

## Review of mugger *Crocodylus palustris* Lesson, 1831 mortality by vehicle collisions in Gujarat state, India

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### Abstract

Railway lines, roadways, canals, and electricity cable networks pose serious problems to wildlife, fragmenting habitats worldwide. These infrastructures are well-recognized as linear intrusions. Today they represent a threat to wildlife, including to the mugger or marsh crocodile (*Crocodylus palustris* Lesson, 1831). The current study documents 15 crocodile–vehicle collisions (CVCs) recorded in 2 years (2021 and 2022); 11 were on roads, and 4 were on railway tracks. Sex was determined for eleven individuals (five males, six females) and four were of undeterminable sex due to crushing. A total of thirteen individuals were found dead at the various sites of collision, and two juvenile individuals were found injured and one of them was treated successfully and returned to the wild. The highest number of CVCs (nine) occurred in Central Gujarat, followed by three CVCs in Saurashtra, two in the Kutch region, and one in North Gujarat. Mitigation measures required for the collision situations in Gujarat are discussed. A literature survey showed that a total of 75 CVCs were recorded within the last 18 years due to the state's road (n= 51, 68%) and railway (n= 24, 32%) networks, with the highest number of CVCs (56) observed in Central Gujarat and the lowest numbers of CVCs noted in North Gujarat (2) and South Gujarat (no CVCs). There was a high number of subadult and juvenile mugger CVC victims. The CVC site location in the different regions of Gujarat state positively corresponds to crocodile populations. However, the mugger crocodile (*C. palustris*) is nationally protected under the Indian Wildlife Act as a Schedule I species, and the IUCN criteria is 'Vulnerable' and it is an Appendix 1 (CITES) species; therefore, conservation measures are required. CVC incidences were recorded widely in the entire species distribution range, from Iran, India, and Sri Lanka, and can be considered as an emerging threat to mugger crocodiles.

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**Key words:** Crocodile–vehicle collision, habitat, linear intrusions, transport networks, threats

### Introduction

The development of infrastructures for the expansion of the economy, especially rail lines, roadways, canals, and electricity cable networks is a serious threat, cutting wildlife habitats across the globe and in India (Nayak et al., 2020). These infrastructures are well-recognized as

linear intrusions. Today they are a threat to biodiversity and now one of the most significant worldwide threats to wildlife (Forman et al., 2003; Benítez-López et al., 2010; van der Ree et al., 2015). Intrusions, such as road, railway, and canal networks act as physical and behavioral barriers to the movement of wildlife and cause fragmentation of habitats. Finally, they disrupt

populations (Rajvanshi et al., 2001; Barrientos and Borda de Águia, 2017). It is well established that road and railway tracks are one of the direct threats to many vertebrate species (Forman et al., 2003; Benítez-López et al., 2010; van der Ree et al., 2015). The impacts of roads and railways on herpetofauna have been extensively reviewed considering various aspects of threats (Vijaykumar et al., 2001; Andrews and Jochimsen, 2007). This threat directly negatively impacts numerous reptilian species, including crocodilians. The direct mortality of crocodiles through collision with a train or speedy vehicle has been documented in 10 species of crocodiles, including the mugger crocodile *Crocodylus palustris* Lesson, 1831 (Vyas and Vasava, 2019). Published data on CVCs (crocodile–vehicle collisions) show that mugger CVCs due to road train networks are a threat to the species. This is of particular concern as CVC incidences were recorded widely in the entire species distribution range, from Iran, India, and Sri Lanka (Vijaykumar, 1997; Mobaraki and Abtin, 2007; Vyas, 2011; Vyas and Vasava, 2019; Vyas et al., 2020; Vyas et al., 2021).

Mugger, or marsh crocodile (*Crocodylus palustris*), is one of the most adaptable and widely distributed crocodilian species in west and south Asia, including Iran, Pakistan, India, Nepal, and Sri Lanka (de Silva and Lenin, 2010). This species is depleted in Pakistan (Zafar and Malik, 2018) and extinct in Bangladesh, Bhutan, and Myanmar (da Silva and Lenin, 2010). The populations of the species are depleted from the distribution range due to major and minor threats, including habitat destruction, fragmentation, alteration, water pollution, and increased fishing activities (de Silva and Lenin, 2010). However, *C. palustris* is legally protected in its entire distribution range, including in India. The species is listed under Schedule I of the Indian Wildlife (Protection) Act, 1972, as 'Vulnerable' under the IUCN Red List of Threatened Species, and in CITES in 'Appendix 1, demonstrating a need for conservation management.

Recently CVCs have been noted as a new threat that is not appropriately addressed due to only scanty available information on the subject. Here, we present the CVC as a new emergent threat for species populations based on new data from Gujarat state, India, and further discuss the reviewed published CVC literature.

