Global amphibian decline: Diversity, Threats and Management strategies

ABSTRACT

Amphibians are small cold blooded tetrapods containing frogs, toads, caecilians and salamanders. There are over 8,500 species of amphibians known all over the world and nearly 447 species from India inhabiting water habitats. The International Union for Conservation of Nature (IUCN)'s Red List of threatened species estimates that at least one-third of known amphibian species are threatened with extinction, a rate much higher than that for other vertebrate groups like birds and mammals. Amphibian population decline represent a leading example of biodiversity crisis as they are continuously disappearing from their habitats on a global scale. Factors responsible for the amphibian decline are numerous and complex likes habitat destruction, alien species invasive, over exploitation, climate change, infectious diseases and chemical contamination. Amphibians are the crucial component of the ecosystem so their conservation becomes the need of hour. The conservation priority should include the population monitoring and environment sensing, reservation of wetlands, reservoirs, ponds, habitat restoration and management, minimizing the use of pesticides, captive breeding program for endangered species and also awareness among local people about the importance of frogs and toads.

INTRODUCTION

The term amphibia arose from the Greek word; '*Amphi*'- means 'both' and '*Bios*'- means 'life', i.e having a dual lifestyle. Amphibians are ectothermic tetrapod's containing frogs, toads, caecilians and salamanders. These constitutes ancient group believed to exist on earth from at least 300 million years ago. It is the only vertebrate group which leads a dual life, part in water as tadpoles and rest on land as adults. Amphibians evolved in the devonian period from fishes became dominant during carboniferous and permian period. These are considered to be the important connecting link between land and water dwelling organisms. The existing modern lineage of amphibia, belonging to the subclass lissamphibia (Duellman and Trueb 1994). This subclass lissaamphibia has three orders: urodela or caudata (salamanders and newts), anura (frogs and toads) and apoda or gymnophiona (caecilians). The life cycle of these organisms is very complex with egg hatching into aquatic herbivorous larvae which undergoes substantial or complete remodeling of the organism (metamorphosis) to form the terrestrial carnivorous adult (Helbing 2012). Amphibian have adapted to utilize different types of habitats like agricultural land, forests, woodlots, meadows, springs, bogs, marshes, swamps, water bodies, wetlands and scrublands, for their survival (Fig 1). Their distribution range across habitats is affected by various environmental factors like rainfall, food (insects), moisture and human interference.

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Amphibian hold a key position in the ecosystem as 'ecological indicators'as they are highly sensitive to environmental changes including changes in water, air, and soil quality. Amphibians provide ecosystem and cultural services to human by serving as a food source and by increasing the quality of life through recreation, religion, spirituality and aesthetics. Amphibians are invaluable as they serve as model in medical and genetic research. Their embryos are used to evaluate the effects of toxins, mutagens, and teratogens. They also provide potential for new pharmaceuticals such as analgesics, anti-biotic and anti-viral drugs derived from skin secretions. Amphibians are also economically useful by potentially controlling pest species, through predation of insect pollinators and by reducing mosquito recruitment from water bodies. The effect of introducing anurans in paddy fields also resulted in improved soil phosphorous availability and yield (Lin and Wu 2020). They affect ecosystem structure through soil burrowing, nutrient cycling and control primary production in aquatic ecosystems. This group of vertebrates is also used to investigate the inter-relationship of humans and the environment based on their sensitivity to climatic and environmental contamination (Rourke 2007; Hocking and Babbitt 2014).

Decline in amphibian population at global level:

Amphibians are one of the most successful groups of wildlife and yet a rapid decline in their population has been seen during the past two decades. According to some estimates, the rate of extinction for amphibians is higher than it has ever been in the past 100,000 years. Amphibians may be a part of the sixth major extinction event in evolutionary history (Wake and Vredenburg 2008). Amphibian population decline represent a prime example of biodiversity crisis as they are continuously disappearing from their habitats on a global scale (Stuart *et al* 2004). Biphasic life stages and highly permeable skin, permeable eggs and presence of gills render them more vulnerable than other vertebrate groups (birds and mammals) to toxic chemicals in their environment (both water and soil).

The first report of amphibian population decline came in 1950s. The scope of global amphibian decline was realized at the First World Congress of Herpetology in 1989 (Blaustein and Wake, 1990). Soon after, the Declining Amphibian Populations Task Force (DAPTF) was established by the IUCN Species Survival Commission (SSC) to examine the nature, reasons and severity of the amphibian population decline across world. The data indicated that decline began as early as the 1950s in USA, Australia, Western Europe, New Zealand, Central and South America. Most documented amphibian decline occurred in 1980s reported from Latin America in which 40 species became extinct and 30 amphibian families

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and nine genera were affected. The 1970s and 1990s also represented the periods of amphibian declines in Puerto Rico. The main causes identified for the decline were habitat loss and synergistic interaction between pathogenic chytrid fungus and climate change (Young *et al* 2001; Burrowes *et al* 2004; Lips 2005). The common feature of these declines was that they have not affected all the amphibian species and were seen in widely separated parts of the world. Due to the severity of amphibian population declines, the IUCN in partnership with Conservation International and Nature Serve, launched the Global Amphibian Assessment (GAA) initiative in 2001. The main aim of GAA was to prevent further losses of amphibian species by developing a complete picture of needs and conservation status of all known amphibian species. In GAA report, amphibian declines were found to be non-random and most prevalent among stream-associated species. Amphibians were also found to be more threatened than birds or mammals. It is also reported that the level of threat is underestimated because many amphibian species are too data deficient or poorly known. The causes of their decline were grouped as overexploited, habitat loss and enigmatic decline other than disease and climate change.

Current Amphibian Diversity Status (Global):

There are 8,500 amphibian species known all over the World, of which 7,500 are frogs and toads, 792 are newts and salamanders and 215 are caecilians till date (Frost and Darrel 2021). Amphibians occur widely distributed throughout the world, even edging north of the Arctic circle in Eurasia. Amphibian diversity is highest in the tropics, especially in the Amazon. Brazil has the most described species, over a 1,000 species. They are absent only in Antarctica, most remote oceanic islands, and extremely xeric (dry) deserts. The IUCN Red List 2021 indicates that 41% of amphibians are threatened with extinction as compared to mammals (27%) and birds (13%). The IUCN Red List indicates that out of 7,317 amphibian species 0.5% are extinct, 9.3% are critically endangered, 15.1% endangered, 10.0% vulnerable, 5.7%% near threatened, 43.4% least concern and 16.1% data deficient worldwide. Globally, at least 42.8% amphibian species are experiencing population decrease, while only 0.4% species are increasing and 24.5% species are stable; 31.3% species have unknown trend. According to IUCN (2004), about 20 countries have threatened amphibian species due to various anthropogenic activities and climate changes.

