Summary Report

Rapid Assessment of the Proposed Biodiversity Heritage Sites in Gaya Forest Division, Bihar

Submitted by

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Front Cover: View from the Barabar Hill entrance, showing the bouldery nubbins and one of the wetlands nearby, in Gaya, Bihar. Photograph: Vijayan Jithin

Summary Page: View from the Ramshila, showing the inselberg portion with human habitations and the river flowing in the backdrop in Gaya, Bihar. Photograph: Vijayan Jithin

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EXECUTIVE SUMMARY

Formed millions of years ago, rock outcrops are unique habitats in terms of their geomorphology, and biodiversity, but have received poor research and conservation attention compared to forested ecosystems globally. They have been identified as small natural features that have ecological roles extending beyond their area, a concept similar to ‘keystone species’, at an ecosystem scale. Rock outcrops of India remain largely understudied, especially the inselbergs of Bihar. Recent research from the southern Indian rock outcrops shows that rock outcrops are cradles of biodiversity with multiple endemic and threatened species, but are facing multiple anthropogenic threats. The Bihar rock outcrops, especially the inselbergs are noteworthy geological structures, that received poor attention compared to other rock outcrops in India, especially in terms of its biodiversity and ecological value. A previous rapid assessment of rock outcrops in Nalanda and Aurangabad Divisions of Bihar has shown a range of diverse microhabitats and the biodiversity wealth of these habitats. To assess the feasibility and scope of declaring some of the preliminarily identified inselbergs of Bihar as potential ‘Biodiversity Heritage Sites’ (BHS), a rapid assessment was undertaken in the Ramshila, Pretshila, Brahmayoni and Barabar hills areas of the Gaya Division. Among the examined sites, Barabar hills and Ramshila show great potential as BHSs, considering its relatively undisturbed status, biological, geological, and heritage values. This preliminary report summarises the microhabitats, and biodiversity recorded from the inselbergs, along with notes on their cultural values, and recommends further actions for the conservation of these important habitats.

1. BACKGROUND

1.1. Rock Outcrops: Overview

Rock outcrops are unique habitats in terms of their geomorphology, biodiversity, and were formed millions of years ago. They are found on all continents, in most climate zones and vegetation types, but have received poor research and conservation attention compared to forested ecosystems (Inselberg Research Initiative, 2024). Rock outcrops can be a wide variety of physical environments, such as escarpments, overhangs, cliffs, boulder heaps and inselbergs (Fitzsimons & Michael, 2017). They can be broadly classified into three types; (i) inselbergs, which are large dome shaped outcrops, of granite or gneiss, (ii) rocky plateaus, which are naturally formed flat expanses of any rock type, and (iii) cliffs, which are steep and almost vertical exposed rock faces (Fig. 1). Rock outcrops can be technically distinguished from neighbouring areas by having an average of 55% area as exposed rock (Wiser & White, 1999). Rocky outcrops provide critical breeding sites for multiple organisms ranging from top order mammalian and avian predators to smaller invertebrates. They have been identified as examples of small natural features (SNF) that have ecological roles extending beyond their area, a concept similar to 'keystone species', but at an ecosystem scale (Hunter, 2017). They are also old climatically buffered infertile landscapes (OCBILs), that have contributed to high biodiversity (Hopper, 2023)

Figure 1. Type of rock outcrops. (a) an inselberg in Dhanhara, Bihar, (b) rocky plateau in Ratnagiri, Maharashtra, and (c) a cliff in Bihar Sharif, Bihar.

Geologically, they form due to erosion and weathering of softer parts of the landscape over millions of years, leaving behind the hard core of parent rock (Twidale, 2012).

Outcrops of West Africa, Madagascar, Australia, Brazil, and USA have received much research attention, while rock outcrop ecology of other regions such as India has largely remained understudied (Kulkarni et al., 2022). Rock outcrops are non--forested open natural ecosystems (ONEs) which support high biodiversity as well as livelihoods of millions of people, but are highly threatened due to land conversion (Madhusudan & Vanak, 2022). Rock outcrops provide a wide range of ecosystem services to humans, and they have played an important role in shaping human civilizations in the past (Rock Outcrop India Network, 2018). Though rock outcrops are known to harbour a broad range of endemic and highly specialised taxa globally (Porembski & Barthlott 2000), there is a knowledge gap in the literature addressing the conservation value of small, rocky outcrops (Michael et al., 2010). This hampers the scientific management of these fragile habitats which is necessary to reverse habitat degradation happening at many of these unique habitats.

1.2. Rock Outcrops in India

India is home to all the three types of rock outcrops across its breadth, which mostly look dry as arid deserts for almost eight months, but transform to green islands from the onset of monsoon rains. They are home to a large number of unique, endemic organisms. For example, the northern Western Ghats rock outcrops, (the most studied rock outcrop system in the country) holds a significant proportion of its flora as endemic (Watve, 2013). The flora and fauna in these landscapes are adapted to the harsh conditions of rock outcrops and many of plant species have evolved unique features such as desiccation tolerance and carnivory (Smrithy et al., 2023). Most of the Indian rocky outcrops are outside of the protected area network, and are used by people for traditional utilities such as grazing, but are also officially classified as ‘wastelands’ by the Government of India due to their ‘barren’ appearance (scarcity of woody species or forest cover) (National Remote Sensing Centre and Ministry of Rural Development, 2019). Recent studies on the rock outcrops of the northern Western Ghats has shown that land-use change associated disturbances are impacting a wide-range of fauna including endemic and threatened animals (Jithin et al., 2023a; Jithin et al., 2024). Despite the huge number of rock outcrops across the country, and their cultural, aesthetic and religious importance,

not much is known about its biodiversity and ecology in India (Inselberg Research Initiative, 2024). This makes these habitats prone to developmental, mining, and industrial activities. These important non-forest habitats thus are vulnerable to anthropogenic threats, despite their ecological, geological, recreational and cultural importance.

1.3. Rock Outcrops in Bihar - Background of Rapid Survey

The Ground Water Information Booklet for the Nalanda district recognizes that the inselberg series of Nalanda surrounded by the Indo-Gangetic alluvium of the Pleistocene age is a notable geological feature, and they mark the northernmost boundary of the Precambrian peninsular shield (Central Ground Water Board, 2013). Similarly, the booklet for the Aurangabad features the granitic gneiss exposures in the region, and states that they occur at places as inlier at the transition parts from hard rock to alluvial plain (Central Ground Water Board, 2013). It also notes the crystalline rocks exposed in Rajgir Hills and bedrock that sloping towards the northern side consist of phyllites and quartzites alongwith pegmatitic intrusions. These Precambrian crystallines have undergone intense structural disturbance in the form of multiple foldings (Central Ground Water Board, 2013). The technical report of the National Biodiversity Strategy and Action Plan (Technical and Policy Core Group & Kalpavriksh, 2005) submitted to the then MoEF (presently The Ministry of Environment, Forest and Climate Change) recognizes the importance of rock outcrops of India, especially the inselbergs found in south India and Bihar (see Box. 4.1 in its chapter 4). It says:

> *"The most prominent rock outcrops in India are as follows: Lateritic plateaus, common in western India in high-rainfall areas. Cliffs form a distinct feature in all the hilly areas, e.g. in the Western Ghats. Inselbergs are isolated rock outcrops rising abruptly above their surroundings and are seen throughout south India and Bihar."*

The draft report of the Biodiversity Strategy and Action Plan for Bihar (Mishra, 2004) also identifies inselbergs in the state's geographic features, though not exactly using the term:

> *"The alluvial filling south of the Ganga is shallow, a mere veneer and the Peninsular edge is very rugged. Many groups of small craggy hills rise up to 488 metres from islands of bare rock or scrub."*

But unfortunately, these reports were not implemented officially, and thus currently these rock outcrops are not under conservation focus.

From 2002 onwards, there have been efforts in different states to declare Biodiversity Heritage Sites (BHS) under section-37 of the Biological Diversity Act-2002. This includes some rocky hillocks in Karnataka (Karnataka Biodiversity Board, 2023), Kerala (Kuttoor, 2020), and Odisha (Odisha Biodiversity Board, 2019). In some areas, such as Ratnagiri in the state of Maharashtra, efforts are ongoing to propose rock outcrops as BHSs and also to conceptualise frameworks for Local Biodiversity Heritage Sites (Watve & Chavan, 2020; Jithin et al., 2023a). At present, there are no BHS in the state of Bihar, and the Biodiversity Board has interest in proposing some of the rock outcrops as BHS in the future. Previous rapid assessments of rock outcrops in the Nalanda and Aurangabad Divisions have shown they are home to diverse microhabitats and biodiversity focusing on saxicolous (living on or among rocks) organisms (Jithin, 2024). This report summarises the findings from the short-term assessment and literature review to suggest future prospects. Since the rock outcrop sites explored as part of this study are inselbergs, a section on inselberg ecology and research is given, before examining the site-specific insights.

2. INSELBERGS: ECOLOGY AND RESEARCH

2.1. Inselbergs: An Introduction

As mentioned before, Inselbergs are isolated rock outcrops that rise abruptly, above the surrounding plains. These granitic and gneissic inselbergs occur throughout different climatic zones across the world, and are geologically and geomorphologically old. The term ‘inselberg’ has been proposed by Bornhardt in 1900 to describe hills or groups of hills rising abruptly from a peneplain as an island rises from the sea (Willis, 1934). Geologically, granitic inselbergs can be classified into three basic types; i.e. (i) Bornhardts, which are steep-sided, bald and domical hills, (ii) castle koppies (tors or kopjes) which are steep-sided but angular and blocky with ordered arrangement, and (iii) nubbins, which are conical hills with chaotic mass of blocks and boulders (Twidale, 1981). But these classifications are not rigid, and intermediate forms are many (Fig. 2).

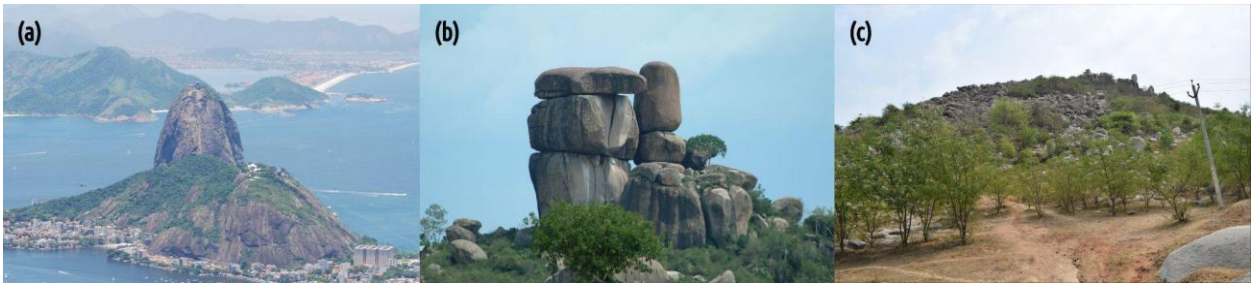


Figure 2. Examples for types of inselbergs; (a) Sugarloaf Mountain, a bornhardt, Rio de Janeiro, Brazil; (b) Kit-Mikayi, a castle kopje near Kisumu, Kenya; and (c) Jhunjhunwa Pahar, a bouldery nubbin in Bihar, India. Photograph (a) by Paul Mannix, CC BY-SA 2.0, and (b) by Valerius Tygart CC BY-SA 3.0 via Wikimedia Commons.

Inselbergs form micro climatically and edaphically dry growth sites, which are home to highly specialised vegetation. Inselbergs are known as ‘microclimatic deserts’ as the air temperature on its slopes and insolation are considerably high, and low relative air humidity compared to the surrounding region (Porembski, 2007). In addition to this, comparatively very less amount of soil is present on these habitats with severe limitation of nitrogen and phosphorus, and high surface water run-off during rains which makes the habitat a harsh environment.

