FORGING HABITAT CONNECTIVITY IN A HUMAN DOMINATED TIGER LANDSCAPE.
Case: Satpura-Pench Corridor.

MASTERS OF LANDSCAPE ARCHITECTURE

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2015MLA018

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MAY, 2017

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Declaration

I, Saikat Bhattacharjee, **2015MLA018** hereby declare that the thesis titled **"FORGING HABITAT CONNECTIVITY IN A HUMAN DOMINATED TIGER LANDSCAPE. Case: Satpura-Pench Corridor"** submitted by me in partial fulfilment for the award of Master of Landscape Architecture in School of Planning and Architecture Bhopal, India, is a record of bonafide work carried out by me. The matter embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

Saikat Bhattacharjee

Certificate

This is to certify that the declaration of **Saikat Bhattacharjee** is true to the best of my knowledge and that the student has worked for one semester in preparing this thesis.

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Abstract

Habitat fragmentation is a common phenomenon as an outcome human settlement, from the past and have become significant problems throughout the world now. Big cats such as tigers, which play a vital role in maintaining the ecosystem balance through prey-predator interaction, are now on the verge of extinction since they require large habitats, but much of their habitats have been fragmented and degraded.

Conserving biodiversity in human-dominated landscapes requires protecting networks of ecological reserves and managing the intervening matrix to maintain the potential for species to move among them. This thesis provides insights into landscape based habitat networking of *Panthera tigris* by assessing the potential for species' movements among habitat patches in a reserve network of Satpura-Maikal Tiger Landscape of central India.

The study attempts to understand the character of the landscape through analysis of the landscape layer cake, with an aim to identify the important landscape elements and changes brought upon it by natural and anthropogenic means. Ecological dependency of the Tiger and other target species, upon each other and the landscape, was minutely studied to understand and correlate the existing and possible landscape flows over the matrix of 455sqkm. The study resulted in identification of target transects in the site, upon which landscape level strategies and a landscape development plan was proposed to improve the landscape function in terms of tiger dispersal between Satpura and Pench Tiger Reserve.

As well, functional coordination between all stakeholders is recommended to conserve tigers.

Acknowledgement

My study on ‘forging habitat connectivity in a human dominated tiger landscape. Case: satpura-pench corridor’ would not have been possible without a very supportive social network of collaborators, friends, and family. I want to thank, first and foremost, my advisor and mentor Ar. Saurabh Popli. Working with him has taught me so much about ecology, research, leadership, and life. I hope to be as good an advisor to my own students one day. I am also thankful to my teachers, Ar. Sonal Tiwari, Ar. Vineet Chaddha and Ar. Arshiya Quereshi, for their thoughtful suggestions and ongoing encouragement. A special thank-you is reserved for Prof. Savita Raje, an inspirational landscape architect and teacher who shared her passion for wildlife and landscape conservation with me.

This research benefited greatly from my collaborations with Madhya Pradesh Forest Department. I would specially thank P.C.C.F of M.P Forest Dept. L.K Chowdhary and C.C.F of Chindwara Division A.K Joshi for their support. A huge thank you for Alok ji and the other forest guards for taking me around the forest and villages under scorching summer sun.

I am also enormously grateful to Prof. V.G Gogate and B.M.S Rathore, who shared many inspiring discussions about my research, particularly at the formative stages, and their sharp thinking helped to clarify and refine many ideas.

Many thanks to my friends – Kshitij, Vivek, Dimpal, Saurav, Oorvi, Rahul, Sandeep, Shivani, Paritosh, Vernika, Gaurab, Arunava, Tanvi, Krishna, Akshay, Vaibhav, Mayukh, Sagar, Samiran, Udit, Nilesh, Shweta and Surabhi - who never let me take myself too seriously. Lastly, thank you to my loved ones: Maa, Baba and Bhai. No words can express what you each mean to me.

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1. LANDSCAPE

Landscape envelopes all of us and yet it is very difficult to get the same meaning of the term from two different individuals. The definition of the term 'Landscape' has been surprisingly varying as the perspective of people viewing the landscape varies with respect to motive, scale and time. Painters and humanists generally perceive landscape from the point of view of visual perception and thus limiting their understanding of landscape to visual landforms and communities.