The most recent version of the IUCN Red List (2017) indicates 30% of anurans, 49% of urodeles and 4% of caecilians as extinct or threatened. In North and South America, a substantial decrease of 54-60% was recorded in amphibian populations whereas in Australia and New Zealand,

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approximately 70% of amphibian population has been declined (Bruhl *et al* 2011). Several species of anuran populations have undergone drastic declines in the Western United States in last 15 years. In California, correlation between pesticide effect and amphibian population deterioration was discovered in alpine frogs, *Rana muscosa* and *Rana sierrae* (Bradford *et al* 2011). Becker *et al* (2007) reported that habitat split (human induced disconnection between habitats) has negative impacts on the species with aquatic larvae like amphibians as compared to species with terrestrial larval development in the Brazilian Atlantic forests. However, the amphibian decline in Costa Rica were not found to be linked with the Chytridiomycosis emergence or climate driven rather population decease was observed due to reduced standing leaf litter which is an important microhabitat for the amphibian species (Whitfield *et al* 2007). Grant *et al* (2016) reported that amphibian populations were being lost at the average rate of 3.79% per year and the effect of the various stressors, their exposure to the species, and response to the stressors varies spatially across North America. Approximately 1, 850 new species of amphibians reported across world from countries including Brazil, China, Madagascar, Peru, India, Vietnam, Papua New Guinea etc during the period 2010-2022. Rovito *et al* (2009) stated that terrestrial microhabitat specialists including have more disappeared in multiple sites in Guatemala as compared to the microhabitat generalists. Reading (2007) linked the relationship between global warming and the amphibian female body (*Bufo bufo*) condition stating that there has been decline in the toad female body condition and annual survivorship with the increase in temperature over the time period 1983-2005 in United Kingdom. Secondly, he also demonstrated the relation between the occurrence of mild winters and lower fecundity rates of females. The diversity, distribution, and species richness of the amphibian fauna have benefited from the work of numerous amphibian taxonomists worldwide. With his textbook "Biology of Amphibia," Noble (1931) made the most impressive contribution to the field of amphibian biology. It was recently documented the presence of 19 amphibian species from the central and northwest parts of Bangladesh with the highest diversity found in the agricultural fields. There is documentation of the presence of total 62 amphibian species in Bangladesh of which 26 % are threatened, 43 % least concern, 8% data deficient and 23% are not accessed as by the IUCN.

Rais *et al* (2015) documented a large number of amphibians and reptiles from the various protected mixed habitat (wildlife sanctuary), Pakistan. He stated that seasonal ponds, whether protected or not, generated during the rainy season in forest regions, low-lying sections of wildlife sanctuaries and permanent wetlands were crucial for aquatic and semi-aquatic species of anurans, freshwater turtles and water snakes Rais *et al* (2012) documented 35 species of herpetofauna including 5 amphibian species from 3 selected districts of North Punjab, Pakistan. Rais *et al* (2021) also reported the explained checklist of amphibian species from Pakistan which includes total 21 species. Silvano and Segalla (2005) reviewed and reported Brazil to be the leader in harbouring

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amphibian diversity with 765 species. Ferreira *et al* (2019) published a checklist for Santa Teresa, Brazil accounting for 108 amphibian species. Brasileiro *et al* (2005) provided information about the habitat use and reproductive activity of 28 frog species from the Estaçao Ecologica de Itirapina (EEI) and compared it with the species of other parts of Cerrado from Southeastern Brazil. It was reported that most frog species reproduction is influenced by the rainy season while their spatial and temporal patterns strongly depend on the hydroperiod of water bodies and other historical factors. Similarly, Atkinson *et al* (2021) accounted that spatial and temporal variability is related to hydroperiod length and is temperature dependent. Also, the development time in amphibians and body size is directly related to the length of the hydroperiod of water bodies. In Central Amazonia, Brazil, Waldez *et al* (2013) observed 160 species of the herpetofauna, of which 75 species were amphibians and also reported the discovery of a new species, *Dendropsophus allenorum*. Molur (2008) reviewed the South Asian amphibian diversity and concluded that only half of South Asia's amphibian biodiversity has been discovered. In South Asia, which includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. A total of 348 amphibian species has been reported from these countries with Srilanka and India having the maximum diversity.

India is one of the top 13 countries in the world in terms of biodiversity (Mittermeier and Werner, 1990). Gunther (1864) gave the first systematic record of Indian amphibians, listing 37 species of anurans and two species of caecilians. Later, in the book "Fauna of British India," documented 130 amphibian species from India, including 134 anurans, one salamander and five caecilians. A field guide for the identification of amphibians from Western India by Daniel and Sekar (1989) was published as part IV of the Journal of Bombay Natural History Society (BNHS), Bombay. For Indian amphibians, Das and Dutta (1998) published a listing of 210 species. An overview of amphibians from various states, protected areas and regions of importance can be found in inventories from State Fauna Series of ZSI. In India, 447 species of amphibians are known, out of which only one species of newt i.e Himalayan Newt (*Tylototriton verrucosus*), 38 species of caecilians and more than 50% of anurans found in India till date. Out of 447 species of amphibians 4% are critically endangered, 8% endangered, 5% vulnerable, 2% near threatened, 39% not assessed yet, 23% least concern and 19% data deficient according to a report of Zoological Survey of India (ZSI) (Dinesh and Radhakrishnan 2020). There are 80% endemic species and concentrated in three biodiversity hot spots, namely the Western Ghats, Himalayas and northeast India (part of Indo-Burma hot spot). The Western Ghats harbours the most diversity of endemic amphibian species. *Bufo stomaticus* is found only in the Indian subcontinent (Daniel 1963).