Despite these stressful conditions, inselbergs mainly contain advanced flowering plants, but are also home to ferns, gymnosperms and basal flowering plants. Within the flowering plants group, most species are from the families Poaceae, Cyperaceae (grasses) and Fabaceae (peas). *Vellozia*, *Rhynchospora, Cyperus* (sedges), and *Utricularia* (bladderworts) are among the most species rich genera (Barthlott & Porembski 2000), as reported from African studies and include biologically interesting groups exhibiting desiccation tolerance, carnivory and succulence. Southeastern Brazil, Madagascar and southwestern Australia are currently known as 'hot spots of inselberg plant diversity' (Barthlott & Porembski 2000). But our knowledge of vegetation on inselbergs of several tropical regions such as India and Angola is still sparse, and this requires research attention.

Inselbergs are known to contribute to the local and regional plant species richness (Burke et al. 2003b). Rocky outcrops such as inselbergs support unique biological communities, with high levels of species endemism, and are considered important in the conservation of biodiversity worldwide (Fig. 3). For example, they occur in fragmented landscapes and play a key role in conserving reptile biodiversity in the modified environments (Michael et al., 2008). Rock outcrops are important to reptiles as they can provide resources such as basking and retreat sites, and micro-gradients in climatic conditions which are often limited in the surrounding landscape (Michael et al., 2010). It is also known that though inselbergs cover a small portion of area, they can provide resources that are uncommon in the landscape, which makes them local hotspots of avian diversity (Trager & Mistry, 2003). Apart from the microscopic organisms that grow on the rocks (Büdel et al., 2000), the rocks also provide spaces suitable for colonisation by macroscopic organisms including cliff flora and carnivorous plants (Larson et al., 2000; Seine et al., 1996). One of the main threats to the inselberg vegetation include invasion of exotic weeds due to high climatic disturbances and human impacts such as intentional burning, grazing, quarrying, construction of buildings such as temples in India, leisure (rock climbing) and touristic activities (construction of buildings, cable cars) (Porembski, 2007; Burke, 2003; Porembski, 2000). Large scale quarrying for granite and gneiss extraction is one of the leading causes of inselberg destruction (e.g., Bangalore, Karnataka).

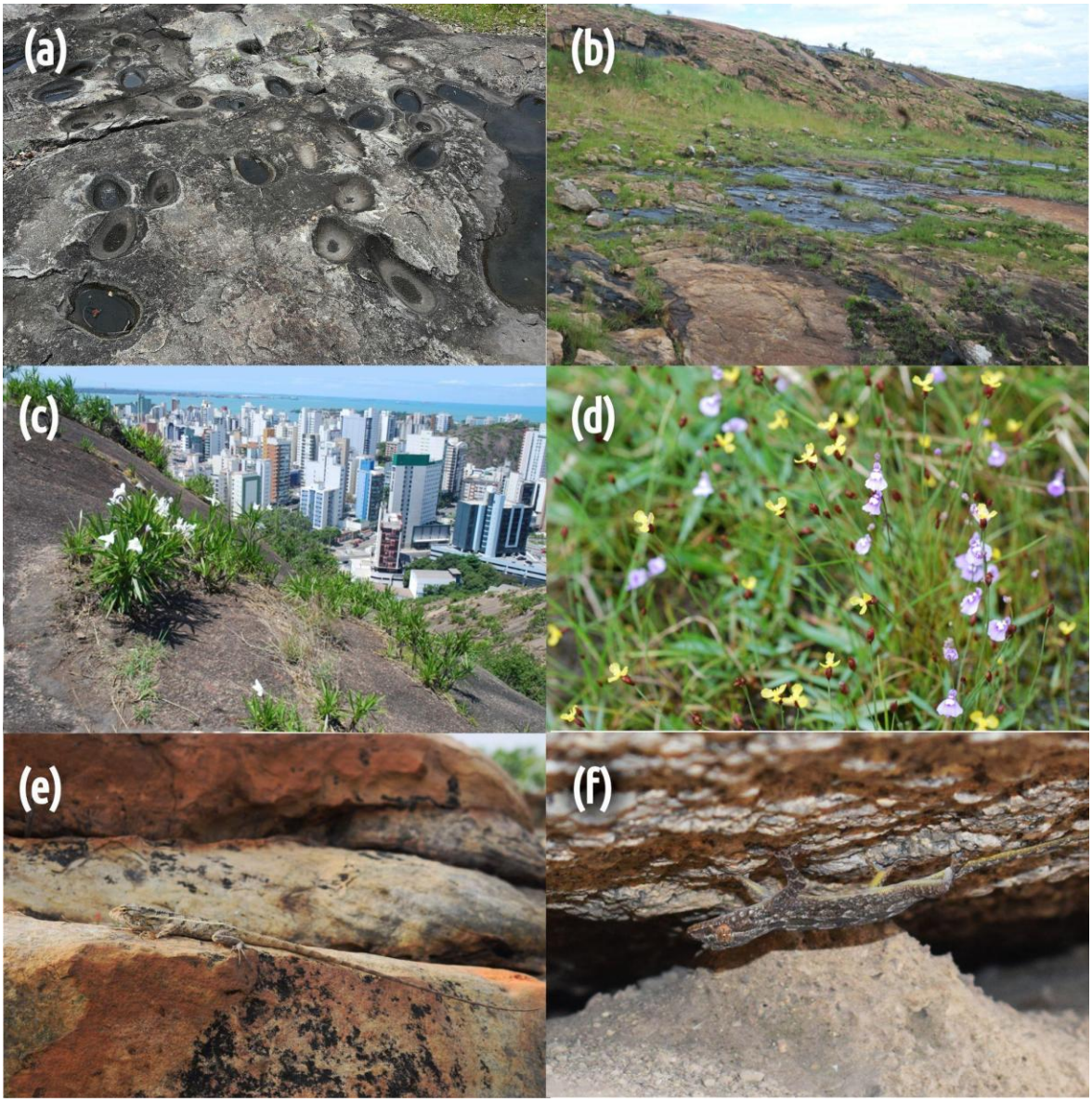


Figure 3. Microhabitats and biodiversity on inselbergs; (a) rockpools on an inselberg in Côte d'Ivoire, Africa; (b) ephemeral flush vegetation on an inselberg in Madagascar; (c) *Vellozia plicata* mats formed in Espirito Santo, Brazil; (d) *Utricularia* sp. and *Xyris* sp. as ephemeral flush vegetation in Madagascar; (e) Common garden lizard and; (f) a Yellow-belly gecko on inselbergs of Bihar, India. Photographs (a-d) courtesy: Inselberg Research Initiative.

2.2. Inselbergs of India

The Indian peninsular landscape, shaped by the divergent weathering and differential erosion after Gondwanaland breakup, are characterised by the granite-gneissic landscape with undulating plains and boulder inselbergs and Deccan Trappean landscape with flat-topped, stepped hills separated by valleys (Kale & Vaidyanadhan, 2014). In peninsular India, especially in the semi-arid continental interior, granite landforms can be seen as rugged clusters of oddly shaped bedrock monoliths and boulders (Gunnell, 2014). Granitic outcrops and boulder-strewn hills (nubbins) create a dramatic landscape in the cratonic parts of the Indian Peninsula. Shravanabelagola, Savandurga, Nandi, and Ramanagara hills near (Bengaluru), Moula Ali and Bhongir Hills (Hyderabad), and Narlai (Aravalli Hills) are examples of domed inselbergs or bornhardts (Fig. 4). Boulder-strewn hills and castle koppies are common such as the one near Hampi, Barabar and Nagarjuni Hills in Bihar. Jalore and Siwana inselbergs in Rajasthan are also well-known (Kale & Vaidyanadhan, 2014).

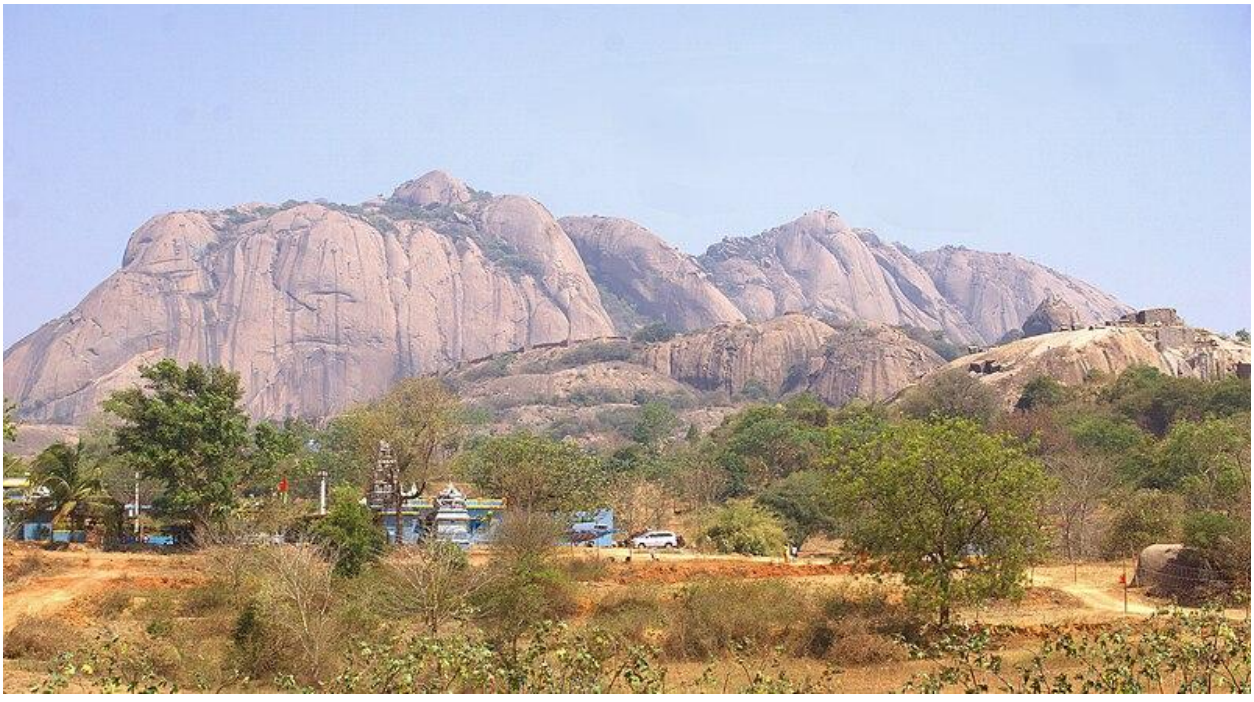


Figure 4. Monolithic Savandurga Hill near Bengaluru in India viewed from the southern side. Photograph by Pravega, CC BY-SA 4.0, via Wikimedia Commons.

Despite the rock outcrop occurrence in huge numbers across the country and their immense multi-dimensional importance, not much is known about their biodiversity and ecology in contrast to the highly studied geomorphology and geology aspects (Inselberg Research Initiative, 2024). Monolithic outcrops are typically found in humid regions such as Kerala, while kopjes dominate the drier parts of India (e.g. Andhra Pradesh, Bihar). It is interesting to note that some of the famous monolithic inselbergs in India are Savandurga near Bengaluru and Mandar hills in Bihar (Rock Outcrop India Network, 2018) (Fig. 5). Indian inselbergs vegetation appearance closely resembles that of other tropical regions with lesser roles of monocotyledonous mats of desiccation-tolerant vascular plants. More information needs to confirm this, in relation to the recent observations of *Tripogon* mats on inselbergs near Bengaluru (Inselberg Research Initiative, 2024).

Figure 5. Mandar hills in Bihar. Photograph by Devesh Bhatta, CC BY-SA 4.0, via Wikimedia Commons.