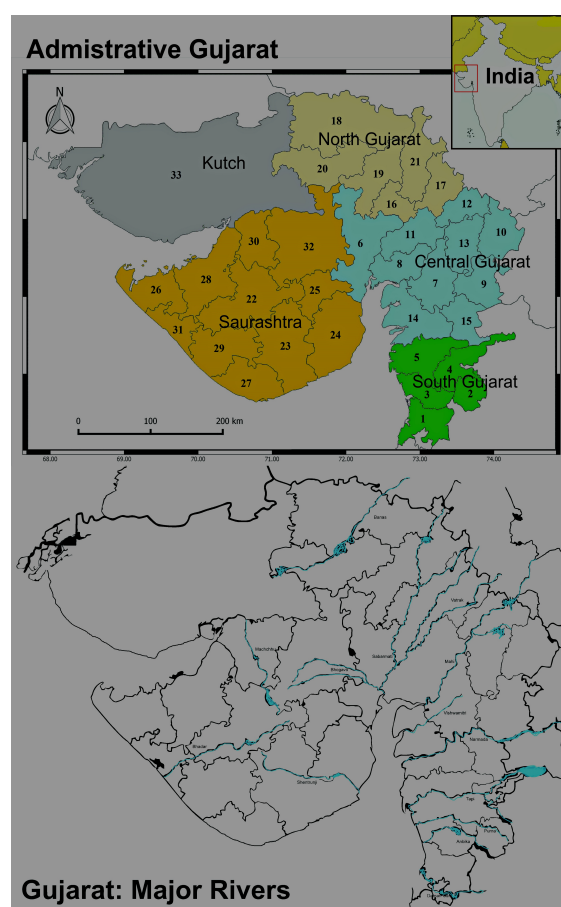
## Material and Methods

### Study area

Gujarat (20°21'–24°6' N, 68°20'–74°40' E) is the westernmost state of India and it shares an international border with Pakistan on its northwest side (Fig. 1). The western part of the state is bounded by the Arabian Sea in the west, by Rajasthan in the north and northeast, by Madhya Pradesh in the east, and by Maharashtra in the south and southeast. Location-wise, Gujarat is a significant state in the country representing four biogeographic zones of India with forty percent of the country's total biogeographic diversity represented in this state (Rodgers et al., 2002). Gujarat is home to one of the

largest populations of *C. palustris* in India, with large populations in Central Gujarat, around Saurashtra and Kutch, and a smaller population in South Gujarat (Vijaykumar et al., 1999; Vyas, 2010, 2013; Vasava et al., 2015; Trivedi et al., 2022).

The area of Gujarat state comprises 196,024 km<sup>2</sup>, of which 14,757 km<sup>2</sup> is covered by different types of forest (FSI, 2017). The forests of Gujarat are divided into four major types, including 3B—south Indian moist deciduous forest; 4B—swamp forest; 5A—southern tropical dry deciduous forest; and 6B—northern tropical thorn forest (Champion and Seth, 1968). The state is administratively divided into 33 districts. For ease of understanding, we have divided the state into five geographical units based on climatic variation, geology, forest types, soil, and drainage patterns: (1) South Gujarat; (2) Central Gujarat; (3) North Gujarat; (4) Saurashtra; and (5) Kutch (Fig. 1).



**Figure 1:** Map of the study area: Administrative and Biogeographic map of Gujarat, 1 to 33 (1 Valsad, 2 Dang, 3 Navsari, 4 Tapi, 5 Surat, 6 Ahmedabad, 7 Vadodara, 8 Anand, 9 Chhota Udaipur, 10 Dahod, 11 Kheda, 12 Mahisagar, 13 Panchmahal, 14 Bharuch, 15 Narmada, 16 Gandhinagar, 17 Aravalli, 18 Banaskantha, 19 Mehsana, 20 Patan, 21 Sabarkantha, 22 Rajkot, 23 Amreli, 24 Bhavnagar, 25 Botad, 26 Devbhoomi Dwarka, 27 Gir Somnath, 28 Jamnagar, 29 Junagadh, 30 Morbi, 31 Porbandar, 32 Surendranagar, 33 Kachchh). Top: district boundaries, after Patel and Vyas (2019); Bottom: river map of Gujarat, after Vyas and Patle (1990).