The Cambridge Dictionary defines landscape as:

"a large area of countryside, especially in relation to its appearance" whiles the Oxford Dictionary views landscapes as *"all the visible features of an area of land, often considered in terms of their aesthetic appeal".*

However experts in the field have defined landscape with much deeper understanding of the process. In geographical literature, the landscape plays a central role, with most definitions focusing on the dynamic relationship between two characteristics-natural landforms or physiographic regions and human cultural groups (Grossman 1977, Mikesell 1968, Sauer 1963). One of the pioneers in the field of Landscape Ecology, Richard Forman (1987), best defines landscape as:

"a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout. Central to this concept is the existence of a cluster of ecosystems found throughout the landscape. Thus in a boreal forest landscape the cluster might include spruce-fir (Picea-Abies) woods, stream corridor, bog, rock outcrop, and aspen (Populus) stand. The definition also indicates that the ecosystems in the cluster are interacting. Thus, animals, plants, water, mineral nutrients and energy are flowing from one ecosystem to another in the cluster. Each cluster is both a source and a sink for different moving objects."

Figure 1 : LANDSCAPE: A heterogeneous land area in Madhya Pradesh, India.

Another important definition has been given by Turner et al (2002) who explain landscape as *"an area that is spatially heterogeneous in at least one factor of interest."* Here the focus has been shifted from groups of ecosystems and their interactions to spatial heterogeneity and its impact on various natural processes.

Landscapes have no precise geographical boundaries or extents neither do they have any precise unit of measurement. The comprising units (building blocks) of landscape, a stand or a patch, are knitted in a pattern to form a whole. The extent of this whole varies with the purpose of for which the principles of landscapes are being analysed. Hence the understanding and definition of landscape changes dramatically with respect to the phenomenon under study and has emerged as a trans-disciplinary concept.

1.1 Landscapes: a human construct.

However enormous the global diversity of landscape types is, from forests to desserts, from grasslands to wetlands, from tundra to seascapes, there have always been human activities occurring within them.

Authors have been debating over the fact that if landscapes are actually a result of human construct or are we 'humans' just a speck in the nature who influence the natural composition to some extent. Rolston (2001) says that:

"it seems that the main idea in nature is that the natural is not a human construct. Intentional, ideological construction is exactly what natural entities do not have: if they had it, they would be artefacts. The main idea in nature is that nature is not our idea."

However others object to the opinion by raising particular opinions in regard to the debate, Sociologists, Greider and Garkovich (1994) argue that:

"*Landscapes are the symbolic environments created by human acts conferring meaning to nature and the environment, of giving the environment definition and form from a particular angle of vision and through a special filter of values and beliefs*".

Landscapes are thus a reflection of our cultural identities. A vast open land amidst a forest can be envisioned as vast array of corn field by a farmer, a businessman will look at it as a farmhouse nestled among the serene backdrop or a potential resource generator for an industrialist.

Our understanding of nature and of human relationships with the environment is really cultural expressions used to define who we were, who we are and who we hope to be at this place and in this space (Greider and Garkovich, 1994).

Nature without cultural manifestations is just as meaningless, as meanings are not inherent to natural things. This context is supported by Berger and Luckmann (1967) when they say that *cultural groups transform the natural environment into landscapes through the use of different symbols that bestow different meanings on the same physical object or conditions. These symbols and meanings are sociocultural phenomenon; they are social constructions.*

In the pursuit of analysing the implications of changes in the environment on human, it is imperative, that the meaning of the change, to those cultural groups who have imbibed that natural environment into the definition of themselves, be understood.

1.2 Landscape Architecture

Landscape architecture is defined as “the art of changing the natural scenery of a place so as to produce the most attractive or desirable effect.” (Webster’s New World Dictionary, 1966) This definition is fine as far as it goes, but it does not really address the cultural, ecological or sustainable aspects of the profession. The **International Federation of Landscape Architects (IFLA)** has more to say on what it means to practise landscape architecture. The goals they outline for the profession include the following:

“- To improve the quality of life for communities and all the inhabitants.