The majority of endemic species are confined to the rainforests of Western Ghats, where they have a limited geographic range (Vijayakumar *et al* 2001). This tropical area is covered with extensive lengths of brooks, marshes, ponds and farmlands, all of which are important amphibian

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breeding grounds and contain a variety of flora. The ecological characteristics of amphibians in the Western Ghats have been studied and inventories of amphibians are available for several areas of these Ghats, including 33 from the Kerala portion of the Nilgiri Biosphere Reserve and 40 from the Anamalai Hills, 35 from the Kalakad Wildlife Sanctuary (Cherian *et al* 2000), 32 from the Kalakad Mundanthurai Tiger Reserve and 35 from the Anamalai Hills (Easa 1998). A significant amount of endemism is present in Indian amphibian species. There are 110 types of endemic amphibians. Outside of India, eight amphibian genera are absent. These include the toad Bufoides, the microhylid *Melano batrachus*, the caecilians *Indotyphlus*, *Gegeneophis* and *Uraeotyphlus*, as well as the frogs *Ranixalus*, *Nannobatrachus* and *Nyctibatrachus*. One of the most notable endemic amphibian genera is the monotypic *Melanobatrachus*, which has a single species known only from a tiny number of specimens collected in the Anaimalai highlands in the 1870s (Groombridge 1993). In recent times, there has been increase in the discovery of amphibian species by the use of modern genetic analysis methods. Many scientists, amphibian specialists and herpetologists have worked in India over the past few years to improve our understanding of the taxonomy, distribution and biology of amphibians. More than 100 species have been described during the decade alone. In India, due to the patchy and fragmented amphibian species distribution very little information is available at the population and species levels. Also, they have neither been adequately recorded nor monitored over time in relation to extinction risks, population vulnerability and human-induced changes (Aravind *et al* 2004). Kumar (2019) reported 12 amphibian species belonging to 4 families namely Bufonidae, Dicroglossidae, Microhyalidae and Rhacophoridae from Rajgir Wildlife Sanctuary, Nalanda District (Bihar). In 2014 survey conducted in the foothills of South-Western Ghats which included 6 wetlands namely Courtallam, Minnagar, Kudirappu, Nannagaram, Melagaram, Ilangi, total of 17 species, 6 families and 14 genera were reported (Vansanthi *et al* 2014). Naryana *et al* (2014) conducted rapid survey at the central and northern parts of Telangana and amphibians were searched in all their possible habitats and reported a total of 14 species belonging to 9 genera. Chandramouli *et al* (2015) presented the quantitative information about species richness and abundance including habitat associations from Anadaman and Nicobar Island. They reported about six anurans and two endemics in their study with the dominance of dicroglossid. They also documented similarlity of 82% and 76% anuran species composition between paddy fields with secondary forests and with evergreen forests.

Mishra and Guru (2013) documented the amphibian community analysis of Bolangir, Odhisa which included a total of 13 amphibian species comprising all anurans (Ranidae 59%, Microhylidae 21%, Bufonidae 14% and Rhacophoridae 4%). Khan and Khan (2019) reported 11 anuran species from Ranthambore, Tonk and Hadoti regions of Rajasthan which included *Rana hexadactyla, Rana cyanophlyctis, Rana limnocharis, Rana tigrina, Rana breviceps, Rana*

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rolandae, Bufo melanositctus, Bufo andersoni, Microphyla ornate, Uperdon systoma and *Polypedates maculates* representing four amphibian families. Wagh *et al* (2017) conducted preliminary study in different habitats of Amravati district, Maharashtra and recorded 11 amphibian species belonging to 9 genera. Total amphibian composition of Maharashtra state includes a total of 43 amphibian species (Padhye and Ghate 2000). Mane and More (2022) accounted for eleven anuran species falling in six families from Sahydri Tiger reserve (Maharashtra), out of which five species were endemic to Western Ghats while one species as endangered. Karunakaran and Jeevanandham (2017) conducted survey using line transect method in three major habitats of amphibians including agricultural land, ponds and grasslands and documented 13 amphibian species in Nagapattinam district of Tamil Nadu. Pal *et al* (2012) reported 33 herpetofaunal species from Durgapur (West Bengal) which included 24 amphibian and 9 reptilian species. Ramachandra *et al* (2017) accounted 47 amphibian species from Uttara Kannada district, Karnataka, out of which about 31 species were found to be endemic to Western Ghats. Families Dicroglossidae and Rhacophoridae reported for maximum species diversity while Ranixalidae and Ichthyophiidae with least species diversity. Adhikary and Boro (2022) surveyed the amphibian species from three different habitats in Baksa district, Assam and recorded 16 amphibian species belonging to 5 families. The three different habitats they surveyed were rice fields, built up habitat and marshland, out of which they reported that maximum diversity was found in the built up habitat while minimum in the rice fields. It also indicates the importance of habitat types in the conservation planning of these amphibian species.

Drivers of amphibian decline:

Many factors are responsible for the decline such as climate change, habitat destruction, pollution, deforestation, infectious diseases, heavy metals, pesticide contamination and UV radiation exposure (Blaustein *et al* 2003). There are six leading hypotheses consisting of two classes were given for the underlying amphibian species declines. The class I includes alien species invasion, over-exploitation and land use change, affected the amphibian species due to their long history of at least 100 years. The class II includes global climate change, UV radiations, chemicals contaminants (pesticides and environmental toxins) and infectious diseases which are recent and have a poor but improving understanding of each might cause changes in amphibian population reductions, and losses of species (Collins and Storfer 2003).

Group I threats:

1. **Invasion of Alien species:**
   Alien species invasion is one of the major threats to amphibian biodiversity loss. Alien species

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were found to influence amphibian fitness, population size and community structure via predation and competition. The amphibians respond by modulating aspects of their behaviour, morphology, or life history (Falaschi *et al* 2020). In the presence of alien species amphibian activity was found to be significantly higher while amphibian development time was found to be significantly shorter. The other negative impacts of these alien species include decrease in body size and weight, decreased breeding activity, decreased egg and larval survivorship, reduced metamorph size, habitat use alteration, tail injury and increased refuge use (Tyler *et al* 1998; Gamradt *et al* 1997; Gamradt and Kats 1996; Gillespie 2001; Nyström *et al* 2001; Kiesecker and Blaustein 1997; Kiesecker and Blaustein 1998). In some instances, adult amphibians were found to show avoidance by developing longer limbs or bulkier bodies in response to alien species (Nunes 2019). In mid 1800, trout was introduced throughout the Sierra Nevada (California) for sport fishing which resulted in decline of 80% *Rana muscosa* species (Bradford *et al* 1994). Similarly, introduction of mosquito fish (*Gambusia affinis*) throughout the world to control mosquito populations negatively affected the amphibians. In experimental studies, mosquito fish shown to decrease the larval survival of larval Pacific tree frogs (*Hyla regilla*) (Goodsell and Kats 1999) and California newts (*Taricha torosa*) (Gamradt and Kats 1996) and inflicted tail injury, reduced metamorph size and altered activity patterns of larval California red-legged frogs (*R. draytonii*) (Lawler *et al* 1999). The effects of American bullfrog (*Lithobates catesbeianus*) invasion on native frog communities in lentic waters, China was examined and both native frog density and species richness were found to be negatively related to post-metamorphosis bullfrog density (Yiming 2011). Nyström *et al* (2001) examined the effects of multiple-introduced predators on a littoral pond community. They found that alien crayfish and rainbow trout (*Oncorhynchus mykiss*) negatively impacted native common frog (*Rana temporaria*) tadpoles and had impacts on multi-trophic levels in the community. Both snail biomass and macrophyte coverage were found to decreased with the alien predators. Similarly, invasive species may act as reservoirs of diseases like chytridiomycosis as in *Xenopus laevis in Southern Africa* (Weldon *et al* 2004) and invasive bullfrogs may serve as the reservoirs for the fungus in the Western United States (James *et al* 2009; Schloegel *et al* 2009). The invasion of cane toads may also exert selection pressure on life-history traits such as breeding seasonality or size at metamorphosis and also through predation and competition in native anurans (Greenlees *et al* 2010; Shine 2010).