## Methodology

Between January 2021 and December 2022, we collected data on mugger CVCs from various sources, including personal observations, nongovernmental organizations (NGOs), the Gujarat Forest Department offices, wildlife rescuers, and print and electronic media. Moreover, we took photographs and collected information on accidents by visiting the collision sites to note specifics of the mugger, including health and circumstances around the collision. These CVC records included size, sex, date, time of the incident, location, month, season, and the number of animals injured or killed. We classified muggers using cm total length (TL) as juveniles (<100 cm TL) and subadults (<101 to 180> cm TL) or adults (>180 cm TL) based on published literature on growth and sizes of *C. palustris* (Whitaker and Whitaker, 1984; Mobaraki et al., 2013). We measured the total length dorsally from the snout to tail tip (Britton et al., 2012). We recorded the season in which the collision occurred and defined the seasons as winter (November–February), summer (March–June), and monsoon (July–October), wherein winter and summer months are dry seasons and monsoon months are the wet season. These months generally correspond to detectable changes in temperature, precipitation, other climatic variables, and the life-history characteristics of *C. palustris* in the region. To better understand CVCs in the context of the breeding ecology of *C. palustris*, we also categorized months into the breeding season (February to August), having various activities like egg laying, nest guarding, and hatching and non-breeding season (September to January) (Whitaker and Whitaker, 1984; Mobaraki et al., 2013).

Here, we followed the methodology of Vyas and Vasava (2019) for the collection of CVC data. All CVC data were compiled using an MS Excel worksheet. We modified a map of Gujarat (after Patel and Vyas 2019) for a better understanding of the five geographical units and the administrative boundaries of the thirty-three districts. A river map of Gujarat was modified after Vyas and Patel (1990). The incidence of each CVC location site (geo-coordinates) was plotted and mapped with Google Earth Pro, after which a final map was prepared.

Here, we added information on CVCs (with vehicles and trains) from Gujarat state from two years recent years (2021 and 2022). The state of Gujarat has one of the most extensive and traffic-intensive road and railway networks in India. The total road network length in Gujarat currently stands at 74500 km (approx.). This road network is broadly divided into two categories, a core and a non-core network. The core network is 24,000 km long and comprises the express highway (974 km), national highways (3,245 km), and state highways (19781 km), and the remaining 50,500 km road network is the non-core network of district roads and village roads (RNBG, 2022). The state railway network is 6,200 km in length, including broad gauge, bullet train, and

dedicated freight corridor; the last two railway lines are under construction (GTN, 2022). Both networks are widespread in the entire state, including in the districts of Central Gujarat, Saurashtra, and Kutch regions, which represent the prime habitat of the species. We also address and review the CVC issue and review based on published literature.

## Results

During the two years of this study, a total of 15 incidences of CVC were recorded in various locations of the state (Fig. 2). These involved five males and six females, and four muggers of undeterminable gender. These CVC victims were recorded according to age group (total body length= TBL) as seven juveniles (TBL= 75 to 100 cm), seven subadults (TBL= 110 to 145), and one large adult (TBL= over 240 cm). Eleven (73.3%) of these collisions occurred on the road (from the state highway to the small village road) with speedy vehicles (Figs. 3 and 4), and four (26.6%) on the railway line (Figs 5 and 6A). Two juveniles were found with minor injuries (Fig. 7); after treatment, only one juvenile of *C. palustris* survived (Fig. 8). It was then released back into nature. The highest number (n= 13) of CVCs was noted in monsoon season and the lowest number of animals (n= 2) was found during winter. None of the CVCs were recorded during the summer period (Table 1).