Many of these tall inselbergs are of potassium-rich late Archean or younger granitic rocks, and compared to other cultures, Indian granitic landscapes have been harnessed in large scale by humans for worship, warfare, runoff agriculture, and stone quarrying. It is also important to note that India has one of the world's largest quarrying industries associated with the rock outcrops (Inselberg Research Initiative, 2024). Many Indian outcrops have small or large shrines and places of worship, and some of the strange rock shapes are explained by myths, anecdotes and stories through traditional knowledge (Rock Outcrop India Network, 2018). Many inselbergs have a pond, or large pool near its base, or agricultural fields, which are using rain water runoff from the inselbergs. They are also places of landscape tourism, wildflower tourism, recreational or adventure tourism. Mass blooming in some of these habitats help pollination of crops nearby (Rock Outcrop India Network, 2018). Though groundwater potentiality is generally poor in inselbergs (Sivakumar et al., 2013), the run-off from these geological formations are critical for adjacent agricultural fields. Studies have shown typical geomorphic attributes such as inselbergs can control the productivity of the land and also the socioeconomic conditions of the local people (Mahato & Jana, 2019).

2.3. Status of Research on Inselbergs

Though the oceanic islands attracted much scientific attention in the past to develop some of the important ecological theories (eg. Charles Darwin - evolutionary processes; Robert H. MacArthur - island biogeography theory), terrestrial habitat-islands such as inselbergs have been somewhat neglected (Porembski, 2007). There is a large knowledge gap on inselbergs of many regions such as India. Discoveries of new rock-dwelling animals and plants continues from rock outcrops in southern India due to the relatively recent research attention it has received (Grandison & Soman, 1963; Biju et al., 2009; Agarwal et al., 2020; Prasanth & Sardesai 2022). There needs to be more research and conservation focus on rock outcrops in other regions of India, such as Bihar.

2.4. Microhabitats on Inselbergs

Recognizing that inselbergs are composed of varying microhabitats relative to their surroundings are important, as they are hypothesised to be bioclimatic ‘islands’ of xeric conditions in a humid matrix in tropical and temperate regions, and ‘islands’ of mesic conditions in arid regions (Burke, 2003). Microhabitats differ mainly with respect to soil type, depth and moisture and each has its specific vegetation (Rock Outcrop India Network, 2018). A few microhabitats that are found on inselbergs are briefly described below:

2.4.1. Loose Rocks

Loose rocks on the surface of inselbergs are important microhabitats for a broad range of animals and plants (Watve, 2013; Jithin et al., 2023a). They are subject to high levels of anthropogenic disturbance, and it is known that land-use change on rock outcrops impacts the animal community living under the loose rocks (Jithin et al., 2023a; Goldsbrough et al., 2003). The percentage of animal occupancy varies across study regions. For example, while fauna were present under almost 90% of surveyed rocks in Sydney, ~45% of rocks harboured fauna in the northern Western Ghats (Jithin et al., 2023a; Goldsbrough et al., 2003). The animal community assemblage is mostly dominated by predators and opportunistic scavengers, indicating the low productivity in the habitat. These loose rocks are also home to cyanobacteria, lichens, moss cushions, ferns, and liverworts while supporting lithophytes (plants that grow on bare rock) such as orchids, bladderworts, and grasses (Watve, 2013).

2.4.2. Rock Pools

Rock pools are seasonally water-filled depressions on the rocks with a thin layer of soil. They are mainly inhabited by short-lived plants (ephemerals), which grow only during favourable moist conditions and passing the unfavourable periods as seeds. They are also home to aquatic plants, cryptogams, and a wide range of aquatic invertebrates (Krieger et al., 2003; Jocque et al., 2010). In the otherwise dry environment (soil and microclimate) of rock outcrops, rock pools provide locally

wet conditions. They can act as critical breeding habitats for animals like amphibians (Jocque et al., 2010; Jithin & Naniwadekar, 2024; Jithin et al., 2024).

2.4.3. Shallow Depressions

Shallow depressions are widespread on inselbergs which are small depressions filled with shallow substrate. They are only briefly inundated compared to the rock pools following heavy rains. Though vegetation cover is sparse, plants from the families Poaceae, Asteraceae, Balsaminaceae, Commelinaceae are common in these habitats. They are also habitats for cyanobacteria, liverworts, mosses, annuals, geophytes, and rarely for trees and shrubs (Porembski, 2007).

2.4.4. Cryptogamic Crust

A continuous layer of cryptogamic vegetation (cyanobacteria, lichens, mosses etc.) which supports other vegetation seen on rocky surfaces is known as cryptogamic crust. The greyish or brownish colours at inselbergs rocks are mostly due to cryptogams, which forms almost continuous biofilm on the exposed rocks. They are extremely tolerant to heat, high rates of solar irradiation and survive complete desiccation (Porembski, 2007). Their composition can vary across the surface on which they are growing; eg. exposed rocky slopes, boulders and drainage channels.

2.4.5. Rock Crevices and Clefts

Rock crevices on the inselbergs can be very deep and are rich in humus and soil. They are favourable microhabitats for plants that develop underground storage organs containing a perennating bud (geophytes) and perennial herbs (Porembski, 2007). Under shade conditions, ferns and mosses also occur in the crevices and clefts. Perennial species can be found in clefts, which are broader and deeper.

2.4.6. Monocotyledonous mats

Monocot plants in large clumps and their network of roots forms a mat-like appearance on flat and inclined open rocky slopes. They are attached to the rocks by dense wiry roots. This characteristic feature has been recorded in plants from

the families Bromeliaceae, Poaceae, Cyperaceae and Velloziaceae. They can be xerophytic (plant adapted to survive with little water availability), and desiccation-tolerant. *Tripogons* (Poaceae) can be seen on inselbergs and cliffs, which can be easily lifted up (Porembski, 2007; Smrithy et al. 2023).

2.4.7. Caves

Caves are naturally formed cavities associated with rock outcrops, shelter fauna such as bats, spiders, lizards, geckos and vultures, and are suitable microhabitats for shade-loving rock-dwelling plants. In general, caves are undisturbed due to inaccessibility and thus, the species occupying the caves is undisturbed (Smrithy & Datar, 2023).

2.4.8. Ephemeral Flush Vegetation

Short-lived vegetation that can be seen on the rock surfaces mainly during the rainy period are known as ephemeral vegetation. Typical plants are bladderworts (*Utricularia*) and pipeworts (*Eriocaulons*). They are dependent on the water seepage, and grow in the matrix formed by Poaceae and Cyperaceae (Porembski, 2007; Rock Outcrop India Network, 2018).

2.5. Adaptations on Inselbergs

High diversity of plants, invertebrates, amphibians and reptiles are common on outcrops, especially during the monsoon. Some of these organisms adapt to these extreme habitats to avoid desiccation in dry periods. Both plants and animals show unique adaptive strategies to survive on outcrops. Much is known about the adaptations of plants compared to animals. Inselbergs are known as 'centres of diversity' for plants that are particularly adapted for survival under its extreme environmental conditions (Porembski, 2007). Water scarcity and low nutrient availability in these habitats are leading causes, among many others such as microclimatic and edaphic dryness. This impacts the floristic composition of inselbergs, resulting in a different plant community on inselbergs compared to its surroundings. Some plant adaptations are briefly described below:

2.5.1. Desiccation tolerance

Some plants in the rock outcrop habitats have the unique ability to recover from almost complete loss of water, and thus they can survive periods of drought and recover when water is available (Tuba et al., 1998). They are called desiccation-tolerant (DT) plants or resurrection plants. Ferns such as *Selaginella*, some grasses (Cyperaceae, Poaceae etc.), Figworts, and Velloziaceae plants are known to have this unique adaptation in extreme habitats such as rock outcrops and deserts (Kulkarni et al., 2023). Rock outcrops (such as cliffs, plateaus, and inselbergs) are found to be the most important sites for Indian DT plants, and 90% of the global DT plants are known to grow on inselbergs (Smrithy et al., 2023; Porembski and Barthlott, 2000). DTs can be found as mat-formers, or in shallow depressions and seasonal rock pools (Porembski, 2007). Some of the DT *Selaginella* species are used in Indian traditional medicine, and considered a magical resurrection herb called 'Sanjeevani' (Sah et al., 2005).

2.5.2. Succulent Plants

Some plants on inselbergs have thick and fleshy parts which can retain water in plant tissues of leaves, stems, and roots, and they are known as succulent plants (Biedinger et al. 2000). *Cactus*, *Opuntia* are some examples.

2.5.3. Carnivory

Inselbergs are nutrient-poor habitats. In such conditions, certain plants are evolved to obtain nutrients like nitrogen and phosphorus through phyto- and zoo-planktons, small insects, and nematodes. They attract, ingest, and digest the prey (Givnish 1989). Plant species of Lentibulariaceae and Droseraceae are known for this adaptation.

2.5.4. Dwarfism

On inselbergs, some plants tend to be extremely short, and are termed ‘dwarfism’. Globally, species of Eriocaulaceae, Scrophulariaceae, Juncaceae, and Cyperaceae are known to show dwarfism (Kulkarni et al., 2022).

2.5.5. Other Adaptations

Presence of dual photosynthetic pathways to deal with the scarcity of water, dominance of pollination using wind (anemophily), mass flowering to simultaneously attract a large number of pollinators are some of the other adaptations plants show in these habitats (Kulkarni et al., 2022).

3. APPROACH

3.1. Scope & Objectives

Rapid visual encounter surveys were carried out across three inselbergs, and one hilly area (Table 1):

a. To rapidly assess the ecological value of the proposed rocky outcrops BHS in terms of rock-dwelling flora and fauna.
b. To suggest future research and management directions for the proposed rocky outcrops BHSs.

3.2. Methodology

Rapid visual encounter surveys were carried out at three inselbergs, and one hilly area (Table 1). The rapid survey site details are explained in the Table below:

Site	Date	Sampling Hours	Duration	Latitude	Longitude
Pretshila	2 December 2024	3	8:00 am - 11:00 am	24°50'41.84"N	84°58'7.96"E
Ramshila	2 December 2024	1.5	11:30 am - 1:00 pm	24°48'43.37"N	85° 0'42.35"E
Brahmayoni	2 December 2024	1.5	3:30 pm - 5:00 pm	24°45'55.30"N	84°58'51.34"E
Barabar hills	3 December 2024	4	10:10 am - 2:00 pm	25° 0'44.28"N	85° 3'32.19"E

Table 1. Rock outcrops visited during the surveys in Gaya forest division of Bihar.

All four sites were explored from the lowest to highest elevation, with only one walkable pathway covering the main portion of these sites. Researchers were accompanied by the Forest Department staff during the surveys. During the survey, microhabitats, flora (herbs, shrubs and woody vegetation) and fauna (focusing on rock-dwelling animals, especially herpetofauna and invertebrates) encountered on the inselbergs were recorded and photographed. These were later identified at broad taxonomic levels using expert inputs. Unidentified plant individuals were collected for identification while no animal materials were collected as part of the survey.

4. INSIGHTS

4.1. Site : Pretshila, Chiraiatanr, Bihar

Pretshila is a granite inselberg that rises abruptly above the surrounding plains. The hill-top offers a panoramic view of the Gaya city from an altitude of 280 m.a.s.l. The hill is also known as ‘Pret Giri’, and ‘Pret Parvat’. It is a sacred site, believed to be the ‘hill of ghosts’. At the hill summit, there is a temple devoted to Yama, the Hindu ‘god of death’. A ritual called ‘Pind Dan’ is performed in this temple, which signifying an offering made to release the ghost from those who died as a result of accidents, suicides or other unnatural deaths (Bihar Tourism, 2025). At the bottom of the hill, a waterbody named ‘RamKund’, where the ‘Pind Dan’ ritual takes place (CPREEC, 2025). This inselberg is around 10 km away from the Gaya town. It is an important pilgrimage site for Hindu devotees, as it is believed that Lord Rama and Lakhshmana performed their final rights to King Dasharadha. The steps from the bottom of the hill to the top, where the temple is situated are occupied by saints, believers and pilgrims. Pretshila hills have been referenced in the Hindu scriptures - *Vayu Purana* and *Garuda Purana*.