- To recognize and nurture cultural diversity and biodiversity.

- To add social and cultural value to sites and outdoor public space.

- To promote an approach to landscape planning and design interventions which enhances social sustainability, cultural and aesthetic needs, and the physical requirements of people.

- To employ an ecological approach to land use planning, design and landscape regeneration to assure sustainable development of the built environment through the appropriate integration with land, water and atmospheric systems.

- To recognize the role of public realm landscape as a place for social and cultural expression and interchange accessible to all individuals and communities.

- To promote equity through work with disadvantaged communities and the development of solutions that are affordable and accessible to the broad population." (IFLA, 2009)

The IFLA goes on to describe how landscape architects must be able "...to give practical expression to the needs of individuals, communities and the private sector regarding spatial planning, design organization and construction of landscapes as well as conservation and enhancement of the built heritage, the protection of the national resources and rational land use planning for the utilization of available resources for the benefit of humankind." (IFLA, 2009).

The vision statement of the **American Society of Landscape Architects (ASLA)**:

"...is a world where the built and natural environments coexist in harmony and sustainable balance; where all peoples can express their diverse heritage and their individual desire to grow and thrive; and where we, as a profession, can substantially contribute to the process of achieving these ends." (ASLA, 2010)

The **Indian Society of Landscape Architects (ISOLA)** sets out the ideals of the profession on its website as follows:

- To promote a high standard of professional service in application of the art and science of Landscape Architecture/ Landscape Design as a whole.
- To promote and conserve natural resources / environment / landscape, recognizing their responsibilities to the community as a whole, both for the present and succeeding generation
- To consider all the questions affecting and relating to the practice of landscape architecture / landscape design and to intimate and watch over the measures affecting or likely to affect professional practice of Landscape Architecture / Landscape Design
- To hold conferences / seminars, meetings, and or exhibitions for discussion and the exchange of information on the problems affecting or

relating to landscape design / landscape architecture / environmental design / planning.

- To ascertain and notify the law and practice relevant to the landscape designer / landscape architect, and to compile, collect, revise, print and publish statistics, professional records or periodicals relating to any of the objective of the Society.

An examination of these definitions and professional association policy statements reveals that the core of their views of landscape architecture lies within the intersection of the nature, its biodiversity and the people inhabiting it. Everything that we do relates to designing environments for humans to traverse, inhabit or preserve. Assuming that this is the case, the landscapes that we create should be recognized as natural artefacts which vary as much as the culture of the host societies that spawned them. This ecological diversity should be held in as high esteem as the cultural variety. If landscape architects are to value ecological diversity and allow it to find expression in the landscape, it follows that the profession should pay close attention to the goals described by IFLA in their Charter for Landscape Architectural Education cited above. These goals have much in common with the tenets of landscape ecology, namely the recognition of, and support for diversity and an emphasis on equality.

Although it may seem obvious, it is worth emphasising that landscape architecture is a service profession in that we provide design and planning oriented services for both private and public clients as well as being an integral part of the construction industry. Given that a significant proportion of spaces designed by landscape architects are meant to be enjoyed by the public, one would expect landscape designs to reflect or respond to the ecological challenges of the landscape the practitioners operate in. Late Prof. Mohammed Shaheer, in the LA Journal of Landscape Architecture, describes real infancy of the profession in India during the eighties and nineties where landscape architects were considered as people of lower credibility as compared to architects, who could name a few trees. "The situation today is quite different, one has only to look around to become aware of the relative proliferation of landscape architecture."

He goes on to explain that:

“But still, environmental benefits accruing from designed public open space have to be marketed! Though, enough people realize that landscape architecture is integral to the planning and development process, planners and architects are educated in what landscape architecture is all about. Site analysis and site planning are basic to any educational programme in the design, planning and development field. Environmental studies form part of the school curriculum from Class 4 to Class 12, and remain with us every day in newspaper headlines. Everyone desires an “integrated approach”, so why doesn’t it happen?”