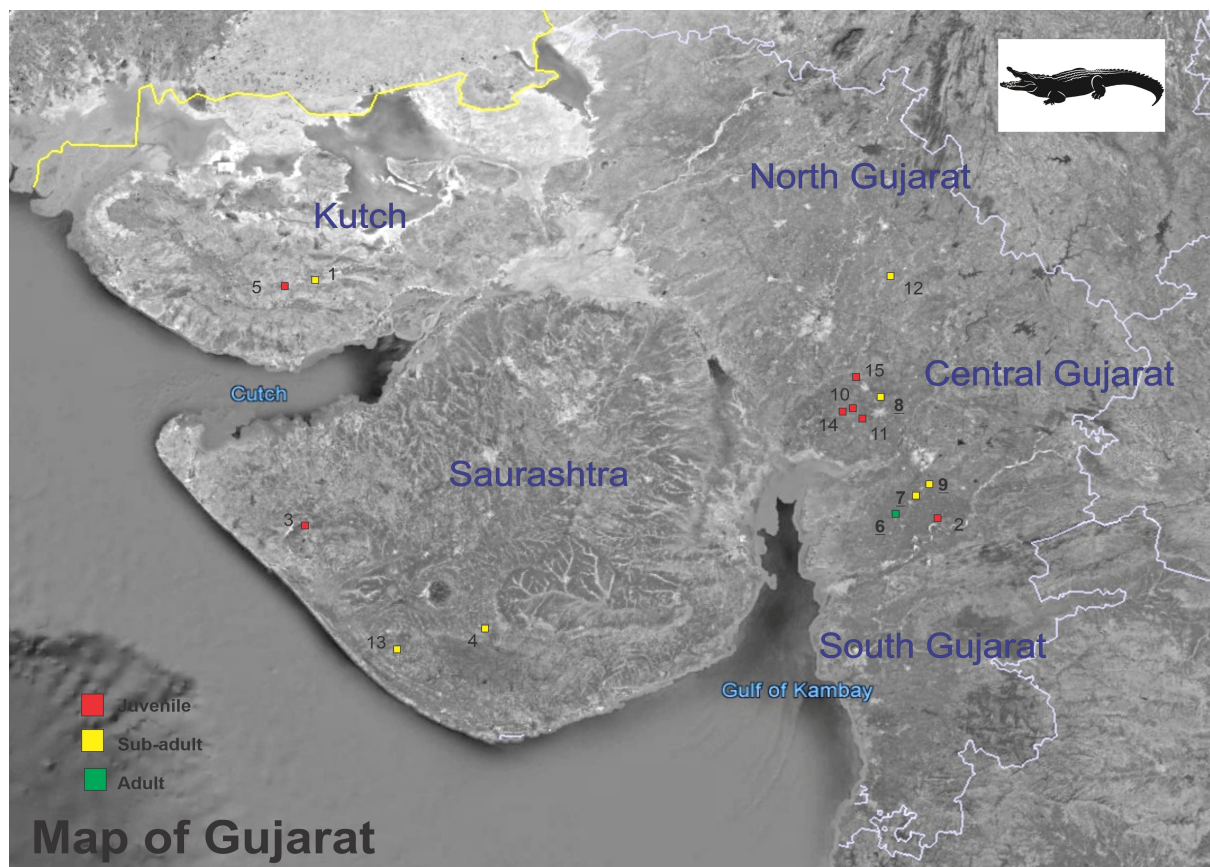
Region-wise, the highest number of CVC incidents was recorded in Central Gujarat (n= 9, 60%), including Vadodara (n= 4) and Kheda District (n= 5). The second highest number of CVC incidents was recorded in the Saurashtra region (n= 3) in the districts of Junagadh (n= 2), Porbandar (n= 1) and Kutch (n= 2). Only one CVC incident was noted in the Sabarkantha district of North Gujarat (n= 1).

The present literature survey showed that a total of 75 CVCs were recorded within the last 18 years (Table 2). The results showed that 51 (68%) CVCs occurred on the state's roads, and 24 (32%) collisions occurred on railway networks. The higher number of 56 CVCs was recorded in Central Gujarat, and the lower number of 2 CVCs (2.6%) was noted in North Gujarat.

## Discussion

A total of 15 CVC incidents were recorded in Gujarat state in 2 years, with a mean of 7.5 animals per year. This represents a lower incidence than in the previous two years of 2019 (Vyas et al., 2020) and 2020 (Vyas et al., 2021). Nonetheless, it is notable compared to results of an earlier study of 2.7 animals per year (Vyas and Vasava, 2019). These CVC data from over the last decade (2013 to 2022) show that mugger mortality due to CVCs is gradually increasing in the state of Gujarat (Fig. 9).





**Figure 2:** Map of Gujarat showing the location sites of mugger (*Crocodylus palustris*) collisions with road (digit without under bar) and railway (bold digit with under bar) networks in Gujarat, India (Source of map, Google Earth).



**Figure 3:** (A) CVC road death of subadult female mugger (*Crocodylus palustris*) at Bhuj, Kutch. (B) CVC road death of juvenile *C. palustris* at Fofalia, Shinor, Vadodara District (Photo credit: Ramesh Modhvadia).





**Figure 4:** (A) Head-crushed juvenile (total body length 75 cm) mugger (*Crocodylus palustris*) involved in CVC near Hanumangadh, Ghumali Road, Porbandar District, Gujarat. (B) Subadult (total body length 130 cm) *C. palustris* found after a road accident between Moniya and Visavadar, Junagadh District (Photo credit: Darshit Acharya).

A literature survey showed a total of 75 CVCs were recorded, including 51 CVCs (68%) on roads and 24 CVCs on railway networks, in the last 18 years (See Table 2). The distribution of CVCs in different regions of the state positively corresponds to crocodile populations (Vyas and Vasava, 2019). The high numbers of CVCs occur in Central Gujarat followed by Saurashtra. This corresponds to crocodile abundance, with frequent accidents in areas with high animal abundance. There were few CVCs in North Gujarat, and no CVC was noted in South Gujarat. It could have been the reason for the low mugger population numbers to flourish in a particular part of the state. The increase in CVCs over the study period is likely attributable to the gradual rise in the mugger population across Gujarat.