	
A long-shot of the Pretshila. Credits: CPREEC - EIACP Programme Centre, Resource Partner on Ecological Heritage and Sacred Sites of India	Ficus tree under which photos of people who died unnatural deaths.

	
Devotees at a temple on the foothills of Pretshila Hill. Credits: Prayagpandits.com	RamKund at the foothills of Pretshila Hill
	
View from the hilltop showing the bouldery nubbins and vegetation	Steps to the temple on the hilltop
	
View of the north facing lower slope of Pretshila Hill	Open savannah habitat at the top of Pretshila Hill

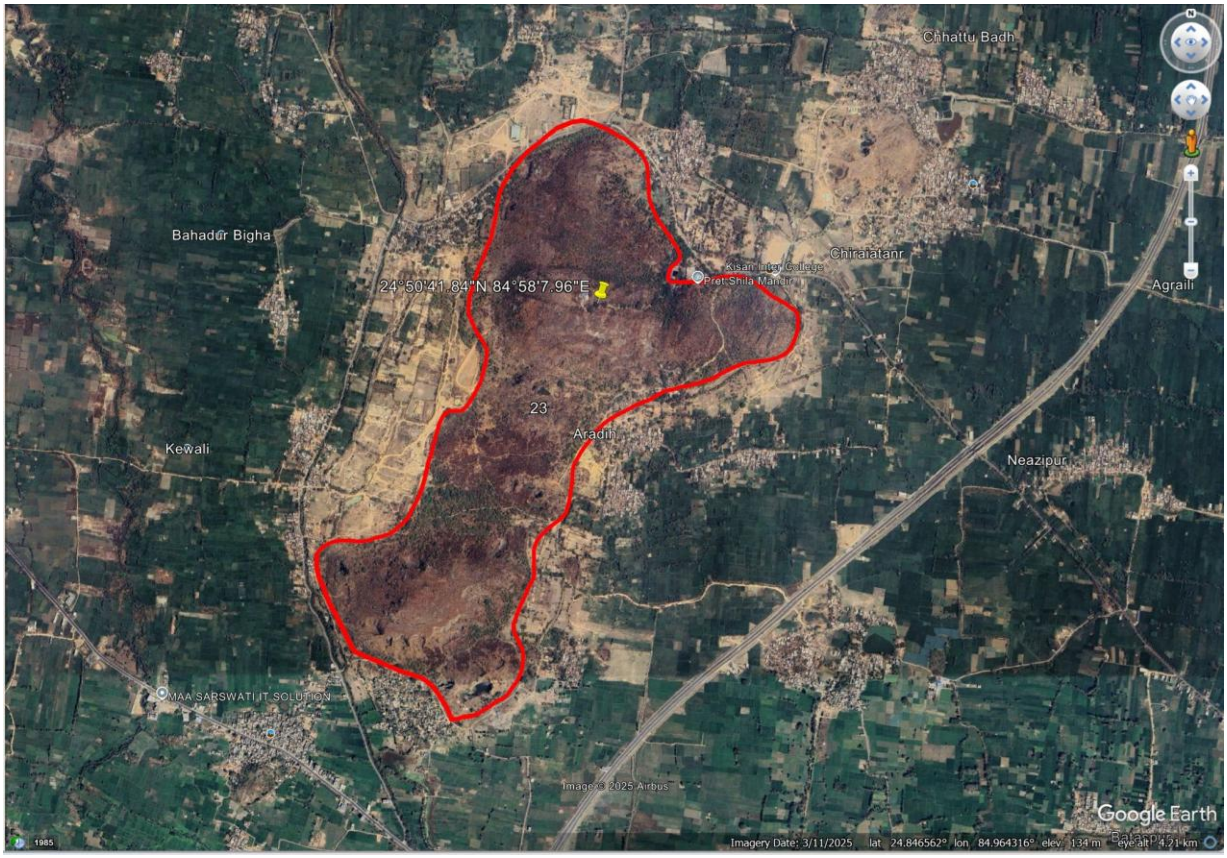


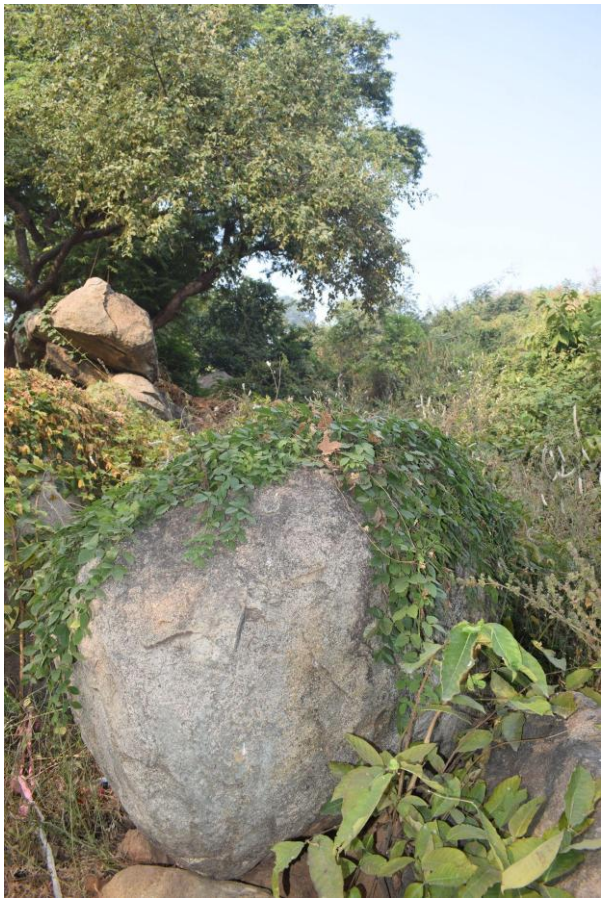
Figure 6. Map showing the Pretshila

The area is extensively utilised by pilgrims, except the nubbin regions that are behind the temple. These site descriptions match with typical rock outcrops that are featured prominently in human landscapes (Technical and Policy Core Group & Kalpavriksh, 2005). Most inselbergs in India have temples on the hill tops (eg. Shravanabelagola shrine in Karnataka) and are centres for religious, aesthetic or nature tourism. Geologically, the inselberg matches with the description of a castellated kopje, with a sloppy side. This needs further examination and verification.

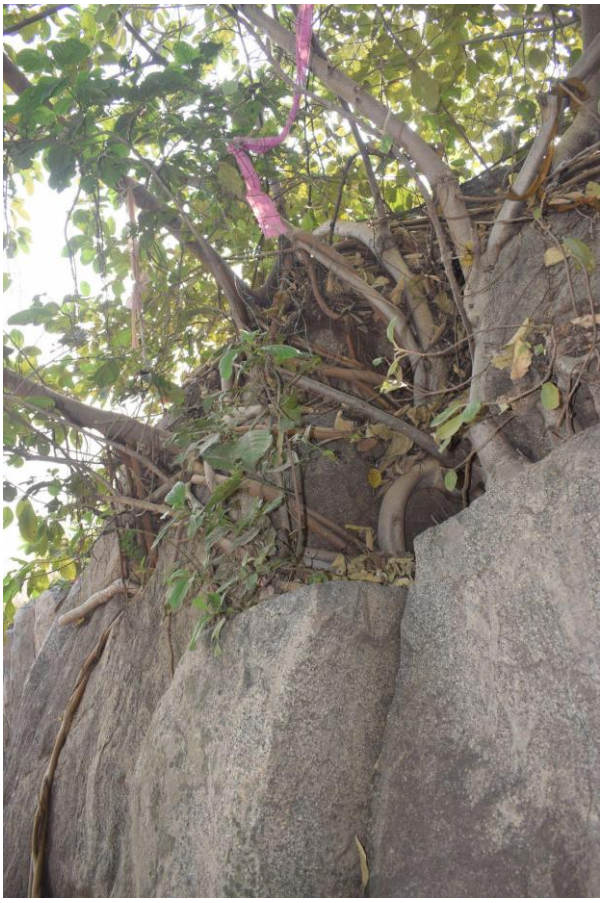
Microhabitat Survey

The details of microhabitats recorded during the rapid survey are given below. Please refer to section 2.4 on microhabitats for detailed descriptions.

	
Rock crevices with soil substrate	A large rock with cryptogamic crusts
	
Underground holes and gaps	Scattered loose rocks in a grass patch



Large boulder with climbers



Trees growing on the ledges of vertical sides of boulders

RamKund - a modified waterbody, used by aquatic animals including frogs

Modified rock microhabitats used by reptiles

Figure 7: Photographs of observed microhabitat from Pretshila inselberg

4.1.1. Biodiversity Survey

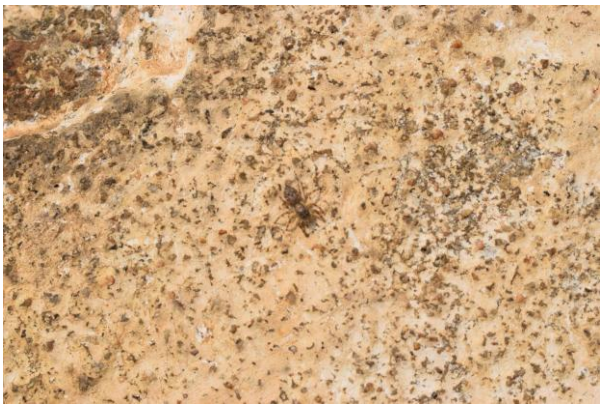
The details of biodiversity elements recorded during the rapid survey are given below. Please refer to section 2.5 for additional details. Please note that the '(?)' mark indicates the identification needs further verification, and the list is not exhaustive.

4.1.1.1. Fauna

From the Pretshila inselberg, we recorded a total of 47 animal species belonging to 23 families with 1 reptile, 1 amphibian, 41 insects, and 4 arachnids. A total of 11 orders were identified. Since the surveyed areas are highly disturbed, further exploration in other, more vegetated areas might improve this documentation. Details are given below:

	
Eutropis carinata	*Euphlyctis cyanophlyctis*
	
Pholcidae (Araneomorphae)	Darkling Beetle (*Gonocephalum* sp.?)

	
Leptocentrus taurus	*Camponotus compressus*
	
Argiope sp.	Wasp nests
	
Antlions (Neuroptera)	*Camponotus* spp. & *Trichomyrmex* ?

	
Spalgis epius	*Papilio demoleus* (larvae)
	
Menemerus sp.	Sparassidae
	
Diptera	Hemiptera (?)

	
Cnaphalocrosis sp.	Hymenoptera
	
Orthoptera (Tettigoniidae ?)	*Sphingonotus* sp.
	