2. Over exploitation:

Amphibians are mainly exploited for food, pet trade, scientific research and biomedical purposes. More than 200 species of amphibians are consumed on a subsistence level or traded

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around the globe**.** Over all the live trade for the global pet market is increasing, with more than 60% of the total live trade recorded after 1996. The USA is top most destination country for amphibian trade followed by Japan and Germany (EU). There are total imports of approx. 30 million+specimens of live amphibians (both CITES and non-CITES listed species) into the USA for commercial trade between 2006-2014. Japan is both a source and destination country for the trade while Germany is known for trade in exotic pet species. Mohanty and Measey (2019) suggested the strong bias for certain amphibian families with high species diversity (e.g Dendrobatidae, Salamandridae), large bodied species, large range size and species with larval stages as best for the global trade. Chanson *et al* (2008) identified 47 amphibian species endangered by unsustainable international pet trade. International trade of amphibians is regulated by the Convention on International Trade in Endangered Species (CITES) of wild fauna and flora, an international agreement between governments whose goal is to ensure that international trade of species in the wild is not a threat to their persistence. Amphibian skin is a morphological, physiological and biochemically complex organ which contains granular glands which synthesize a wide range of chemical compounds including amines, bufodienolides, alkaloids, peptides and proteins. It was also identified four main trade groups which includes eggs, skins, meat and individuals. Trade in amphibian leather focused on *Hoplobatrachus tigerinus*, whereas trade in eggs focused on *Ambystoma mexicanum*. However, trade in skins and eggs was found to be small as compared with trade in meat and live animals.

3. Habitat modification (destruction and fragmentation):

Habitat modification is the key factor contributing to amphibian declines globally with an estimated 63% of all amphibian species affected, and approximately 87% of the threatened amphibian species affected (Chanson *et al* 2008). Habitat destruction is a major reason for the decrease in genetic diversity among local and regional amphibian populations making them more vulnerable to the events (environmental and demographic) which further reduce the population size. The most common habitat modifications include clearance for crops, urbanization and industrial development. Most of these processes are happening in tropical forests, where the majority of amphibian species (72%) are found (Gallant *et al* 2007). Hamer *et al* (2008) suggested negative relationship between urbanization and amphibian species richness, abundance and community structure. Also, amphibians require more than one habitat for the completion of their life cycle-forests and grasslands (for feeding), water bodies (for breeding) and land (corridors). Habitat fragmentation leads to decrease in larval dispersal and genetic diversity (Gibbs 1998; Reh and Seitz 1990), increase in mortality (Fahrig *et al* 1995). A study by Davidson *et al*

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(2002) found that habitat destruction due to urbanization has significantly contributed to the declines of the California red-legged frog (*Rana draytonii*). *Xenopus gilli* has lost 60% breeding sites in South Africa due to its wetland habitat loss. Decline in the population size of karez frog, *Chrysopaa sternosigmata* from Jammu and Kashmir of India has been reported due to anthropogenic activities and climate change (Saba and Balwan 2016). Decline in the population of great crested newt (*Triturus cristatus*) in United Kingdom as reported by Wood *et al* (2003) was due to loss of the water bodies by urbanization. The number of salamander populations has fallen by nearly half, the number of spotted frog populations has declined by 68%, and the number of chorus frog populations is down by 75% due to wetland dessication (McMenamin *et al* 2008).The study done in Ajara tahsil of Kolhapur district, Maharashtra (India) revealed 22 species of amphibians belonging to 17 genera and 7 families in Gavase and Dhanagarmola wetlands while due to high anthropological activities, Yarandol and Ningidage wetlands exhibited lesser diversity (Patil and Patil 2019). Thirty-six species of anurans and six species of caecilians were recorded in the Kudremukh National Park, India. Among these, 20 species were found to be distributed in both disturbed and undisturbed sites, while 22 were found only in undisturbed sites suggesting how anthropogenic activities affected the distribution (Krishnamurthy 2003). Hence, over all amphibian declines can be directly associated with landscape structure changes like decrease in wetland area and density, and increase in wetland isolation, decrease in wetland vegetation, forest cover and terrestrial habitat. (Lehtinen *et al* 1999; Parris 2006; Gagne and Fahrig, 2007).

Group II threats:

4. Global climate change and UV radiations:

Earth climate is changing continuously in response to various anthropogenic activities. The average global temperature has risen by 0.7℃ over last century and will raise up to the range of 1.1-6.4℃ by 2100. Similarly, there will be an increase in average mean precipitation by the end of this century (Lawler *et al* 2009). Environmental cues like temperature, moisture or the timing and amount of precipitation are the main components that affect amphibian phenology directly. Hence, any change in temperature, moisture or precipitation can trigger changes in the period of hibernacula or disrupt breeding cycle. The major direct effect of global warming is a trend towards early breeding in amphibians (McMenamin *et al* 2008). Beebee (1995) showed that over a 17-year period, amphibians spawned 2 to 3 weeks earlier in the period (1990-1994) than the period (1978-1982) in Britain in response to increasing temperature. The Western toads (*Bufo boreas*) of Oregon were found to breeding increasingly

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early in response to increasing temperature (Blaustein *et al*2001). However, some studies suggested that amphibians were late breeding as compared to their normal reproductive cycles (Reading 1998; Beebee 1995; Gibbs and Breisch 2001). Changes in climate change can also alter survival, growth, dispersal capabilities and could result in range shifts. It can also influence the food availability, pathogen-host dynamics, predator-prey interactions (Blaustein *et al* 2008). It has also been suggested that drier climate due to less rainfall and reduced cloud cover in some place has forced the amphibians to concentrate in hiding places leading to increased spread of parasites and diseases. Several studies also suggested that increased temperature also resulted in the increased host susceptibility towards *Batrachochytrium dendrobatidis* infection (Catenazzi 2015). The elevated temperatures significantly delay the development and can reduce the growth of tadpoles. It can increase the vulnerability of amphibians towards diseases by affecting the immune system. The elevated temperature treatments when given in lab conditions to amphibians, reduced the white blood cell count and the percentage of thrombocytes while increased the percentages of lymphocytes, monocytes and neutrophils. Increased temperature may also affect the sex ratio (number of males: females) of amphibians in a season (Nakamura 2009). But, the climate change has been least studied in relation to amphibian population declines (Linder *et al* 2003). McMenamin *et al* 2008 observed severe reduction in the number and diversity of amphibian population which were driven by long term climate changes and wetland desiccation in North America. Similarly, Pounds *et al* (1999) showed the correlation of dry periods with the amphibian diversity losses. Climate change also exposes the amphibians to other environmental stressors like UV radiations.