Further emphasising on the moral responsibilities of a landscape architect, Forman et al. ASLA, (1996) explain that:

“Land planners and landscape architects are well poised to play key roles for the society, to provide new solutions. They are professionals and scholars who focus on the land. Solve problems. Design and create plans. Look to the future. Are optimistic, can do people. Are synthesisers who weave diverse needs into a whole. Have ingenuity and creativity. Know aesthetics or economics. Know that human culture is essential in a design or plan. And know that ecological integrity of the land is critical.”

The landscapes we thrive upon cannot be neutral, they are a product of our culture and in turn help to shape that culture, creating a feedback loop.

In an ecologically diverse and rich country like India, where indigenous societies are largely dependent on the natural resources, it is one of the major responsibilities of the profession to ensure that the ecological sustainability is reflected fairly. In fact, landscape architects should seek to provide redress for past injustices by putting additional effort into facilitating the restoration and conservation of historically disadvantaged landscapes in the creation of human domains.

1.3 Landscape Ecology

The term **"landscape ecology"** was first used by Troll (1939); it arose from European traditions of regional geography and vegetation science. Many disciplines have contributed to the recent development of landscape ecology.

Ecology is generally defined as the study of interaction among organisms and their environment, and a landscape as a wide mosaic over which particular local ecosystems and land uses recur. These concepts have proven to be both simple and operationally useful. Thus landscape ecology is simply the ecology of landscapes.

Landscape Ecology emphasizes broad spatial scales and the ecological effects of the spatial patterning of ecosystems.

Specifically, it considers the following (Forman et. Al, 1984):

- the development and dynamics of spatial heterogeneity,
- interactions and exchanges across heterogeneous landscapes,
- the influences of spatial heterogeneity on biotic and abiotic protettes, and
- the management of spatial heterogeneity.

1.4 Integrating Landscape Architecture and Ecology

Landscape ecology, as the name implies, is the study of the composition, structure, and function of landscapes, among which a common theme is their patterns, processes, and changes (Hobbs 1997). In recent years, landscape ecology as a science has progressed towards studying and improving relationships between human requirement and ecological processes in the environment and particular ecosystems. This is largely due to trends in urbanization, which has seen the global human population shift from predominantly agrarian to urban throughout the past century (Wu 2008). As a result, integration between landscape ecology and landscape architecture, in both theory and practice, is imperative. Landscape architecture encompasses the analysis, planning, design, management, and stewardship of the natural and built environments (Chen and Wu 2009), and involves the systematic investigation of existing social, ecological, and geological conditions and processes in the landscape, and the design of interventions that will produce the desired outcome.

2. THEORETICAL FRAMEWORK

2.1 Landscape components

2.1.1 Landscape structure

Landscape structures are the physical, tangible elements of ecosystems. They can be living (biotic) or non-living (abiotic), mobile or fixed. Trees and forest stands, bodies of water, bogs and wetlands, rock and scree are all examples of landscape structures.

2.1.2 Landscape functions

Landscape functions are the activities, roles or processes performed by landscape structures. Functions can be classified in a variety of ways, with five main types generally recognised:

1. Capture (input): resources such as organisms, materials and energy are brought into the system from outside, e.g., rainfall or snow caught in a drainage system, photosynthesis by the forest trees capturing energy, animals migrating into an area.
2. Production: resources are “manufactured” within the system, e.g., animals producing young, trees regenerating, growing and producing wood, and complex soil development.
3. Cycling: resources are transported within the system, e.g., nutrients released by rotting vegetation being taken up again by growing plants, rain water taken up by trees and transpired back into the atmosphere, animals moving from place to place within the system.
4. Storage: resources are conserved for a time within the system, e.g., carbon (as wood in trees), water in lakes or wetlands, sediments in lakes or wetlands.
5. Output: resources leave the system, e.g., outmigration by animals, water flowing out of an area or timber being harvested and transported away.