Vyas and Vyas (2002) estimated a population of 70 individuals in 2001 at Vadodara, which increased to an estimated 250 individuals in a recent survey in

2017 (Vyas, 2018), and now has increased with 300 individuals of *C. palustris* of various sizes (Pagdand, 2019; Forest Department, 2020). Similarly, in 2014 Vasava et al. (2015) estimated about 98 individuals in the ponds of Anand–Kheda districts, whereas the recent population counts (Voluntary Nature Conservancy, 2022) found 161 individuals of the species in 2022. These data of the population status and successful breeding records of the mugger populations from various regions of Gujarat point out that there has been a substantial increase in the mugger population across its distributional range in Gujarat (Vyas, 2013; Vasava et al., 2015; Talati et al., 2022).

The highest numbers of mugger mortality in CVCs represent subadult animals between 1 to 2 meters in length ( $n= 32$ , 42.6%) and juvenile animals less than 1 meter length ( $n= 27$ , 36%), while fewer animals ( $n= 14$ , 18.6%) over 2 meters were associated with CVCs (Table 3).

**Table 1:** Details of mugger (*Crocodylus palustris*) found dead or injured during the study period (2021 and 2022) due to collusion with road and railway vehicles, Gujarat state, India.

Year	No.	Date of incidence	Location (numbers correspond with map in Fig. 2)	Networks	Geo-coordination	Total body size (cm)	Sex	Remarks
2021	1	26 February	Nr. Bhuj, Kutch District (1)	Road	---	Subadult (110)	Female	Dead
	2	2 July	Nr. Mota Fofalia, Shinor, Vadodara District (2)	Road	21°56'36.23" N 73°21'32.71" E	Juvenile (95)	Female	Dead
	3	28 July	Nr. Hanumangadh, Ghumali Road, Porbandar District (3)	Road	21°47'26.17" N 69°47'55.83" E	Juvenile (75)	?	Dead
	4	1 September	Moniya to Visavadar, Junagadh District (4)	Road	21°22'00.4" N 70°41'57.6" E	Subadult (130)	Male	About to die
	5	2 September	Nr. Deshalpar, Bhuj–Nakhatrana Road, Kutch District (5)	Road	23°12'3.36" N 69°26'51.94" E	Juvenile (100)	Female	Dead
	6	13 September	Nr. Lakhodar, Bharuch–Karjan, Miyagam, Vadodara District (6)	Railway	21°59'32.96" N 73°5'55.52" E	Adult (240)	Male	Dead
	7	1 October	Nr. Karjan, Dethan–Lakhodara, Vadodara District (7)	Railway	21°59'24.08" N 73°5'51.78" E	Subadult (110)	Female	Dead
	8	23 October	Kanjari, Nadiyad, Kheda District (8)	Railway	22°37'13.40" N 72°54'38.90" E	Subadult (115)	Female	Injured <sup>l#</sup>
	9	26 October	Nr. Varnama, Vadodara District (9)	Railway	22°12'27.70" N 73°10'26.70" E	Subadult (145)	Male	Dead
2022	10	14 July	Malataj–Dabhu Road, Kheda District (10)	Road	22°58'21.59" N 72°72'80.03" E	Juvenile (90)	?	Dead
	11	14 July	Malataj–Valetva Road, Kheda District (11)	Road	22°35'34.16" N 72°47'27.06" E	Juvenile (65)	?	Dead
	12	17 July	Ambaliyara, Nr. Bayad, Arvali District (12)	Road	23°12'56.85" N 73°2'17.07" E	Subadult (150)	?	Dead
	13	14 October	Panidhra, Nr. Kesod, Junagadh District (13)	Road	21°11'21.19" N 70°15'53.18" E	Subadult (120)	Male	Dead
	14	25 October	Malataj, Kheda District (14)	Road	22°35'3.06" N 72°44'59.29" E	Juvenile (95)	Female	Injured <sup>*</sup>
	15	12 November	Nr. Vaso, Vado–Deva Road, Kheda District (15)	Road	22°64'87.04" N 72°75'79.07" E	Juvenile (100)	Male	Dead

<sup>\*</sup> found injured and after treatment was released in nature; <sup>l#</sup> found injured and after treatment died.

**Table 2:** Summary of mugger crocodiles (*Crocodylus palustris*) in collisions with trains and other vehicles in different regions of Gujarat state, India (2005 to 2022).