UV-B radiations: The exposure to the level of UVB radiations has been increased since 1970 and is often liked with the climate change. Increase in UV-B radiations has been shown damaging to amphibians in general and their eggs and larvae in particular. Extreme dry years, reduced pond depth increases exposure of amphibian embryos to ultraviolet (UV-B) radiation (Cramp and Franklin 2018). UVBR can result in decreased growth and developmental abnormalities (Romansic *et al* 2009). The increased exposure also found to increase their vulnerability to various infectious diseases like *Saprolegnia ferax*, which causes egg and embryo mortality in amphibians (Kiesecker *et al* 2001).

5. Chemical contaminants (pesticides and heavy metals):

Exposure of pesticides has been hypothesized as second major cause after habitat destruction for amphibian declines globally. Amphibian use water bodies associated with the fields as breeding sites

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and hence, get easily exposed to these chemicals from industrial discharges and agricultural runoff. Pesticides can be effective at reducing pest populations, but they can also harm the ecosystem, for example by contaminating pond water. Following application in the crop field, agricultural runoff and rainwater from the crop fields transport many of the dangerous pesticides into surface and groundwater. This pesticide runoff from agriculture may eventually cause the surface and groundwater to become dangerously poisoned (Bagchi *et al* 2008). De Lange *et al* (2009) used population vulnerability to contaminants (DDT and chlorpyrifos) to show that reptiles and amphibians were the most vulnerable species among the 144 species from seven taxonomic groups of vertebrates with direct impact on their ecological characteristics like life histories and feeding behaviour. These chemicals are being directly consumed by the amphibians with food and water. These water pollutants and pesticides interfere with the enzymatic activities leading to biochemical and physiological changes in the individuals. It has been reported that agricultural fields especially rice fields are not suitable habitat for amphibian species due to the overuse of pesticides, field water contamination with heavy metals (Bruhl *et al* 2013). As many pesticides, insecticides, and herbicides used in agriculture are reported to possess the potential to interfere with physiology, growth, behaviour and regulation of reproductive and developmental processes of these organisms. Since, most amphibian species undergo dramatic hormone-dependent developmental and metamorphic changes during larval development, including limb development, central nervous system modifications, digestive tract remodelling, gill regression, lung formation, and sexual differentiation, they are particularly vulnerable to xenobiotics during this time (Carey and Bryant 1995; Sachs and Shi 2000). The effect has been seen on clutch size, larval survival rate hence directly affecting the population trajectories of amphibians. These chemicals are being directly consumed by amphibians with food and water. These chemicals also cause alterations in the neurological and immune system of the organism (Andreia *et al* 2019). Chemicals like DDT have reported to cause improper gonadal growth in larval forms of tiger salamanders as DDT was found to interfere with the steroid hormone biogenesis (Clark *et al* 1998). Many morphological deformities like hind limb deformities, dysplasia or an extra number of limbs are commonly seen in frogs and toads. Deformity rates tend to be higher at agricultural areas with higher use of these agrochemicals. In some habitats 98% of the tadpoles and adults have shown malformed limbs, open eye slits, edema, scoliosis due to water contamination with pesticides and other pollutants. According to Immerman and Drummond (1985), lawns and gardens in the United States were found to be treated with 338 different active substances in their geological survey investigation. Urban streams in the Lake Washington (Seattle, WA) drainage basin were examined as part of a survey (Frans 2004) to look for the presence of 155 pesticides and pesticide metabolites. Thirty-seven of the substances (20 herbicides, 9 insecticides, 2 fungicides and 6 products of pesticide transformation) were found at least once during the research. Thirty six species

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of anurans and six species of caecilians were recorded in the Kudremukh National Park, India. Among these, 20 species were found to be distributed in both disturbed and undisturbed sites, while 22 were found only in undisturbed sites suggesting how anthropogenic activities affected the distribution (Krishnamurthy 2003). Agro-chemicals are affecting amphibians both directly and indirectly by disrupting their natural life cycle and leading to abnormalities.

Gurushankara *et al* (2007) have reported the abnormalities in the four species of dicroglossid frogs inhabiting forest, water bodies, agriculture (paddy) fields and coffee plantations with a suggestion of long-term scientific studies to decipher the reason for such deformities. Teratogenic effects of the diverse pesticides have been documented, both in laboratory and field studies majority in frogs and toads. Pesticides residues also have been quantified in two species (*Fejervarya limnocharis* and *Hoplobatrachus crassus*) from conventional paddy farms. Among *T. rufescens,* anopthalmia, brachydactyly and ectrodactyly were prevalent in equal incidence of 4% whereas in agricultural fields brachydactyly (4.41%) and in coffee plantations, brachydactyly and ectromelea were predominant ie. 4.40% each (Gurushankara *et al* 2007). Recently, high rate of incidence of morphological abnormality (7.36%), increased hepato-somatic index (14.86%) and gonado-somatic index (male; 8.88% and female; 17.51%) and low acetylcholine esterase activities in the brain (41.5%) and liver (46.9%) indicating the lower health status of frogs living in coffee plantations that were regularly treated with agrochemicals reported (Hedge *et al* 2019). Three frog species (*Limnodynastes tasmaniensis, Limnodynastes fletcheri* and *Litoria raniformis*) when surveyed in rice bays reported with abnormality index of 7% with ectrodactyly being the most common aberration (Spolyarich *et al* 2010). Khan (2010) reported that three species tiger frog (*Hoplobatrachus tigerinus*), Indian burrowing frog (*Tomopterna breviceps*), Indian cricket frog (*Limnonectes limnocharis*) listed as threatened species solely due to pesticide contamination. Based on the monsoon studies Rathod and Rathod (2013) have discussed about the amphibian species composition across the different regimes of coffee plantations of Western Ghats. Also, frogs from conventional but none from the organic farms revealed deformities (Kittusamy *et al* 2014). The abnormalities percentage recorded among four species of frogs: *Limnonectus limnocharis*, *L. keralensis*, *L. brevipalmata* and *Tomopterna* (*Spherotheca) rufescens* inhabiting forest (0%), water bodies (3.92%), agriculture (paddy) fields (3.98%) and coffee plantations (4.64%) on the basis of usage amount of chemical fertilisers which was maximum in coffee plantations and none in forests. The morphological abnormalities recorded were abnormal limbs, missing eye or small eye, and bulged abdomen. *L. limnocharis* inhabiting water bodies displayed brachydactyly (1.65%) while in paddy fields ectromelea (1.26%) was more prevalent followed by brachydactyly (1.01%).