Orthetrum sabina	Hesperiidae

Figure 8: Documentation of fauna from Pretshila inselbergs

Table2: List of butterflies (Insecta: Lepidoptera) from Pretshila

Common Name	Scientific Name	Family
Lime Swallowtail	*Papilio demoleus*	Papilionidae
Common Grass Yellow	*Eurema hecabe*	Pieridae
Lemon Emigrant	*Catopsilia pomona*	Pieridae
Mottled Emigrant	*Catopsilia pyranthe*	Pieridae
Common Albatross	*Appias albina*	Pieridae
Indian Wanderer	*Pareronia hippia*	Pieridae
Lesser gull	*Cepora nadina*	Pieridae
Yellow orange tip	*Ixias pyrene*	Pieridae
Psyche	*Leptosia nina*	Pieridae
Indian cabbage white	*Pieris canidia*	Pieridae
The common gull	*Cepora nerissa*	Pieridae
Lime Blue	*Chilades lajus*	Lycaenidae
Plains cupid	*Luthrodes pandava*	Lycaenidae
Common pierrot	*Castalius rosimon*	Lycaenidae
Indigo flash	*Rapala varuna*	Lycaenidae
Rice swift	*Borbo cinnara*	Hesperiidae
Smaller dartlet	*Oriens goloides*	Hesperiidae
Dark Palm Dart	*Telicota bambusae*	Hesperiidae
Common Sergeant	*Athyma perius*	Nymphalidae
Tawny coster	*Acraea terpsicore*	Nymphalidae
Common crow	*Euploea core*	Nymphalidae
Lemon pansy	*Junonia lemonias*	Nymphalidae
Plain tiger	*Danaus chrysippus*	Nymphalidae
Common castor	*Ariadne merione*	Nymphalidae
Common Leopard	*Phalanta phalantha*	Nymphalidae
Common sailer	*Neptis hylas*	Nymphalidae
Common evening brown	*Melanitis leda*	Nymphalidae

Flora

The Pretshila inselberg is mostly covered by mixed vegetation ranging from woodland savanna at the lower slopes of the hill to more grass dominated vegetation with sparsely

distributed shrubby vegetation towards the top of the hill. The ephemeral streams and ravines support a different set of species as compared to the more exposed slopes. From the surveyed area, we recorded 89 plant species belonging to 38 families comprising 21 trees, 15 shrubs, 16 climbers and 37 herbaceous species (Table 3). Out of the total, two species belong to pteridophytes. Most of the plants are weeds and exotic.

Table 3: List of recorded plants from the Pretshila inselberg

Family	Species	Habit
Angiosperms		
Acanthaceae	*Andrographis longipedunculata*	Herb
	Blepharis maderaspatensis	Herb
	Dicliptera paniculata	Herb
	Eranthemum pulchellum	Herb
	Justicia procumbens	Herb
	Peristrophe paniculata	Herb
Amaranthaceae	*Achyranthes aspera*	Herb
	Alternanthera sessilis	Herb
	Celosia argentea	Herb
	Gomphrena globosa	Herb
Anacardiaceae	*Lannea coromandelica*	Tree
Apocynaceae	*Carissa spinarum*	Shrub
	Gymnema sylvestre	Woody climber
	Hemidesmus indicus	Climber
	Holarrhaena pubescens	Tree
	Gongronemopsis tenacissima	Climber
	Wrightia tinctoria	Tree
Arecaceae	*Borassus flabellifer*	Tree
	Phoenix sylvestris	Tree
Asteraceae	*Chromolaena odorata*	Shrub
	Tridax procumbens	Herb
Brassicaceae	*Brassica juncea*	Herb
Boraginaceae	*Ehretia laevis*	Tree
Burseraceae	*Boswellia serrata*	Tree
Capparaceae	*Capparis sepiaria*	Shrub
	Capparis zeylanica	Shrub
Celastraceae	*Gymnosporia montana*	Tree
Cleomaceae	*Cleome viscosa*	Herb
Combretaceae	*Combretum roxburghii*	Woody climber
	Terminalia arjuna	Tree
Convolvulaceae	*Distimake aegyptius*	Climber
	Rivea hypocrateriformis	Woody climber
Cucurbitaceae	*Diplocyclos palmatus*	Climber
	Luffa acutangula	Climber

Family	Species	Habit
Cyperaceae	*Bulbostylis barbata*	Herb
	Cyperus amabilis	Herb
	Cyperus sp.	Herb
Ebenaceae	*Diospyros cordifolia*	Tree
Euphorbiaceae	*Euphorbia hirta*	Herb
Fabaceae	*Abrus precatorius*	Climber
	Abrus pulchellus	Climber
	Albizia odoratissima	Tree
	Bauhinia racemosa	Tree
	Butea monosperma	Tree
	Cajanus scarabaeoides	Herb
	Cassia fistula	Tree
	Mimosa rubicaulis	Shrub
	Pleurolobus gangeticus	Herb
	Rhynchosia sp.	Climber
	Senegalia sp.	Woody climber
Hypoxidaceae	*Curculigo orchioides*	Herb
Lamiaceae	*Anisomeles indica*	Herb
	Mesosphaerum suaveolens	Herb
	Leonotis nepetifolia	Subshrub
Lauraceae	*Cassytha filiformis*	Twinning herb
Malvaceae	*Bombyx sp.*	Tree
	Grewia hirsuta	Shrub
	Helicteres isora	Shrub
	Sida cordifolia	Herb
	Sterculia urens	Tree
Menispermaceae	*Cocculus villosus*	Twinning shrub
Moraceae	*Ficus mollis*	Tree
	Streblus asper	Tree
Passifloraceae	*Passiflora foetida*	Climber
Phyllanthaceae	*Breynia vitis-idaea*	Shrub
	Bridelia montana	Shrub
	Flueggea virosa	Shrub
Poaceae	*Apluda mutica*	Herb
	Aristida sp.	Herb
	Cenchrus pedicellatus	Herb

Family	Species	Habit
	Chrysopogon fulvus	Herb
	Dactylotenium aegyptianum	Herb
	Digitaria sp.	Herb
	Eragrostiella sp.	Herb
	Eragrostis sp.	Herb
	Heteropogon contortus	Herb
	Oplismenus burmanii	Herb
	Oropetium thomaeum	Herb
Rhamnaceae	*Ziziphus oenopolia*	Shrub
Rubiaceae	*Mitragyna parviflora*	Tree
Rutaceae	*Aegle marmelos*	Tree
	Murraya exotica	Shrub
Salicacea	*Casearia tomentosa*	Shrub
	Flacourtia ramontchi	Tree
Sapindaceae	*Cardiospermum halicacabum*	Climber
Ulmaceae	*Holoptelea integrifolia*	Tree
Verbenaceae	*Lantana camara*	Shrub
Vitaceae	*Causonis trifolia*	Climber
Pteridophytes		
Pteridaceae	*Hemionitis tenuifolia*	Herb
Schizaeaceae	*Lygodium flexuosum*	Climbing herb

Note: A diverse array of natural and modified microhabitats of cracks and holes are present here. The relatively less number of invertebrates (spiders, grasshoppers etc.) might be an indication of the high disturbance in the area.

It is important to note that species identification from photographs are preliminary in nature. ***Further detailed field studies during monsoon are essential to confirm some of these observations, and it is possible that there are more interesting animals and plants, especially geckos, and other ephemeral plants, which needs further exploration across seasons and time*** *(eg. Night time surveys are required*

for more detection of herpetofaunal species including amphibians, agamids and skinks; wet-season surveys are required for ephemeral vegetation).

4.2. Site : Ramshila Hill, Gaya, Bihar

Ramshila hill is situated on the south-east side of Gaya city. It is a sacred place for Hindu devotees as it is believed that Lord Rama had offered ‘pinda’ (offering for the departed souls) on the hill. A temple is situated at the hill summit, known as Ramesvara or Patalesvara temple, which is believed to have been built in 1014 A.D. Devotees offer ‘Pindas’ here, during the *pitrapaksh* (a time dedicated to ancestors followed in the Hindu calendar). There is also a pavilion before the main temple (District Administration- Gaya, 2025; CPREEC, 2025). The hillock is mostly covered by thickets and shrubby vegetation, except a few places where exposed rock boulders can be seen. Human habitations are present, of which some are even built on the rocky slopes of the hill. A few built structures, old temple remnants and stairs to the old and main temple, and the temple complex at the hill bottom are the main human modifications here. It is situated near the banks of Falgu river.

	
View of Falgu river from the hills, showing human habitations in the hill-sides and rocky areas.	View of the nearby town and plains of Falgu river from the hills

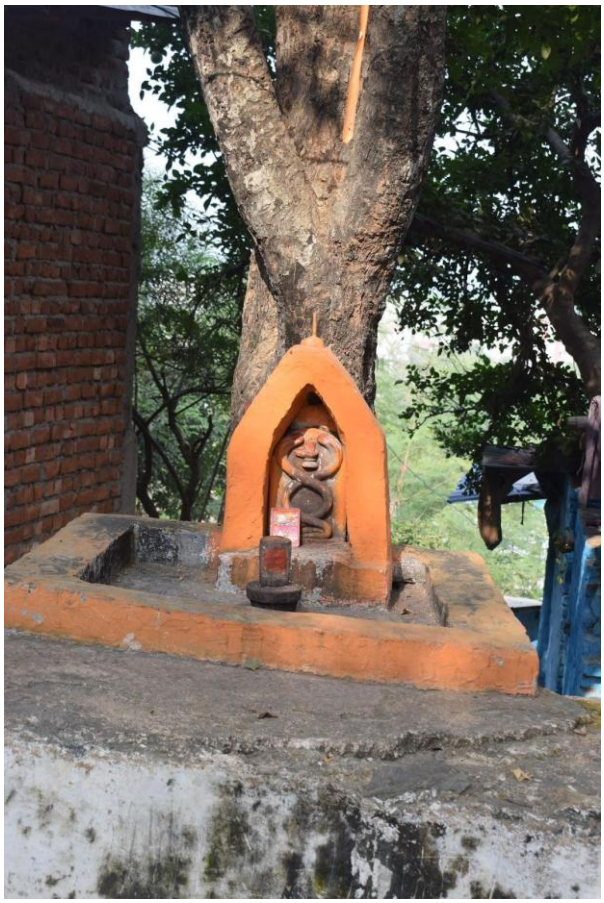
	
The Ramesvara temple on top of the Ramshila Hills	Vegetation on the summit of the Ramshila Hills
	
Stairs leading to the temple	Idol worshiping on the way to the main temple

Figure 9. Map showing the Ramshila area.

4.2.1. Microhabitat Survey

The details of microhabitats recorded during the rapid survey are given below. Please refer to section 2.4 on microhabitats for detailed descriptions.

	
Holes on the built structures, used by geckos	Exposed rocky areas at the hill-bottom
	
Burrows under rocks, covered with moss	Rock sheet structures with crevices

	
Exposed bare rocks at hill-top invaded by *Mesosphaerum suaveolens*	Lithophytes growing on built structures

Figure 10: Documentation of microhabitats observed in Ramshila inselberg

4.1.2. Biodiversity Survey

The details of biodiversity elements recorded during the rapid survey are given below. Please refer to section 2.5 for additional details. Please note that the '(?)' mark indicates the identification needs further verification, and the list is not exhaustive.

4.2.1.1. Fauna

From the Ramshila inselberg, we recorded a total of 14 animal species belonging to 7 families with 2 reptiles, 11 insects, and 1 mammal. A total of 5 orders are documented during the short visit. Details are given below:

	
Diabolocatantops innotabilis	*Hemidactylus flaviviridis*
	
Calotes versicolor	*Leptoglossus* sp. ?

	
Prismatocerus prominulus	*Rhinopoma* sp. (Mouse-tailed bat)

Figure 11: Documentation of fauna from Ramshila inselberg

Table 4: List of butterflies (Insecta: Lepidoptera) from Ramshila

Common Name	Scientific Name	Family
Common Grass Yellow	*Eurema hecabe*	Pieridae
Lemon Emigrant	*Catopsilia pomona*	Pieridae
Mottled Emigrant	*Catopsilia pyranthe*	Pieridae
Common Albatross	*Appias albina*	Pieridae
Indian Wanderer	*Pareronia hippia*	Pieridae
Yellow orange tip	*Ixias pyrene*	Pieridae
The common gull	*Cepora nerissa*	Pieridae
Common evening brown	*Melanitis leda*	Nymphalidae

4.2.1.2. Flora

Ramshila inselberg covers a mixed vegetation comprising herbaceous species to woody trees. Total 72 plant species belonging to 34 families comprising 25 trees, 14 shrubs, 14 climbers and 19 herbaceous species were recorded (Table 5). The post monsoon vegetation has been replaced with invasive species.