Structures are normally involved in more than one function, and a function may involve more than one structure. For example, a stand of trees may capture sunlight, produce seed, cycle nutrients and water and become an output as timber. Water storage may involve rivers, lakes, ponds, wetlands, soil and vegetation.

2.1.3 Landscape interactions

Landscape interactions are a key aspect of the way we understand ecological systems. There are three main kinds of interactions to consider.

1. Interdependencies exist among functions: e.g., capture and cycling must take place in order for production to be sustained.
2. Structure and functions are co-dependent, and act to change each other: As Forman and Godron state, "Past functioning has produced today's structure; today's structure produces today's functioning; today's functioning will produce future structure."
3. Transfer between scales: Ecological systems should be viewed as nested scales that interact with larger and smaller systems. No ecosystem is completely isolated, so in order fully to understand an ecosystem it is also important to understand its connections to other systems at larger and smaller scales. These interactions may operate between spatially separate systems at the same scale, for example several eco-regions or several watersheds, or they may operate between different scales, such as a watershed within an eco-region, or both simultaneously.

2.1.4 Ecosystem resistance and resilience

Ecosystem resistance and resilience are interrelated aspects of stability. Resistance refers to the ability of an ecosystem to absorb and contain disturbance in ways that prevent large-scale alteration. Resilience is a description of the ability of an ecosystem to return to a reference state, productivity level, or composition and structure following a significant disturbance. Resilience is especially important in this topic as forests with tiger landscapes all over the world are prone to periodic stand replacement natural disturbances.

2.2 Landscape patterns and processes

2.2.1 Landscape mosaics

The term “landscape mosaic” describes the pattern of patches, matrices, corridors and stepping stones associated with the underlying landform, and is of key interest, since it is the spatial arrangement of these elements that largely determines ecological functions and processes.

2.2.1.1 PATCHES

Patches are areas of vegetation that are relatively homogeneous internally (in terms of composition, three-dimensional structure, successional stage, etc.). Forman describes patches as being relatively homogeneous,and non-linear in shape. A particular patch should be readily distinguished from others in its vicinity. In a forest landscape, clearcuts, young, mature or old growth forest, grassy areas, wetlands or rock outcrops are common patch types, along with rare or unique stands, such as an aspen grove in pine woodland. In fragmented landscapes the mature forest may exist as a series of disconnected patches.

2.2.1.2 MATRIX

A matrix is normally defined as the most dominant patch in a landscape, either by total area or degree of connectivity. A very important ecological feature of the matrix is that it is thought to exert strong control over landscape dynamics (movement of material, energy and organisms).

2.2.1.3 CORRIDORS

Corridors are relatively narrow, linear landscape elements that provide connectivity among similar patches through a dissimilar matrix or aggregation of patches. The patches connected by corridors are often called nodes, meaning that they are larger or wider habitats linked within a system. Roads and streams are corridors that may connect early successional patches (along the roadside verge), or aquatic habitats, respectively. A protected riparian zone may be a corridor connecting patches of relict mature forest in an otherwise heavily logged landscape. Different kinds of corridors facilitate flows (the cycling function) of different materials or organisms across the landscape. This functionality is what distinguishes a corridor from a linear-shaped patch that may provide no flow facilitation. The effectiveness of a corridor to provide connectivity often depends on how wide it is (how much is actually edge) and how frequently breaks or discontinuities are encountered.

2.2.1.4 STEPPING STONES

Stepping stones are usually thought of as clustered patches that act as corridors in terms of allowing wildlife to move between habitats that would otherwise be unreachable. They may be particularly important for birds and butterflies in urban and agricultural landscapes, but can also be important in forests.

2.2.2 Spatial arrangement of landscape mosaics

2.2.2.1 COMPOSITION

Composition is the physical and biological expression of a landscape element. It includes the types of vegetation present, in terms of the different species, age/size class (in the case of trees) and the three-dimensional structure. Composition largely determines how a landscape element interacts with various landscape flows. For example, a Dry Deciduous Teak forest of Central India offers different food sources from a Tropical Rain forest of North Eastern India, and thus will facilitate the flow of different species of mammals and birds.