In coffee plantations ectromelea (1.36%) was dominant whereas, *L. keralensis* ectrodactyly predominates water bodies (1.235%) and ectromelea common in paddy fields and coffee plantations

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ie. 1.37% and 3.19%, respectively. In case of *L. brevipalmata* brachydactyly, microphthalmea, ectrodactyly and anophthalmia were in equal proportions (1.35%) in water bodies, whereas in agricultural fields and coffee plantations, the predominant abnormality was ectrodactyly (1.99% and 3.19%), respectively. Decline in the population size of Karez frog, *Chrysopaasterno sigmata* from Jammu and Kashmir (India) has been reported due to anthropogenic activities and climate change (Saba and Balwan 2016). Kanagavel *et al* (2017) have cracked the false myth of frogs eating cardamom in the cardamom plantations of the Western Ghats and reported some of the range restricted rare amphibians with a stress on the studies on the effect of pesticides on the amphibians of cardamom plantations. Svinin (2016) reported a case of hyperxanthism of the eye on one *Rana arvalis* specimen, one asymmetric amely in *Bombina bombbina* and 21 specimens of *Pelophylax ridibundus* with deformed fore and hind limbs. In 1992, World Health Organization (WHO) recognized that cypermethrin is an alpha-cyanopyrethroid which is a commercial insecticide,
reported that primary target site is the vertebrate nervous system and cause twisting, writhing and non-coordinated swimming type of behavioural response in amphibian's species on poisoning (Berril *et al* 1993; Farhana *et al* 2011). These pesticides can be deleterious to the amphibian species and thus, reducing their diversity from the ecosystem leading to biotic imbalance. Cholinesterase (ChE) activity in tadpoles was found to be depressed due to pesticide residues. Up to 50% of the sampled population in areas with reduced ChE had detectable organophosphorous residues. Also, up to 86% of some populations had measurable endosulfan concentrations and 40% had detectable 4,49-dichlorodiphenyldichloroethylene, 4,49-DDT, and 2, 49-DDT residues (Sparling *et al 2000*). It has also found that malathion directly resulted in the death of anuran tadpoles (Releyea *et al* 2005). The effects of five insecticides like metasystox, malathion, folithion, rogor and metacid on eggs, feeding stage and limb bud stage tadpoles were studied and found that the insecticides caused a prolongation of life history in case of Indian bull frog (*R.tigerina*) (Hejmadi and Dutta 1981). Evidence has been found of these pesticides to be acting as Endocrine Hormone Disruptors (EHD) which results in the delay of metamorphosis, abnormal gonadal differentiation and even in disease contractions (Tyrone *et al* 2006). The effect of methyl parathion (MPT) an organophosphate pesticide on survival and development of common paddy field frog *F. limnocharis* in a laboratory condition was studied using different concentrations. It was found that MPT reduced the survival of tadpole affecting its capability to metamorphose. Also, an increase in mortality rate was seen with the increase in the concentration of pesticides (Puttaswamy *et al* 2017). Effects of mixtures of malathion and carbaryl insecticides on the survival of tadpoles and emergence of froglets of *F. limnocharis* shown reduction in survival rate and froglet emergence (Nataraj *et al* 2019). The herbicide atrazine reported to cause the improper gonadal development and feminizes the gonads of developing males. Gonadal malformations induced by atrazine include hermaphroditism, single sex polygonadism. Non-

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pigmented ovaries occurred at high frequencies in atrazine treated larvae due to disruption androgen synthesis and activity (Tyrone *et al* 2006).

6. Heavy metals:

The intense agricultural and industrial production from mines has increased the prevalence of heavy metals in surface waters. The toxicity of heavy metals like copper, cadmium, lead, mercury to various amphibians has been studied mostly in tadpole/larval stages and found to be a major cause of mortality (Joseph 1991). Heavy metal pollution has been considered one of the major causes for the amphibian population decline worldwide (Blaustein *et al* 2003). Several studies, including those by Blem and Blem (1991); Dorchin and Shanas (2010), found significant negative effects on the levels of population and individuals. In *Rana esculenta*, inflammations and an increase in parasitic cysts is found to be directly related to the heavy metal contamination (Fenoglio *et al* 2011). On the other hand, some surprising responses of amphibians to heavy metal stress have been described (Freda 1991). High incidence of morphological abnormalities (mostly of limbs) and tumour-like dysplasias were recorded in three species of anurans (*Bombina bombina*, *Bufo viridis* and *R. ridibunda*) where water bodies were highly contaminated with heavy metals like Fe, Zn, Mn, Cu, Pb, Ni and Cd (Flyaks *et al* 2004). It was also found that frog tadpoles exposed to chromium in water that is used to irrigate the paddy fields revealed a marked teratogenic effect leading to abnormal behavioural responses (Abbasi *et al* 2007). When two species of frogs (*R. tigerina* and *Euphylctis cyanophlyctis)* collected from polluted areas were studied for heavy metal toxicity. The result showed the accumulation of heavy metals like Cd, Pb, Fe, Ni, Co, Zn, Mn, and Cr in different tissues. The difference in skin color and decreased body length and weight were also found as compared to the frogs of unpolluted areas (Qureshi *et al* 2015). On survey, it was found that amphibian habitats in Central and Eastern Europe which were severely contaminated with heavy metals like copper, arsenic etc and extremely acidic water bodies were found to be devoid of amphibians. However, they also addressed the fact even moderately contaminated habitats or acidic pH of soil and water does not affect amphibians to much extent. They also accounted for six species including *Bombina variegata*, *Rana ridibunda*, *R. temporaria*, *Bufo viridis*, *Salamandra salamandra* and *S. atra* to be present in moist habitats, especially streams, puddles and ponds which were being fed by drainage water. Several frogs appear to have a low tolerance for heavy metals despite the great likelihood that they will absorb the toxins. The hardness, pH, DOC of the water as well as the amphibian species and developmental stages, all play a role in the extremely complex phenomenon known as aluminium toxicity. Most sensitive stage to acidic water in life cycle of amphibians is the amphibian embryos (Freda 1986). After hatching into larval stage, the tolerance to the acidic water eventually increases. Aluminium sensitivity is most in newly hatched tadpoles followed by embryos and older tadpoles.