Table 5: List of Flora (Pteridophytes and Angiosperms) from Ramshila

Family	Species	Habit
Acanthaceae	*Andrographis longipeduculata*	Herb
	Blepharis maderaspatensis	Herb
	Dicliptera paniculata	Herb
Amaranthaceae	*Achyranthes aspera*	Herb
	Alternanthera sessilis	herb
	Gomphrena globosa	Herb
Anacardiaceae	*Lannea coromandelica*	Tree
Apocynaceae	*Carissa spinarum*	Climber
	Gymnema sylvestre	Woody climber
	Hemidesmus indicus	Climber
	Holarrhaena pubescens	Tree
	Wrightia tinctoria	Tree
Arecaceae	*Phoenix sylvestris*	Tree
Asteraceae	*Chromolaena odorata*	Shrub
	Tridax procumbens	Herb
Boraginaceae	*Ehretia laevis*	Tree
Fabacaea	*Bauhinia racemosa*	Tree
	Cassia fistula	Tree
Capparaceae	*Capparis sepiaria*	Shrub
	Capparis zeylanica	Shrub
Cleomaceae	*Cleome viscosa*	Herb
Celastraceae	*Gymnosporia montana*	Tree
Combretaceae	*Combretum roxburghii*	Woody climber
Convolvulaceae	*Merremia tridentata*	Herb
	Revia hypocrateriformis	Climbing shrub
Cucurbitaceae	*Coccinea grandis*	Climber
	Diplocyclos palmatus	Climber
	Luffa acutangula	Climber
Cyperaceae	*Bulbostylis barbata*	Herb
	Cyperus amabilis?	Herb
Ebenaceae	*Diospyros cordifolia*	Tree
Fabaceae	*Abrus pulchellus*	Climber
	Albizzia lebbeck	Tree
	Albizia odoratissima	Tree
	Butea monosperma	Tree
	Pleurolobus gangeticus	Herb
	Mimosa rubicaulis	Shrub
	Mucuna monosperma	Woody climber
	Rhynchosia sp.	Climber

Family	Species	Habit
	Senegalia sp.	Tree
Lamiaceae	*Leonotis nepetifolia*	Subshrub
	Mesosphaerum suaveolens	Herb
	Premna latifolia	Tree
Malvaceae	*Bombyx* sp.	Tree
	Grewia hirsuta	Tree
	Helicteres isora	Shrub
	Sida cordifolia	Herb
	Sterculia urens	Tree
Menispermaceae	*Cocculus villosus*	Twinning shrub
Moraceae	*Ficus mollis*	Tree
	Streblus asper	Tree
Oleaceae	*Nyctanthes arbor-tristis*	Tree
Passifloraceae	*Passiflora foetida*	Climber
Phyllanthaceae	*Breynia vitis-idaea*	Shrub
	Bridelia montana	Shrub
	Fluggea virosa	Shrub
Rhamnaceae	*Ziziphus oenopolia*	Shrub
	Ziziphus xylopyrus	Shrub
Rubiaceae	*Gardenia latifolia*	Shrub
	Mitragyna parviflora	Tree
Rutaceae	*Aegle marmelos*	Tree
Poaceae	*Cenchrus pedicellatus*	Herb
	Heteropogon contortus	Herb
	Oplismenus burmanii	Herb
	Oropetium thomaeum	Herb
Salicaceae	*Casearia tomentosa*	Tree
	Flacourtia ramontchii	Tree
Sapindaceae	*Cardiospermum halicacabum*	Climbing herb
Scrophulariaceae	*Lindenbergia* sp.	Herb
Ulmaceae	*Holoptelea integrifolia*	Tree
Verbenaceae	*Lantana camara*	Shrub
Vitaceae	*Causonis trifolia*	Climber

4.3. Site : Brahmayoni Hill, Maranpur, Gaya, Bihar

Brahmayoni hill is situated to the south of Gaya city is named after a natural fissure on the hill top. It is believed that this fissure represents the female energy or ‘yoni’ of the God Brahma (CPREEC, 2025). The hill is a large expanse of smaller hillocks, rocky areas, waterfalls, streams, and other wetlands. The hill is home to two caves, and a temple. It is believed that this temple was constructed by a Maratha-chieftain, Rao Bhau Saheb, in the bygone era (CPREEC, 2025). This area is also a sacred place for the Hindus, where they conduct offerings to departed souls during the *pitrapaksha* time.

	
View from the hill summit showing dense vegetation	Small waterbody at the hill bottom, fed by a waterfall
	
A water storage area, modified by the Forest department, also acts as a marshy area	The water storage area with scattered rocks

Figure 12: Field photographs from the landscapes of Brahmayoni hills

Figure 13. Map showing the Brahmayoni.

4.3.1. Microhabitat Survey

The details of microhabitats recorded during the rapid survey are given below. Please refer to section 2.4 on microhabitats for detailed descriptions.

	
Small man-made well used by Euphlyctis frogs.	*Selaginella bryopteris* growing on the rocky patches near the stream
	
Crevices on the vertical rocks	Weathered rocks and gravelly soil

Figure 13: Documentation of microhabitats from Brahmayoni hills

4.1.3. Biodiversity Survey

The details of biodiversity elements recorded during the rapid survey are given below. Please refer to section 2.5 for additional details. Please note that the '(?)' mark indicates the identification needs further verification, and the list is not exhaustive.

4.3.1.1. Fauna

From the Brahmayoni hills, we recorded a total of 14 animal species belonging to more than 9 families with 1 amphibian, and 13 insects. A total of 6 orders were documented during the short visit. Details are given below:

	
Euphlyctis cyanophlyctis	*Paragomphus lineatus*
	
Orthoptera	*Scopula* sp.
	

Mantis cocoon	Orthoptera
	
Orthoptera	*Crocothemis servilia*
	
Chiasmia cf. *hebesata*	Orthoptera
	
Pentatomidae ?	*Castalius rosimon*

	
Ixias marianne	*Ceriagrion coromandelianum*

Figure 14: Documentation of fauna from Brahmayoni hills

4.3.1.2. Flora

Brahmayoni hills largely cover shrubby vegetation which are highly invasive species. Total 72 plant species belonging to 34 families comprising 9 trees, 9 shrubs, 3 climbers and 22 herbaceous species were recorded (Table 5).

Table 6: List of vascular plants (Pterydophytes and Angiosperms) from Brahmayoni hills

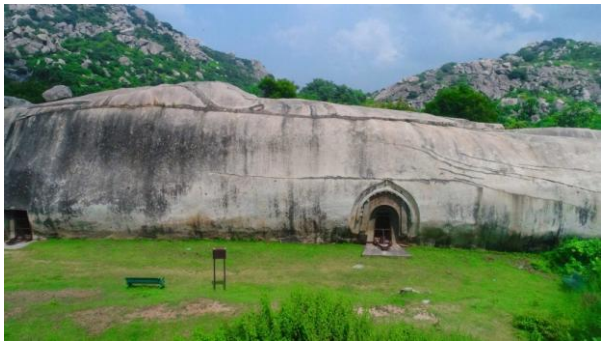
Family	Species	Habit
Angiosperms		
Acanthaceae	*Barleria cristata*	Herb
	Blepharis maderaspatensis	Herb
	Dicliptera paniculata	Herb
	Justicia sp.	Herb
Amaranthaceae	*Alternanthera sessilis*	Herb
	Celosia argentea	Herb
Apocynaceae	*Hemidesmus indicus*	Climber
Arecaceae	*Phoenix sylvestris*	Tree
Asteraceae	*Blumea* sp.	Herb
	Chromolaena odorata	Shrub
	Tridax procumbens	Herb
Bignoniaceae	*Fernandoa adenophylla*	Tree
Boraginaceae	*Coldenia procumbens*	Herb
Celastraceae	*Gymnosporia montana*	Tree
Combretaceae	*Terminalia arjuna*	Tree
Convolvulaceae	*Ipomoea quamoclit*	Climber
Cyperaceae	*Cyperus difformis*	Herb
	Schoenoplectiella praelongata	Herb
Fabaceae	*Albizzia lebbeck*	Tree
	Pterocarpus marsupium	Tree
	Senegalia catechu	Tree
	Vachellia leucophloea	Tree
Hydrocharitaceae	*Ottelia alismoides*	Herb
Lamiaceae	*Mesosphaerum suaveolens*	Shrub
Malvaceae	*Urena lobata*	Herb
	Waltheria indica	Shrub
Olacaceae	*Olax scandens*	Climbing shrub
Onagraceae	*Ludwigia perennis*	Herb
Phyllanthaceae	*Bridelia montana*	Shrub
Plantaginaceae	*Limnophila indica*	Herb

Family	Species	Habit
Poaceae	*Cenchrus pedicellatus*	Herb
	Heteropogon contortus	Herb
	Oplismenus burmanii	Herb
Rhamnaceae	*Ziziphus oenopolia*	Shrub
Rubiaceae	*Canthium coromandelicum*	Shrub
	Mitracarpus hispidus	Herb
	Pavetta tomentosa	Shrub
Rutaceae	*Murraya exotica*	Shrub
Sapotaceae	*Madhuca longifolia* var. *latifolia*	Tree
Verbenaceae	*Lantana camara*	Shrub
Pteridophytes		
Marsileaceae	*Marsilea* sp.	Herb
Pteridaceae	*Hemionitis tenuifolia*	Herb
Selaginellaceae	*Selaginella bryopteris*	Herb

4.4. Site : Barabar Hills, Makhdumpur, Jehanabad, Bihar

Barabar hills is a renowned place in Bihar, with archeological, and biological wealth. The ancient rock-cut Buddhist chambers known as 'Barabar Caves' are situated at the foothills of these hills. They are one of the oldest rock-cut caves in India, dating from the Maurya Empire (322–185 BCE), with the Ashokan inscriptions. Considering its cultural and geological history, it has been included in the prospects for geoheritage and geotourism (Sharma et al., 2024). The caves are a popular ecotourism destination, and part of the tourist circuits, and also a protected monument of national importance (Patro et al., 2024). There are adventure eco-camps on the hills by private groups who offer activities such as mountaineering, trekking, nature walks, rock climbing etc. (Ministry of Tourism, GoI, 2025). There has also been a study to assess the ecotourism potential and its socio-economic impacts at Barabar and Nagarjuni hills caves sites (Kumar & Kumar, 2009).

At the highest peak of the hill range, the Baba Siddhnath temple (Siddheshwar Nath Temple) is situated, which was built during the Gupta period in the 7th Century A.D. It is famous because of the annual festival in which thousands of people participate. Regions of the main pathways are therefore occasionally polluted with plastic wastes, due to pilgrim tourism.

	
The Baba Siddhnath temple on the summit of the Barabar hills. Credits: District Administration, Jehanabad	The Barabar Caves in the backdrop of rocky nubbins of the hills. Credits: District Administration, Jehanabad

	
Entrance to the Baba Siddhnath temple	Views of the hill range from the Baba Siddhnath temple
	
A wetland at the bottom of the hill, a typical natural depression that collects the run-off water from the inselbergs	Another wetland nearby and a bouldery nubbin in the backdrop, part of the hill range, opposite to the Barabar caves

Figure 15: Field photographs from the landscapes of Barabar hills

<Map need to be added>
Figure 16. Map showing the Barabar hills, demarcating the Barabar caves.

4.4.1. Microhabitat Survey

The details of microhabitats recorded during the rapid survey are given below. Please refer to section 2.4 on microhabitats for detailed descriptions.

	
Loose flat rocks	Underground holes with rock cover
	
Monocotyledonous mats	Large rock crevices
	
Large boulders and rock-dwelling flora	*Selaginella* mats on rock surface

Rock pool

Burrow in soil filled areas with *Selaginella* growth

Soil filled depressions among rocks with *Selaginella* and shrubs.