2.2.2.2 ORIGIN

Origin refers to the means by which a landscape structure was created. It could be natural (fire, blow-down, beaver dam, avalanche, natural succession from young to mature forest) or caused by human activity (logging, planting, building a dam, constructing a road). Origin is important for understanding landscape dynamics from the perspective of the rate of change. How likely is it that more structures originating from the same cause will be created and at what rate?

Early successional forests can be thought of as ephemeral systems in terms of composition and structure that are rapidly changing towards something different. By contrast, the old growth forest stage may persist for hundreds of years with little change. Some wetlands may dry out and be taken over by forest while others may last indefinitely. Landscapes naturally dominated by ephemeral elements function differently from those dominated by persistent ones. For example, forests dominated by a mosaic of early successional patches may be home to a range of fauna comprising species capable of using many elements and suited to changing landscapes, while those dominated by old growth may favour fauna with much narrower habitat requirements, and may be unable to cope with rapid change.

2.2.2.3 CONTRAST

Contrast refers to the degree to which adjacent landscape elements differ from each other in terms of species composition and physical attributes. For example, there is a high amount of contrast between a wetland and late successional Dry Deciduous forest, not only in plant species but also in structure, height, soil wetness/dryness, origin and stability. A late successional Dry Deciduous forest and an old growth Dry Deciduous forest display much less contrast – the species may be very similar, the tree height almost the same, the main difference being dead wood content and openness of the canopy (greater in the old growth). Contrast exerts an influence over landscape dynamics to the extent that it controls landscape flows.

2.2.2.4 EDGE

Edge refers to the character of the interface between landscape elements of different composition and structure, for example between a clearcut and closed canopy forest. Edges have environmental conditions (temperature, light, atmosphere, humidity, wind) that are different from either of the adjacent elements. In abrupt edges to high-contrast elements this may be less marked than where there is a more gradual transition, although edge conditions affect each adjacent element to a degree, such as shade cast on the clearcut or light penetrating into the edge of the closed canopy forest. Very often, the plant composition of the edge is a mixture of those belonging to both components. Some animals may use edges differently from the interiors of each adjacent element and some species use edges as their habitat. This can mean that edge species benefit when a landscape is fragmented and contains more edges than usual, while those species needing interior habitats suffer.

2.2.2.5 PATCH SHAPE

Patch shape is important because of the effect it has on the proportions and amounts of edge and interior habitat. Regular-shaped patches, which are closer in shape and proportion to circles or squares, have the highest ratio of interior conditions to edge, whereas those with highly convoluted shapes have proportionately more edge. Patch shape also tends to reflect the origin of the landscape element. Regular, and especially geometric, shapes are almost always of human origin, whereas irregular shapes are more likely to have been created through natural processes. However, shape is related to size – small patches of forest are limited in terms of shape variability, whereas larger ones can be highly convoluted and irregular. The shape of naturally created patches frequently reflects the influences of landform and microsite or microclimate conditions and tends to be simpler where landform is simple and more complex when it is more broken and contains a greater complexity of microsites. Patch shape can be measured by its fractal dimension, which is the degree to which the shape differs from a simple circle or other geometric figure.

2.2.2.6 PATCH SIZE

Patch size refers to the scale of individual patches. Size is important for the habitat requirements

of some species. The greater the size the greater the proportion of interior habitat will be available for a given degree of complexity, assuming that the edge zone width is constant. Some patch sizes are controlled by landform, and it is difficult for large patches of a single forest type to occur in a complex topography full of wet hollows or steep peaks. Other patch sizes may result from types of disturbances. Some man-made patches have often been of a standard size due to regulations on permitted maximum sizes of clearcuts.

2.2.2.7 CONNECTIVITY

Connectivity refers to the spatial contiguity within a landscape. It is a measure of how easy or difficult it is for organisms and energy to move about without encountering insurmountable barriers. Connectivity occurs both within a matrix and via corridors. Some species may prefer to use the matrix while others might be confined to particular corridors. The degree of connectivity is a functional definition which changes from one species or flow to the next. Some may need completely connected corridors while others, such as birds, may fly from one patch to another, using them as stepping stones, as long as the patches are not too far apart.

