context, the present study systematically documents the diversity, ecological associations, and behavior and venom profiles of snakes within Kota district, Rajasthan with their predominant ecological heterogeneity centered on the Chambal River basin and its associated ravine landscape, supporting a diverse assemblage of fifteen species belonging to seven families. All the "Big Four" medically important species are present, and in the broad swath of rural agricultural landscape, the often high monsoon-season risk of human-snake contact is a major public health reality. The highlights are as follows: (i) overall the highest species richness and also species richness is in riparian and agricultural interface; (ii) clear temporal niche partitioning with diurnal colubrids and nocturnal vipers and elapids, contributing to the reduction in interspecific competition; (iii) diverse venom within snake assemblage - encompassing neurotoxic, hemotoxic, and cytotoxic characteristics with clinical implications; and (iv) the assemblage broadly aligns with the expected ophidian community in semi-arid dry deciduous habitats of north-central India. These conclusions underlie the following conservation and management guidelines: 1) Implement community-based snakebite prevention education programs

throughout villages in agricultural areas with special emphasis on nocturnal risk times, as well as footwear and torch-lighting use outdoors at night. Second, first-responder training in snakebite recognition and appropriate referral protocols should be institutionalized at each primary health center in Kota district. Third, ravine scrub and riparian zones need to rank number one among the priority habitats for reptile communities within Chambal Wildlife Sanctuary and Mukundra Hills Tiger Reserve targeting habitat management. Fourth, well-coordinated long-term herpetofaunal monitoring using VES and mark-recapture protocols should be developed to facilitate detection of population trends over time. Fifth, intraspecific variation in venom in populations of *Echiscarinatus* and *Daboiarusselii* in Rajasthan should be investigated, as geographical venom variation may impact antivenom efficacy and guide clinical treatment protocols. Because snakes play ecological roles as predators of agricultural pests and as consumers for raptors, mammals and other predators, their conservation is not only a question of biodiversity value, but of direct importance for agricultural productivity and ecosystem stability in the Chambal surroundings.

## 8. REFERENCES

- [1] Aird, S. D. (2005). Taxonomic distribution and quantitative analysis of free purine and pyrimidine nucleosides in snake venoms. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 140(1), 109–126. <https://doi.org/10.1016/j.cbpc.2004.09.020>
- [2] Alirol, E., Sharma, S. K., Bawaskar, H. S., Kuch, U., & Chappuis, F. (2010). Snake bite in South Asia: A review. *PLOS Neglected Tropical Diseases*, 4(1), e603. <https://doi.org/10.1371/journal.pntd.0000603>
- [3] Bonnet, X., Naulleau, G., & Shine, R. (1999). The dangers of leaving home: Dispersal and mortality in snakes. *Biological Conservation*, 89(2), 175–185. [https://doi.org/10.1016/S0006-3207\(98\)00140-2](https://doi.org/10.1016/S0006-3207(98)00140-2)
- [4] Boulenger, G. A. (1890). *The fauna of British India including Ceylon and Burma: Reptilia and Batrachia*. Taylor & Francis.
- [5] Calvete, J. J. (2017). Venomics: Integrative venom proteomics and beyond. *Biochemical Journal*, 474(5), 611–634. <https://doi.org/10.1042/BCJ20160577>
- [6] Champion, H. G., & Seth, S. K. (1968). *A revised survey of the forest types of India*. Manager of Publications, Government of India.
- [7] Chippaux, J.-P. (1998). Snake-bites: Appraisal of the global situation. *Bulletin of the World Health Organization*, 76(5), 515–524.
- [8] Das, I. (2002). *A photographic guide to snakes and other reptiles of India*. New Holland Publishers.
- [9] Fox, J. W., & Serrano, S. M. T. (2008). Exploring snake venom proteomes: Multifaceted analyses for complex toxin mixtures. *Proteomics*, 8(4), 909–920. <https://doi.org/10.1002/pmic.200700777>
- [10] Fry, B. G., Wüster, W., Kini, R. M., Brusic, V., Khan, A., Venkataraman, D., & Rooney, A. P. (2003). Molecular evolution and phylogeny of elapid snake venom three-finger toxins. *Journal of Molecular Evolution*, 57(1), 110–129. <https://doi.org/10.1007/s00239-003-2461-2>

- [11] Greene, H. W. (1997). *Snakes: The evolution of mystery in nature*. University of California Press.
- [12] Gutiérrez, J. M., Calvete, J. J., Habib, A. G., Harrison, R. A., Williams, D. J., & Warrell, D. A. (2017). Snakebite envenomation. *Nature Reviews Disease Primers*, 3, 17063. <https://doi.org/10.1038/nrdp.2017.63>
- [13] IUCN. (2023). *The IUCN Red List of Threatened Species* (Version 2023-1). International Union for Conservation of Nature. <https://www.iucnredlist.org>
- [14] Kini, R. M. (2006). Anticoagulant proteins from snake venoms: Structure, function and mechanism. *Biochemical Journal*, 397(3), 377–387. <https://doi.org/10.1042/BJ20060302>
- [15] Mackessy, S. P. (Ed.). (2010). *Handbook of venoms and toxins of reptiles*. CRC Press.
- [16] McDiarmid, R. W., Foster, M. S., Guyer, C., Gibbons, J. W., & Chernoff, N. (Eds.). (2012). *Reptile biodiversity: Standard methods for inventory and monitoring*. University of California Press.
- [17] Mohapatra, B., Warrell, D. A., Suraweera, W., Bhatia, P., Dhingra, N., Jotkar, R. M., Rodriguez, P. S., Mishra, K., Whitaker, R., & Jha, P. (2011). Snakebite mortality in India: A nationally representative mortality survey. *PLOS Neglected Tropical Diseases*, 5(4), e1018. <https://doi.org/10.1371/journal.pntd.0001018>
- [18] Rodgers, W. A., & Panwar, H. S. (1988). *Planning a wildlife protected area network in India* (Vols. 1–2). Wildlife Institute of India.
- [19] Sasa, M. (1999). Diet and snake venom evolution: Can local selection explain intraspecific venom variation? *Toxicon*, 37(2), 249–252. [https://doi.org/10.1016/S0041-0101\(98\)00166-5](https://doi.org/10.1016/S0041-0101(98)00166-5)
- [20] Sharma, R. C. (2002). *Fauna of India and the adjacent countries: Reptilia (Serpentes)* (Vol. 3). Zoological Survey of India.
- [21] Shine, R. (1994). Sexual size dimorphism in snakes revisited. *Copeia*, 1994(2), 326–346. <https://doi.org/10.2307/1446982>
- [22] Vitt, L. J., & Caldwell, J. P. (2009). *Herpetology: An introductory biology of amphibians and reptiles* (3rd ed.). Academic Press.
- [23] Warrell, D. A. (2010). Snake bite. *The Lancet*, 375(9708), 77–88. [https://doi.org/10.1016/S0140-6736\(09\)61754-2](https://doi.org/10.1016/S0140-6736(09)61754-2)
- [24] Whitaker, R., & Captain, A. (2004). *Snakes of India: The field guide*. Draco Books.
- [25] World Health Organization. (2019). *Snakebite envenomation: A strategy for prevention and control*. WHO. <https://www.who.int/publications/i/item/9789241515641>