Cracks and crevices in vertical rocks

Figure 16: Documentation of microhabitats from Barabar hills

4.1.4. Biodiversity Survey

The details of biodiversity elements recorded during the rapid survey are given below. Please refer to section 2.5 for additional details. Please note that the '(?)' mark indicates the identification needs further verification, and the list is not exhaustive.

4.4.1.1. Fauna

From the Brahmayoni hills, we recorded a total of 83 animal species belonging to more than 24 families with 5 reptiles, 75 insects, and 3 arachnids. We documented 9 orders during the short visit. The habitat is very suitable for rock-dwelling animals such as agamids, geckos, skinks, and many insects. Orthoptera (grasshoppers and allied insects) and butterfly diversity is remarkable in this site. Details are given below:

	
Sitana cf. *sivalensis*	*Calotes versicolor*
	
Hemidactylus flaviviridis	*Hemidactylus* cf. *kushmorensis*

	
Eutropis carinata	Orthoptera
	
Chrotogonus trachypterus	Orthoptera
	
Orthoptera	Orthoptera

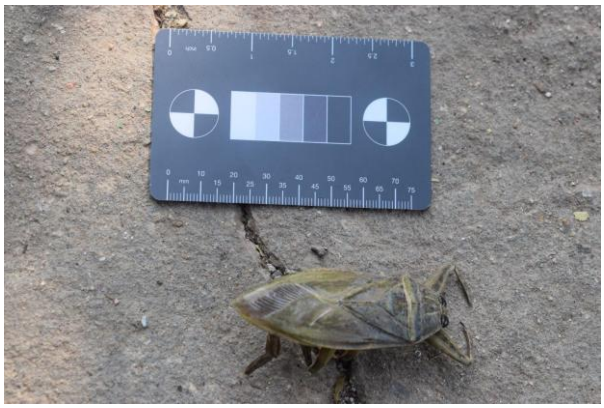
	
Orthoptera	Orthoptera
	
Acrida sp. ?	Orthoptera
	
Orthoptera	Orthoptera

	
Tettigoniidae	Diptera
	
Lycaenidae	*Nephila pilipes*
	
Argiope aemula	Lycosidae

	
Acraea terpsicore	Polyommatinae
	
Castalius rosimon	*Symphaedra nais*
	
Cepora nerissa	*Amblypodia anita*

	
Myllocerus sp.?	*Gryllodes* sp.?
	
Sphecidae ?	*Rhynocoris* sp. ?
	
Polyura cf. *arja*	*Cigaritis vulcanus*

	
Leptodialepis sp. ?	*Rhynocoris* sp. ?
	
Junonia hierta	Taractrocerini *?*
	
Darkling Beetle (*Gonocephalum* sp.?)	*Camponotus compressus*



Lethocerus sp.

Apis dorsata & *Apis cf. mellifera*

Diplacodes trivialis

Bradinopyga geminata

Figure 17: Documentation of fauna from Barabar hills

Table 7: List of butterflies (Insecta: Lepidoptera) from Barabar Hills

Common Name	Scientific Name	Family
Rice swift	*Borbo cinnara*	Hesperiidae
Leaf Blue	*Amblypodia anita*	Lycaenidae
Common pierrot	*Castalius rosimon*	Lycaenidae
Plains cupid	*Luthrodes pandava*	Lycaenidae
Zebra blue	*Leptotes plinius*	Lycaenidae
Slate Flash	*Rapala manea*	Lycaenidae
Common Flash	*Rapala nissa*	Lycaenidae

Common Name	Scientific Name	Family
Indigo flash	*Rapala varuna*	Lycaenidae
Apefly	*Spalgis epius*	Lycaenidae
Common Silverline	*Cigaritis vulcanus*	Lycaenidae
Tawny coster	*Acraea terpsicore*	Nymphalidae
Angled castor	*Ariadne ariadne*	Nymphalidae
Common castor	*Ariadne merione*	Nymphalidae
Pallid nawab	*Polyura arja*	Nymphalidae
Plain tiger	*Danaus chrysippus*	Nymphalidae
Striped tiger	*Danaus genutia*	Nymphalidae
Common crow	*Euploea core*	Nymphalidae
Great eggfly	*Hypolimnas bolina*	Nymphalidae
Peacock pansy	*Junonia almana*	Nymphalidae
Grey pansy	*Junonia atlites*	Nymphalidae
Yellow pansy	*Junonia hierta*	Nymphalidae
Lemon pansy	*Junonia lemonias*	Nymphalidae
Blue pansy	*Junonia orithya*	Nymphalidae
Common evening brown	*Melanitis leda*	Nymphalidae
Commander	*Moduza procris*	Nymphalidae
Common sailer	*Neptis hylas*	Nymphalidae
Common glider	*Neptis sappho*	Nymphalidae
Sullied sailer	*Neptis soma*	Nymphalidae
Glassy tiger	*Parantica aglea*	Nymphalidae
Baronet	*Symphaedra nais*	Nymphalidae
Blue tiger	*Tirumala limniace*	Nymphalidae
Painted lady	*Vanessa cardui*	Nymphalidae
Common jay	*Graphium doson*	Papilionidae
Common rose	*Pachliopta aristolochiae*	Papilionidae
Common Mormon	*Papilio polytes*	Papilionidae
Lime Swallowtail	*Papilio demoleus*	Papilionidae
Common Albatross	*Appias albina*	Pieridae
Lemon Emigrant	Catopsilia pomona	Pieridae
Mottled Emigrant	Catopsilia pyranthe	Pieridae

Common Name	Scientific Name	Family
Lesser gull	Cepora nadina	Pieridae
The common gull	Cepora nerissa	Pieridae
Common Jezebel	Delias eucharis	Pieridae
Small grass yellow	Eurema brigitta	Pieridae
Common Grass Yellow	Eurema hecabe	Pieridae
Great Orange-tip	Hebomoia glaucippe	Pieridae
Yellow orange tip	Ixias pyrene	Pieridae
Psyche	Leptosia nina	Pieridae
Indian Wanderer	Pareronia hippia	Pieridae
Indian cabbage white	Pieris canidia	Pieridae

4.4.1.2. Flora

Total 103 plant species was recorded, comprising 34 herbaceous, 29 shrubs and 25 trees. Herbaceous vegetation and grasses are most common in Barabar hills. These are xerophytes that thrive in crevices and cracks of the rocks. Typical examples of outcrop herbaceous plants include *Merremia tridentata, Phyllanthus maderaspatensis, Anisochilus carnosus, Vicoa indica*, and *Paramollugo nudicaulis*. The exposed granitic rocks are partially covered by cryptogamic crusts (lichens) and soil-filled depressions or pockets that support resurrection species such as *Selaginella bryopteris, Oropetium thomaeum, Eragrostiella* sp., and various mosses, which form mat communities in flat depressions. These *Selaginella* species occasionally grow on boulders, coexisting with mosses. During drier periods, however, invasive species like *Mesosphaerum suaveolens* often colonize these areas, restricting the growth of native xerophytic plants. Runoff soil and weathered soil create gravelly patches, occupied by opportunistic species from families such as Asteraceae (*Vernonia* sp., *Emilia sonchifolia, Tridax procumbens, Xanthium strumarium*), Lamiaceae (*Coleus strobilifer, Leucas* spp.), and Acanthaceae (*Lepidagathis* sp., *Peristrophe paniculata, Blepharis maderaspatensis, Justicia* sp.).
Barabar Hills, characterized by typical nubbins, feature soil-filled areas between large boulders. These regions are colonized by shrubs, thickets, climbers, and thorny plants.

Many of the species found on gravelly patches also thrive in these soil-filled zones, showcasing the diverse plant communities adapted to the challenging terrain.

Table 8: List of Flora (Pteridophytes and Angiosperms) from Ramshila

Family	Species	Habit
Angiopserms		
Acanthaceae	*Andrographis longipedunculata*	Herb
	Blepharis maderaspatensis	Herb
	Eranthemum pulchellum	Herb
	Justicia procumbens	Herb
	Lepidagathis cristata/hamiltoniana	Herb
	Peristrophe paniculata	Herb
	Petalidium barlerioides	Shrub
Amaranthaceae	*Celosia argentea*	Herb
Apocynaceae	*Carissa spinarum*	Shrub
	Gymnema sylvestre	Woody climber
	Hemidesmus indicus	Climber
	Holarrhaena pubescens	Tree
	Ichnocarpus frutescens	Climber
Asteraceae	*Emilia sonchifolia*	Herb
	Tridax procumbens	Herb
	Vernonia sp.	Herb
	Vicoa indica	Herb
	Xanthium strumarium	Herb
Brassicaceae	*Breynia vitis-idaea*	Shrub
	Bridelia hamiltonii	Shrub
Boraginaceae	*Ehretia laevis*	Tree
	Heliotropium indicum	Herb
Burseraceae	*Boswellia serrata*	Tree
	Garuga pinnata	Tree
Cactaceae	*Opuntia elatior*	Succulent shrub
Capparaceae	*Capparis sepiaria*	Shrub
	Capparis zeylanica	Shrub
	Crataeva adansonii	Tree
Caryophyllaceae	*Polycarpea corymbosa*	Herb
Celastraceae	*Celastrus paniculata*	Woody climber
	Gymnosporia montana	Tree
	Reissantia indica	Woody climber

Family	Species	Habit
Combretaceae	*Combretum roxburghii*	Woody climber
Convolvulaceae	*Aniseia martinicensis*	Climbing herb
	Erycibe paniculata	Woody climber
	Evolvulus alsinoides	Herb
	Ipomoea hederifolia	Climber
	Ipomoea obscura	Climber
	Merremia tridentata	Herb
	Porana paniculata	Climbing shrub
	Revia hypocrateriformis	Climbing shrub
Cyperaceae	*Bulbostylis barbata*	Herb
	Cyperus amabilis?	Herb
Ebenaceae	*Diospyros cordifolia*	Tree
Euphorbiaceae	*Euphorbia hirta*	Herb
	Euphorbia caducifolia	Succulent shrub
	Mallotus repandus	Climbing shrub
Fabaceae	*Abrus precatorius*	Climbing shrub
	Acacia catechu	Tree
	Acacia sp.	Shrub
	Albizia odoratissima	Tree
	Bauhinia vahlii	Climbing shrub
	Dalbergia lanceolaria	Tree
	Indigofera linifolia	Creeper
	Mucuna pruriens	Climber
	Senegalia torta	Shrub
	Senna sophera	Shrub
Lamiaceae	*Anisochilus carnosus*	Herb
	Mesosphaerum suaveolens	Subshrub
	Leonotis nepetifolia	Subshrub
	Leucas biflora?	Herb
	Premna latifolia	Tree
Loganiaceae	*Strychnos potatorum*	Tree
Malvaceae	*Helicteres isora*	Shrub
	Bombyx sp.	Tree
	Grewia hirsuta	Shrub
	Grewia serrulata	Tree
	Hibiscus sp.	Herb
	Sida cordata	Herb
	Sterculia urens	Tree
Menispermaceae	*Tinospora cordifolia*	Climbing shrub
Molluginaceae	*Paramollugo nudicaulis*	Herb