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The 96 h LC_{50} for total monomeric aluminium, for instance, in *R. pipiens* at pH 4.8, was less than 250 µg liter^{-1} for newly hatched tadpoles, 403 µg liter^{-1} for embryos. For tadpoles that are 3 weeks old, 1000 µg liter^{-1} (Freda and McDonald, 1990). With aluminium-spiked water, embryos can successfully hatch but the larvae perish shortly after hatching. This is based on qualitative observations. In contrast, Clark and LaZerte (1985) discovered that pre-stage 25 tadpoles did not exhibit a toxic response to aluminium, despite finding that embryos were sensitive to the metal. Aluminium toxicity in embryos is mostly influenced by the pH of the water. Aluminium toxicity affects in some species at extremely low pH (<4.5), whereas in others it only does so at higher pH (> 4.5). In addition, a third case exists where aluminium is toxic at relatively high pH, while it ameliorates acid toxicity at lethal pH. Although the exact cause of aluminium toxicity dependence on water pH is unknown, it may be related to variations in aluminium speciation or perhaps competition between aluminium and hydrogen ions for binding sites on vitelline or epithelial membranes. Heavy metal concentrations in amphibian breeding ponds have been observed in several investigations (Clark and Hall 1985; Freda *et al* 1991). On the other hand, streams that have been impacted by acid mine drainage may have metal concentrations that are hundreds of times greater than the danger level (Mathews and Morgan 1982).

Guezgouz *et al* (2021) highlighted the point source of heavy metal pollution in the upstream surroundings of the Medjarda basin and their ecological status. The water pH, water temperature, dissolved oxygen and biological oxygen demand and levels of heavy metals in toad’s skin using an atomic absorption flame spectrophotometer were measured. At all locations, the concentrations of lead (Pb) in water and toad skin were greater than 60 and 96 times the respective standard reference levels. The concentrations of heavy metals in water and the skin of male toads were found as Pb>Fe>Cu>Zn and Fe>Pb>Zn>Cu, respectively. The toxicity of the heavy metal cadmium to the Indian skipper frog (*Rana cyanophlyctis)* was assessed by Srivastav *et al* (2016). For the frog *R. cyanophlyctis*, the LC_{50} values for cadmium chloride were 32.586, 29.994, 27.219 and 23.048 mg/L at 24, 48, 72 and 96 hours, respectively. The findings have been discussed in relation to fish, another aquatic vertebrate whose toxicity has been reported. They concluded that cadmium caused the frog to die, which may be one of the factors contributing to the population loss of frogs that live in heavy metal-contaminated water. Cadmium exposure has been shown to produce sublethal effects on herpetofauna. Compared to control and 5 g/L treatments, *Bufo americanus* tadpoles with chronic exposure to 54 g/L cadmium lost their tails earlier and heavier. Only 7.1% of the 540 tadpoles underwent metamorphosis as compared to 91.2-100% in all other treatments (James and Little 2003). Despite significance of zinc in biology as a micro element, zinc pollution can have a detrimental effect on amphibians and reptiles. It was shown by Herkovits and Pérez-Coll (1991) that exposing *Bufo arenarum* larvae to 32 mg/L zinc for 72 hours had adverse effects as compared to controls and

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120 h significantly increased mortality (35% and 65%, respectively).

7. Infectious diseases:

In Australia, North America, South America, Europe and Africa a pathogenic fungus group named Chytridiales caused mass mortalities among amphibians. Chytridiomycosis is caused by two fungal species, *Batrachochytrium dendrobatidis* (also referred as BD- the amphibian fungus) (discovered in 1998) and *B. salamandrivorans* (discovered in 2013). It was reported that chytridiomycosis has been a reason for the decline of 501 amphibian species around the globe which is documented as the greatest loss of biodiversity to a pathogen. The reason behind this mass decline is the wide host range of *B. dendrobatidis* which include approximately 13 amphibian families. The other causative agents which received recent attention in relation to amphibian decline are *Saprolegnia ferax* (pathogenic water mould) and *Ambystoma tigrinum* virus (ATV- iridovirus). These pathogenic outbreaks have been linked with climatic induced changes like reduction in water depth which increase the exposure of the amphibian eggs to UVB radiations and make them more vulnerable to infectious diseases. *Saprolegnia ferax* was reported to be a major reason behind the decline of *Bufo boreas* and *Rana cascadae* in USA as a result of climatic induced changes (Kiesecker *et al* 2001). Rana virus is another group which is associated with the mass mortalities in amphibian populations. Two rana viruses - *Ambystoma tigrinum* virus (Arizona) and RRV(Saskatchewan, Canada) are considered to be species specific and reason behind the thousands deaths of common frogs in United Kingdom and tiger salamanders in USA. The trematode infestation (*Ribeiroia ondatrae)* has been reason behind the limb deformities in the Pacific tree frog (*Pseudacris regilla*) metamorphs).

Management strategies:

Amphibian decline has various reasons which act in various interactive ways. Hence, there is no single solution for the prevention. The main issue is the lack of an amphibian biodiversity studies, including taxonomic, systematic, phylogeographic, and ecological investigations, thus knowledge of their diversity across various habitats should be encouraged. Microhabitat preferences, as well as species behavioural and physiological reactions to rising temperatures and decreased water availability, have all been studied in order to understand how amphibians may adapt to climatic unpredictability (Griffis-Kyle 2016). Such investigations have aided in the creation of a plan for climate adaptation for at least one diminishing species. In order to lessen the effects of habitat loss and fragmentation, vocalisation behaviour has been used to draw individuals to newly created habitats. Several physiological metrics, such as stress responses, heat tolerance and evaporative water

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loss, have also been used to assess amphibian responses to habitat modification (including urbanization). Studies on behaviour and physiology have revealed how different species react to invasive predators and the results have led to the development of creative strategies to lower the risk of predation.