South Gujarat	Central Gujarat	North Gujarat	Saurashtra	Kutch	CVC-Road	CVC-Railway	CVC-Total	Year (Sources)
0	34	0	3	1	24	14	38	2005 to 2018 (Vyas and Vasava, 2019)
0	07	0	1	4	10	02	12	2019 (Vyas et al., 2020)
0	06	1	3	0	06	04	10	2020 (Vyas et al., 2021)
0	09	1	3	2	11	04	15	2021–2022 (Present study)
0	56	2	10	7	51	24	75	

**Table 3:** Summary of different sizes of mugger crocodiles found in collision with trains and other vehicles recorded in different regions of Gujarat state, India (2005 to 2022).

<1 m	<1–2>	>2	Unknown size	Total	Year (Sources)
10	18	8	2	38	2005 to 2018 (Vyas and Vasava, 2019)
6	3	3	0	12	2019 (Vyas et al., 2020)
4	4	2	0	10	2020 (Vyas et al., 2021)
7	7	1	0	15	2021–2022 (Present study)
27	32	14	2	75	

The higher number of subadult and juvenile muggers killed in CVCs is a probable indication that animals of these age groups migrate in search of new habitats and to avoid competition with dominant large adult animals (Mobaraki and Abtin, 2007).

The higher number of 61 CVCs was recorded between July and November, with a peak in August, which is also the peak monsoon in the Indian subcontinent. The lower number of CVCs was noted between January and June during the winter and summer periods (Fig. 10). These data show the activity patterns of the species within the

state. Abundant rainfall may flood the burrows of muggers, making them unable to access oxygen and also compromising their thermal regulation and forcing them to seek new refuges and favorable areas (Vyas, 2013; Vasava et al., 2015). This seasonal movement may be responsible for the high frequency of CVCs in Gujarat. Studies have reported that the season of the year is one of the strongest predictors of wildlife–vehicle collisions, and knowledge about seasonal patterns of wildlife–vehicle collisions is important to improve suitable mitigation measures (Main and Allen, 2002).





**Figure 5:** (A) Large (total body length 240 cm) dead mugger *Crocodylus palustris* found on railway track from Lakhodar–Karjan, Miyagam, Vadodara District. (B) Dead animal collected by local NGO (Photo credit: Hemant Vadhavana).