2.2.2.8 LANDSCAPE GRAIN

Grain is the average size of elements, which provide a texture to the landscape. Fine-grained landscapes consist of numerous small patches, while coarse-grained ones have fewer, larger patches. Grain may change as a result of species composition, landform, microsite variation or shelter. Often human alterations create a landscape of more regular, uniform and fine grain than natural examples, which tend to have a wider range of patch sizes.

2.2.2.9 POROSITY

Porosity is the density of a particular patch type within a matrix. A landscape with many small patches of a similar type distributed through a matrix is highly porous and has a lot of edge, although the matrix may still display a high degree of connectivity. If porosity becomes too high, resulting in too much edge and too little interior habitat, then the landscape is fragmented.

2.2.2.10 PATCHINESS

Patchiness is the density of all patch types compared with the area of matrix. It is a similar measure to porosity but takes all patch types into account. Some landscapes are naturally very patchy, such as areas in Newfoundland that are full of small ponds, bogs, rock patches and scrubby forest. Other landscapes are not naturally patchy yet may have become so through human activities such as logging, farming or suburban sprawl.

2.2.2.11 HETERGENITY

Heterogeneity refers to the variation in aggregations of elements. If there are many different elements per unit area, the landscape can be said to be micro-heterogeneous. If there are different combinations of elements in one area compared with another, the landscape is macro-heterogeneous. It is useful to be able to determine what the average degree of heterogeneity would be for a particular landscape under natural conditions.

2.2.3 Landscape flows

Landscape flows are phenomena that move across and interact with landscapes, moving on, under or above the ground. They often respond to multiple elements (a pond, stand of trees, or road, for example). Flows include both organic and inorganic phenomena such as mammals, seeds, birds, water, air, soil, etc. As each flow passes through or interacts with an element, one or more ecological functions (capture, production, cycling, storage or output) occur. For example, a Deer (the landscape flow) might use a wetland for food, and a mature forest stand for thermal cover (production and storage). Water might flow to a pond, where some of it is used by aquatic plants (production), some evaporates back into the atmosphere (cycling) and the rest recharges the ground water (storage). A landscape mosaic of multiple elements therefore provides an animal such as a deer (the flow) with food, cover and breeding sites (production, storage, output). It is relatively easy to identify, map and describe landscape elements at a scale of resolution useful for analysis. It is more difficult to select the appropriate flows for diagnostic purposes. In part this is because there may be hundreds if not thousands of flows in any given forest.

2.2.4 Choosing appropriate landscape flows

According to Bell and Apostol, 2007, it is most useful to choose flows that are most representative of the general ecosystem type, that use a significant part, if not all, of the landscape and that are in some way indicative of ecological health. The following categories can be used to help to decide which flows are best to use for analysis.

2.2.4.1 KEYSTONE SPECIES

Keystone species play prominent roles in forest ecosystems, affecting the habitat of other species by their presence or absence. For example, carnivores may affect the populations of their prey, which in turn may alter grazing pressure. Keystone species are those that affect the linkages in food webs so strongly, and their role is so specialised, that their removal may result in a radical reorganisation of the food web.

2.2.4.2 UMBRELLA SPECIES

Umbrella species are those with large area requirements, and often represent the top of the food chain. Many conservation biologists believe that if natural resources are managed to ensure the range and distribution of these species, then species at the lower trophic levels will also benefit. Typical examples of umbrella species include large carnivores such as Tiger, Lion, Leopard etc.

2.2.4.3 RARE, THREATENED AND ENDANGERED SPECIES

Rare, threatened and endangered species are represented in the biodiversity legislation of most countries, and their potential presence in a particular area of forest is usually public knowledge.

2.2.4.4 INDICATOR SPECIES

Indicator species are those that if present, tend to mean that a set of other species will also be present. They are generally used as a surrogate for other species too difficult to track or measure.

2.2.4.5 FLAGSHIP SPECIES

Flagship species, or “charismatic megafauna”, often capture the public’s imagination. Flagship species are also often rare, threatened and/or endangered. Typical example of tropical forests of India is the Royal Bengal Tiger.