There is also need for the precise understanding of their home ranges, life histories and habitat requirements which will help us to plan various conservation strategies. The water bodies (ponds and wetlands) restoration and re-establishment of habitat corridors should be done. There are several ways to prevent or lessen landscape fragmentation, including preserving existing elements (patches or corridors that facilitate movements), enhancing the quality of such elements or creating new habitat patches or new corridors by means of restoration measures (McRae *et al* 2012). Gabor *et al* (2018) compared baseline corticosterone and stress response in urban locations to rural sites over a three-year period. Using a non-invasive water-borne hormone assay to measure corticosterone release rates, they discovered that in 2 of the study's 3 years, corticosterone levels were greater in urban locations than in rural ones. There should be legal check on the trade and exploitation of native and exotic amphibian species. The IUCN endorses captive breeding as an upbeat preservation method for amphibians. Disease surveillance and clear understanding of the link between the climatic changes and disease outbreaks in amphibian populations is required. The awareness by educating public and students regarding conservation of amphibians using tools like media should be encouraged. New methods like genetic analysis using environment DNA should be adopted for biodiversity monitoring.

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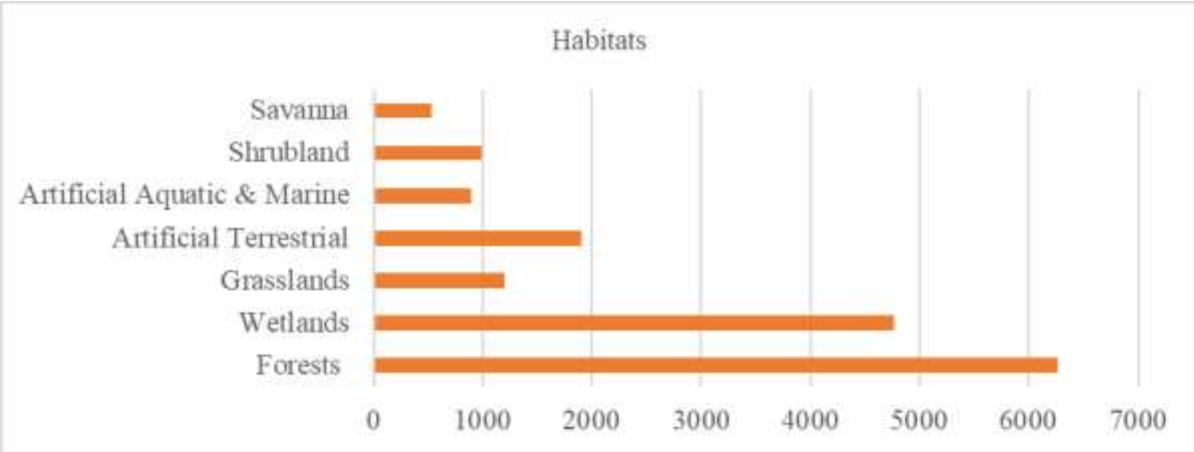
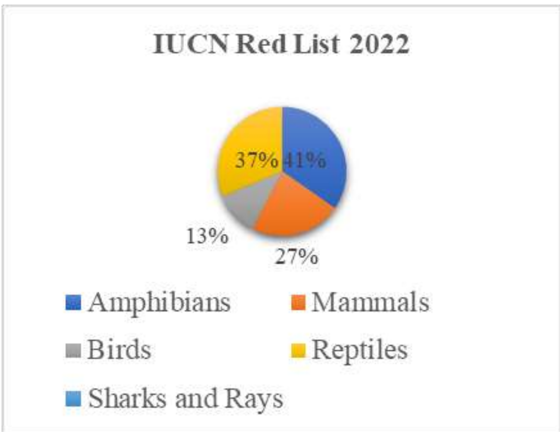


Fig 1: Amphibians inhabiting different habitats



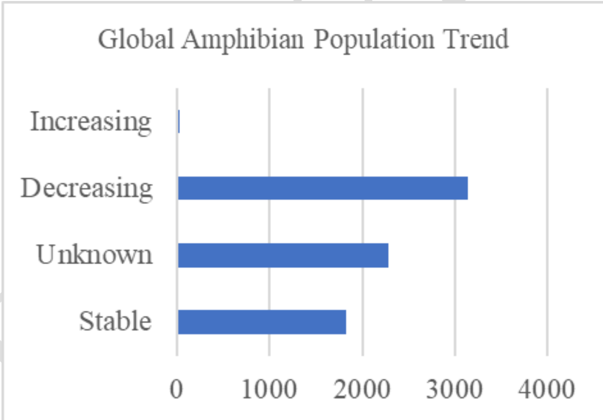


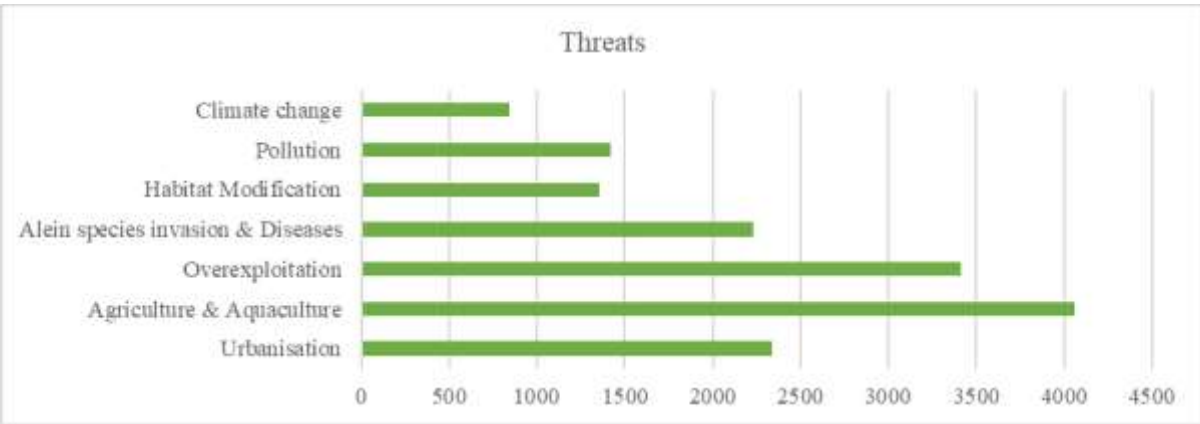
Fig 2: IUCN Red List 2022

Fig 3: Global Amphibian Population Trend

Fig 4: Group I and Group II threats to amphibians

Table 1 : Current Amphibian Diversity Status (India):

Comparison of threatened categories for amphibians, birds and mammals (2022)



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	Amphibians	Birds	Mammals
Endangered	15.1% (1,103)	3.8% (423)	9.2% (549)
Critically endangered	9.3% (681)	2.1% (231)	3.9% (232)
Data deficient	16.1% (1,177)	0.4%(47)	14.0% (838)

Table 2 : Global Pesticide usage (1990-2019)

Year	Pesticide usage (Mt tonnes)
1990	2,303,814
2000	3,082,416
2010	3,754,920
2019	4,168,778 (81% more than1990)

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