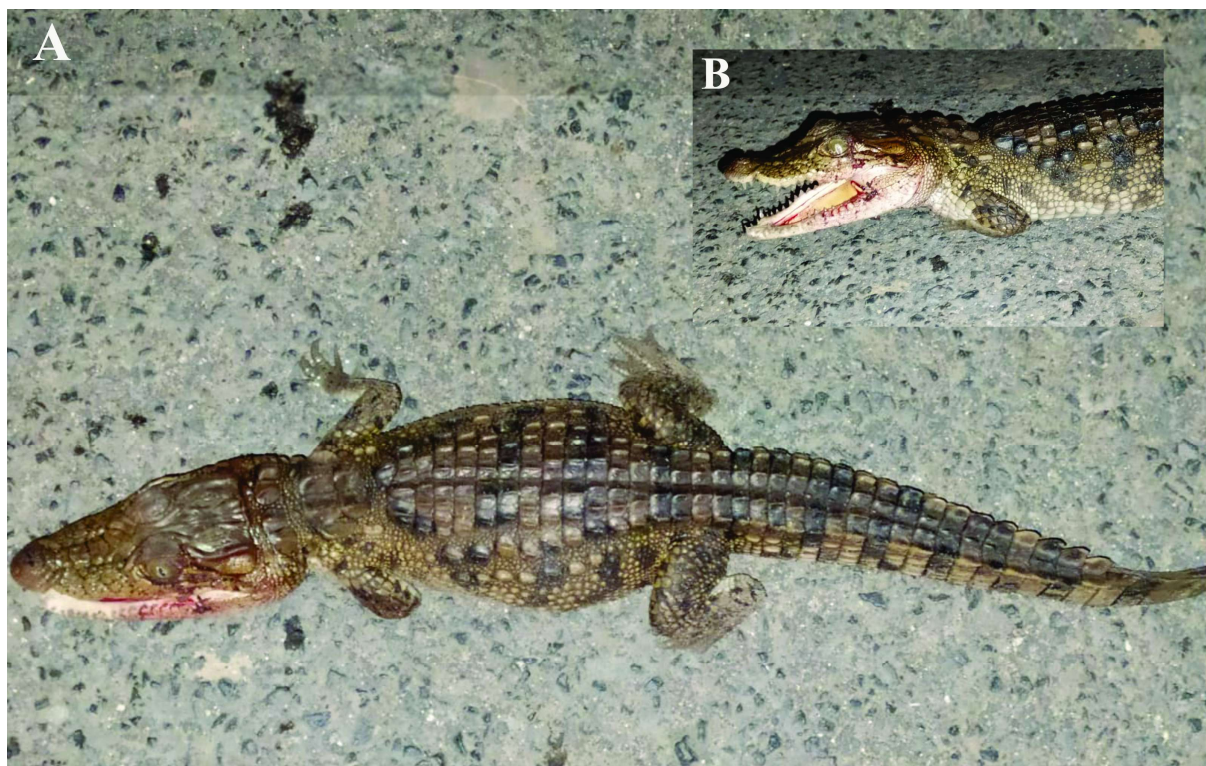


**Figure 6:** (A) Juvenile (total body length 110 cm) mugger *Crocodylus palustris* found after a railway accident near Karjan, Vadodara District. (B) Jaw-cut mugger (total body length 145 cm) after a railway accident near Varnama Railway Station (Photo credit: Raj Bhavasar).



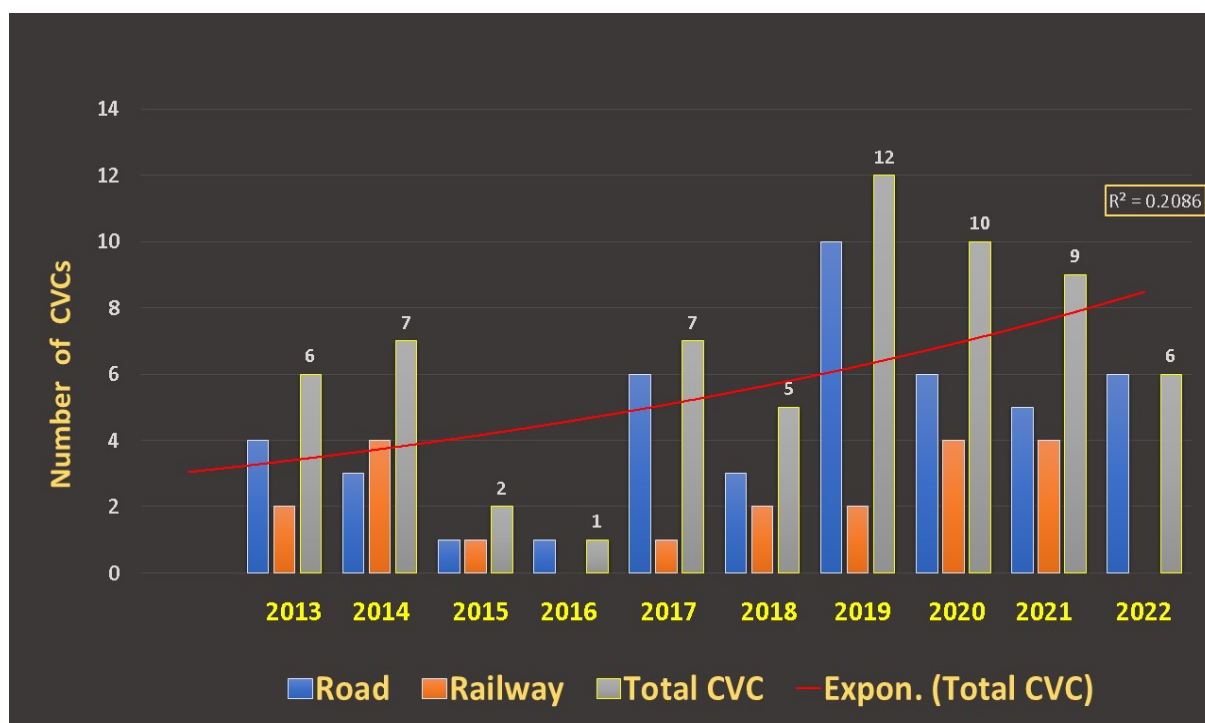


**Figure 7:** (A) Injured mugger *Crocodylus palustris* (total body length 115 cm) found on the railway line near Kanjari, Nadiyad, Kheda District. (B) The same mugger on the veterinary table for treatment (Photo credit: Vishal Mistry).