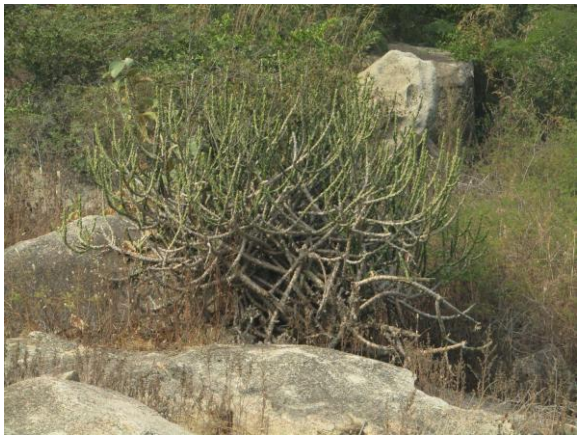
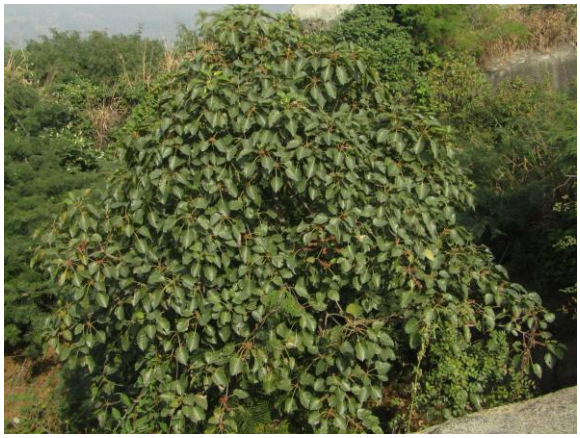
Family	Species	Habit
Moraceae	*Ficus arnottiana*	Tree
	Ficus microcarpa	Tree
	Ficus mollis	Tree
	Streblus asper	Tree
Olaceae	*Olax scandens*	Woody climber
Oleaceae	*Jasminum* sp.	Shrub
	Jasminum arborescens	Climbing shrub
Onagraceae	*Ludwigia adscandens*	Aquatic herb
Pedaliaceae	*Sesamum indicum*	Herb
Phyllanthaceae	*Fluggea virosa*	Shrub
	Phyllanthus maderaspatensis	Herb
Poaceae	*Cenchrus pedicellatus*	Herb
	Chrysopogon fulvus	Herb
	Eragrostiella	Herb
	Heteropogon contortus	Herb
	Oplismenus burmanii	Herb
	Oropetium thomaeum	Herb
Rhamnaceae	*Ventilago* sp.	Woody climber
	Ziziphus oenopolia	Shrub
	Ziziphus xylopyrus	Shrub
Rubiaceae	*Ixora pavetta*	Tree
	Pavetta tomentosa?	Shrub
Rutaceae	*Aegle marmelos*	Tree
	Murraya exotica	Shrub
Salicaceae	*Casearia tomentosa*	Tree
	Flacourtia ramontchii	Tree
Sapindaceae	*Cardiospermum helicacabum*	Climbing herb
Verbenaceae	*Gmelina arborea*	Tree
Pteridophytes		
Pteridaceae	*Hemionitis tenuifolia*	Herb
Selaginellaceae	*Selaginella bryopteris*	Herb

Figure 18:Photographs representing the flora across the surveyed four sites

	
Cassytha filiformis	*Abrus precatorius*
	
Distimake aegyptius	*Diplocyclos palmatus*
	
Adiantum philippense	*Hemionitis tenuifolia*

	
Mesosphaerum suaveolens	*Sesamum indicum*
	
Coccinea grandis	*Leonotis nepetifolia*

	
Acacia catechu (?)	*Cardiospermum halicacabum*
	
Helicteres isora	*Achyranthes aspera*

	
Hibiscus sp.	*Lindenbergia* sp. (?)
	
Euphorbia caducifolia	*Combretum roxburghii*
	
Ficus sp.	*Porana paniculata*

	
Ehretia laevis	*Ipomoea hederifolia*
	
Andrographis longipedunculata	Boswellia serrata
	
Olax scandens	*Ipomoea obscura*

	
Merremia tridentata	*Luffa acutangula*
	
Paramollugo nudicaulis	*Selaginella bryopteris*

4. DISCUSSION

The rapid surveys show that the explored inselbergs are of great biological, geological and hydrological significance, especially in light of the increasing anthropogenic disturbance and habitat modification. Though much of the seasonal biodiversity has not been documented due to the limited scope of this short-duration assessment in the dry season, a further exploration in the wet-season is highly recommended to reveal the ecological value of these least studied rock outcrops. The preliminary observations that are made in this report will be useful for ecologists and conservation practitioners alike, as these record some of the first documented biodiversity observations of Bihar rock outcrops, which were so far neglected. Bihar is home to some of the very interesting rock outcrops that are of conservation values including the Mandar Hills, Inselberg near the Durgavati Reservoir (Fig. 19), and small inselbergs embedded in the agricultural-human settlement matrix. They can act as patches that support unique biodiversity in the already heavily modified landscape, providing necessary ecosystem services to neighbouring regions, with cultural, touristic and aesthetic values.

Figure 19. Inselberg near the Durgavati Reservoir (Karamchat Dam), Kaimur, Bihar. Photograph by Binay Babu, CC BY-SA 4.0, via Wikimedia Commons.

Considering the high tourism potential (Hindusthan Team, 2019), cultural and archeological values of these poorly known habitats, thorough explorations and ecological studies need to be undertaken in the future, with support from other departments. Keeping

in mind the limited information this report has generated, a few conservation recommendations and future research dimensions are suggested below:

4.1. Conservation Recommendations

4.1.1. The conceptual framework developed for establishing Local Biodiversity Heritage Sites (LBHS) for rock outcrop conservation in the northern Western Ghats can be used as a model, keeping the socio-ecological landscape in mind (Watve & Chavan, 2020).

4.1.2. Possibilities of giving 'Conservation Reserve Status' to the inselbergs can be explored, following similar effort by the joint initiative of the Western Ghats Task Force, Karnataka Biodiversity Board, (Government of Karnataka), and the Ministry of Science and Technology, and Ministry of Environment and Forests (Government of India) (Chandran et al., 2012).

4.1.3. Since some of these inselbergs are also acting as grasslands, their management needs to be in accordance with the guidelines developed to provide clear strategies and steps that different government agencies can undertake to secure and conserve grasslands in India (Watve et al., 2019).

4.1.4. It may be important to note that the proposed conservation measures consider the fact that restricting all forms of human land use and herding activities in these areas (Michael et al. 2008), may decrease biodiversity by reducing habitat diversity. Thus, historical relationships between prehistoric human land-use practices and contemporary conditions of biodiversity requires continued investigation, species inventories and statistical analyses (Bauer, 2018).

4.1.5. How the Biodiversity Act (2000) can be utilised for rock outcrop conservation is a topic that of recent interest, especially with regards to the Konkan lateritic outcrops in Maharashtra. More details on this

can be obtained at the Rock outcrop of India Network Website (https://rockoutcropofindia.in/conservation-action/f/use-of-biodiversity-act-2002-for-conservation-of-sada). The extensive discussion arising from this project can be considered as a template for inselberg conservation in Bihar.

4.1.6. Tree plantation in the inselberg habitat would alter the open habitat structure and negatively impact the biodiversity and microclimatic conditions of the original ecosystems.

4.1.7. Since the inselbergs are also of importance in terms of geodiversity and geoheritage, which are integral parts of biological diversity and natural heritage, assessments of geoheritage and prospects of geotourism need to be undertaken in these habitats similar to Karnataka and West Bengal (Prabhakar & Radhika, 2022; Ghosh et al., 2021). The scope for this needs to be discussed with the help of Geological Survey of India and other relevant departments in the light of recently announced 'Draft Geoheritage Sites and Geo-relics (Preservation and Maintenance) Bill, 2022'.

4.1.8. Involvement of the Maharashtra Forest Department in rock outcrop conservation and an extensive discussion following that is publicly available. These resources can be utilised (Biome Conservation Foundation, 2013).

4.1.9. Since rock outcrops are classified as 'wastelands' in the Govt. of India records, but are important open natural ecosystems (ONEs), examination of identified inselbergs in the background of ONE map need to be done. This can be carried out using the interactive web application (Madhusudan & Vanak, 2022) through which state and district-level- summaries of their area and distribution, and other overlay statistics can be obtained (Available here: https://mdm.users.earthengine.app/view/open-natural-ecosystems).

4.1.10. Conservation of rock outcrops, related land-use and their utilisation as touristic centres needs a nuanced, multi-stakeholder approach

(eg. determining the carrying capacity of tourist influx). A recent global literature review on these aspects (Fitzsimons & Michael, 2016) can be another starting point. Micro-planning for this purpose needs to be undertaken by the Forest department, Revenue department, scientists, local NGOs, local community and other relevant stakeholders.

4.1.11. Identification of rock outcrops within working plans of the Forest departments need attention. Capacity building of Forest department staff to deal with conservation of ecologically sensitive areas and special habitats such as the inselbergs is of importance.

4.1.12. Extensive constructions on the rock surface need to be avoided.

4.1.13. Preparation of 'ecotourism/ conservation tourism' plans and 'ethical guidelines for tourism' are of importance. Since scientific management of rock outcrops in India is at its early stages, rigorous scientific monitoring of managemental impacts and mid-course corrections as and when required need to be done. Panchgani Tableland conservation and related Supreme Court orders can be a background for such activities (The honourable Supreme Court upheld conservation of a small 100 acre rocky plateau, and reducing impacts of tourism infrastructure, using zonation in a revenue land).

4.1.14. Specific management recommendation based on the rapid survey are:

4.1.14.1. Protect inselbergs from human disturbances that cause damage to the microhabitats on rocks (trampling of flora, removing plants and animals from microhabitats, removal and displacement of loose rocks etc.). This could be achieved by restricting the visitors along the designated paths leading up the temples

4.1.14.2. Regular monitoring of vegetation changes on the inselberg (using repeated photography across seasons, maybe at bi-weekly intervals) would be useful to gauge the degree of

human disturbance (such as tree cutting, firewood extraction and human induced fires) as well as spread of invasive species.

4.1.14.3. Among the four sites visited, Ramshila and Barabar hills may be developed as benchmark inselbergs of this division. Ensuring the proper identification and removal of invasive species such as *Mesosphaerum suaveolens* and *Lantana camara* by uprooting them at the seedling stage is proposed as a long-term management strategy to preserve and naturally restore the inselberg-specific species.

4.1.14.4. Restoration of disturbed (rock removal, grazing, vandalism, loss of native vegetation, chance of weed invasion and fires etc.) rocky habitat areas needs a more nuanced approach based on studies from Australia, and requires further field studies at the site itself (O'Sullivan et al., 2023; Jithin et al., 2023a).

4.2. Research Directions

4.2.1. As the first stage, species inventories of inselbergs need to be developed, with the help of experts in various taxa to identify unique species occurring here, in terms of endemism and special adaptations. Help of experts in rock habitat biodiversity from India and abroad can be availed as inselberg ecology is still at a relatively nascent stage in India. Seasonal studies of ephemeral vegetation, cliff-dwelling flora, and rock-dwelling animals need to be undertaken to have a clear picture of the biodiversity in these habitats, which will be crucial in determining its ecological value. This can be done with student volunteers and interns who are interested in conservation and ecological research. Appropriate training for these needs to be conducted.

4.2.2. Identification and mapping of all rocky outcrops in the Bihar state, following proper scientific floral and faunal study need to be undertaken. Their cultural value, importance as habitats of endangered, endemic and rare species, species with unique adaptations, species which are not occuring in the surrounding area, and as ecosystem service providers needs to be understood, which can help managers to decide appropriate conservation measures.

4.2.3. Taxonomists and ecologists need to work together on lesser known taxa such as spiders, fungi, orthopterans, and lichen on inselbergs, and research should be conservation oriented which give feedback to area managers.

4.2.4. Fuel wood collection, medicinal plants extraction (eg. *Selaginella* sp.), and grazing, their sustainability and impacts on biodiversity need to be studied with the involvement of the local community.

4.2.5. Research needs to be undertaken on the livelihood impact in terms of water and nutrient incomes, and to know how the importance of these habitats can be communicated to the local people and tourists in this area.

4.2.6. Research needs to be undertaken to know how the inselbergs are acting as islands, and thus influencing the evolutionary radiation of rock-dwelling animals such as reptiles in the region, along with threat status assessment of the flora and fauna.

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