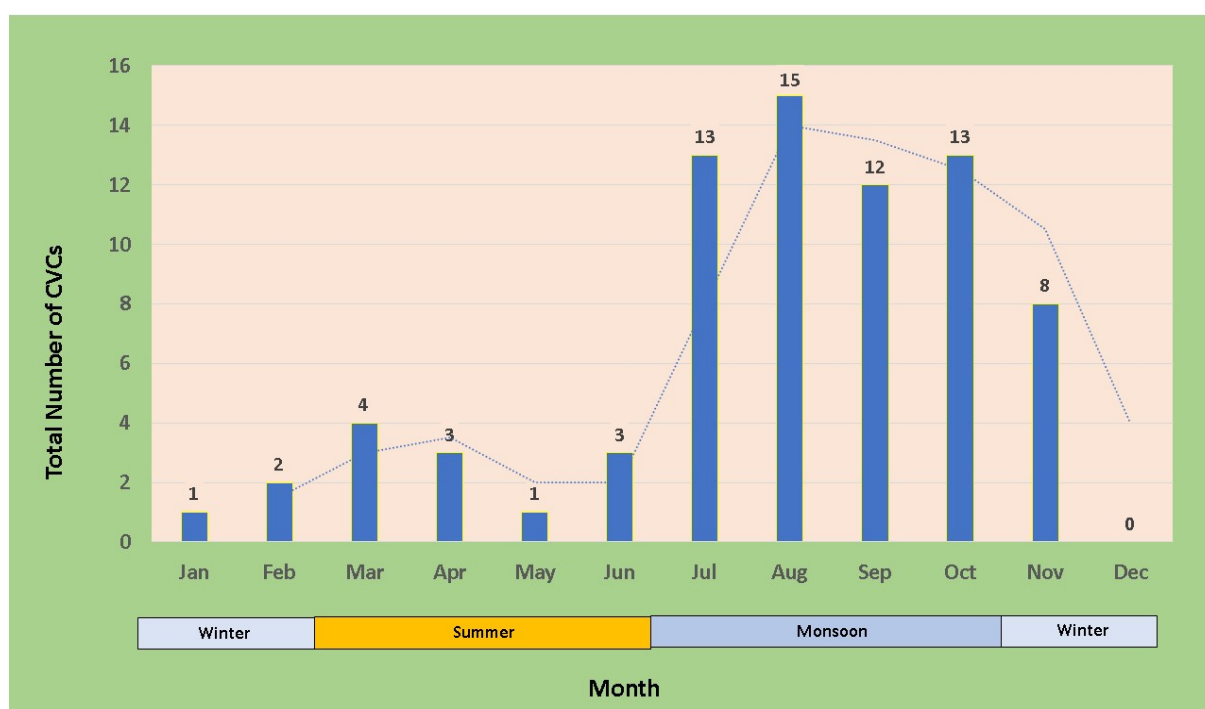


**Figure 8:** (A) Juvenile (total body length 95 cm) mugger *Crocodylus palustris* with minor injuries found on the road at Malataj, Kheda District. (B) Minor head injury. Individual was released in nature after treatment (Photo credit: Tushar Rana, Daya Foundation).





**Figure 9:** Collisions involving muggers (*Crocodylus palustris*) and vehicles (CVCs), including speedy road and railway vehicles, during the last decade (from 2013 to 2022) in Gujarat, India (Source: Vyas and Vasava, 2019; Vyas et al., 2020; present study).



**Figure 10:** Total numbers of mugger (*Crocodylus palustris*) collisions with vehicles (CVCs), including speedy road and railway vehicles, by month and season from 2005 to 2022 in Gujarat, India (Source: Vyas and Vasava, 2019; Vyas et al., 2020; present study).

However, the present CVC data show that 4.16 animals/year are killed. The CVC issue is not negligible but a clear emerging threat to mugger crocodiles (Vyas et al., 2021). The problem should be appropriately addressed, and solutions for its mitigation should be found because CVC was not noted only in Gujarat, but also observed in other states of India, including Uttarakhand (Joshi, 2013), Chhattisgarh (See: Vyas and Vasava, 2019), Uttar Pradesh (See: Vyas and Vasava, 2019), Telangana (Vyas et al., 2020), and Rajasthan (Sharma et al., 2021). The present review showed that CVCs occur in the entire geographical range of the species from Iran (Mobaraki and Abtin, 2007; Parchizadeh, 2019) to India (Vijaykumar, 1997; Vyas and Bhavsar, 2009; Vyas, 2011; Joshi, 2013; Vyas, 2014; Vyas and Vasava, 2019; Vyas et al., 2020, Sharma et al., 2021; Vyas et al., 2021) and Sri Lanka (Vyas and Vasava, 2019).

Globally, CVCs have been known in 10 species of crocodylians (Vyas and Vasava, 2019), showing that this threat is widespread and particularly acute where concentrated crocodile populations intersect with rapidly developing transport corridors. We believe that these few records of CVCs in relatively small numbers in the state are but the tip of an iceberg, and that a majority of CVCs occur in undocumented and remote locations and that the prevalence and effects of CVCs are much greater than our data would suggest, not only for a highly visible apex freshwater predator but also for more obscure components of affected ecosystems.

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### Conflict of interest

All the authors declare that there are no conflicting issues related to this research article.

### Author contributions

RV: data review and analysis, draft preparation. VM: field data collection, South and Central Gujarat. PV: field data collection, Saurashtra region. DC: field data collection, map design and graph preparations.

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