2.2.4.6 SOCIALLY OR ECONOMICALLY IMPORTANT SPECIES

Socially or economically important species are usually game animals, and may be important for subsistence hunting, the tourist economy or simply as representative of what local people feel should be in a healthy forest.

2.2.4.7 WILDLIFE GUILDS

Wildlife guilds are groups of species that have similar habitat and dispersal characteristics. If carefully selected, they provide a wider perspective on ecosystem function than single species.

2.3 Landscape dynamics

All landscapes change over time and an understanding of the rates, scales, intensities and types of dynamics is vital. No ecosystem or landscape is forever unchanging. In fact, change is crucially important to maintaining ecosystem functioning and resilience. Without plants growing, dying and decaying there could be no production, storage, cycling or outputs. It is therefore necessary to understand the dynamics of the natural and human-caused processes at work in any given landscape. This is particularly important for the purpose of developing management systems for forests that enable the production of outputs such as timber while maintaining the ecosystem functioning. Two main types of landscape or ecosystem dynamics are particularly important: disturbance and succession.

2.3.1 Disturbance

Disturbances are events that result in significant change to vegetation pattern and structure, often over a short space of time. Disturbances can be described in terms of their type, intensity, frequency, duration and effect. They can be natural or human-caused events that interact with and initiate changes to landscape structure.

2.3.1.1 NATURAL DISTURBANCES

Natural disturbances include fire, flood, wind, avalanches, landslides, insects and pathogens, all of which affect forest landscapes. Some affect very large areas while others tend to be more localised. Windstorms may do their work in only a few hours while root rot can take years. Most disturbances follow somewhat predictable cycles of occurrence, with the most extensive and severe usually having a low frequency of occurrence. Disturbances mutually interact with the landscape mosaic in that the current pattern and structure in part determines the location and spread of disturbance, while the disturbance sets the stage for future landscape structural development.

2.3.1.2 HUMAN INDUCED DISTURBANCES

Human-induced disturbances can be as or more important than natural disturbances in terms of impacting landscape pattern and structure. These may include gradual forest change brought on by over-grazing by domestic livestock, fire suppression, introduced pests, rapid change through the introduction of large-scale clearcuts, and forest fires. In most cases, human-caused disturbances produce very different effects on the landscape compared with natural disturbances. For example, a natural fire may affect a large area but it will leave behind pockets of unburned trees, fringes of partly burned edges and even occasional thick-barked single trees that survive, together with ash, carbonised wood, standing dead but not burned trees and so on. A clearcut of the same area may leave few or none of these biological legacies. Thus there may be a lack of long-term nutrients, and little habitat for organisms that use charred wood, perching posts and tree cavities, as well as insufficient seed sources for natural regeneration.

2.3.2 Succession

Succession is the process by which plant communities grow and gradually change in composition and structure over time. Classic succession models refer to open fields or barren areas becoming a pioneer forest of sun-loving plants, then mature forest and finally a “climax” community of shade-tolerant plants that is internally stable until the next large disturbance comes along. In reality, most tropical forest communities never lock into a stable climax. A particular area might follow various trajectories, depending on a number of factors, including intensity and scale of disturbance, distance from seed sources, presence of legacies and the vagaries of the weather. By combining models for both disturbance and succession it is possible to determine the “average” pattern of the landscape over time, in terms of the proportion of different patch types and matrices across different areas or sub-zones. This can be very useful when it comes to deciding the ecological “desired future condition”.

2.4 Metapopulation dynamics

The concept of metapopulation was introduced by Richard Levins (an American ecologist) in 1969.

Metapopulation is a population in which individuals are spatially distributed in a habitat in two or more subpopulations. Human activities and natural disasters are the main causes of metapopulation and increase the population that occurs as metapopulatons. Such factors cause the fragmentation of a large habitat into patches. Species are distributed to a number of populations that are either isolated or have some exchange of individuals. Such a collection of populations and its dynamics is called metapopulation dynamics.

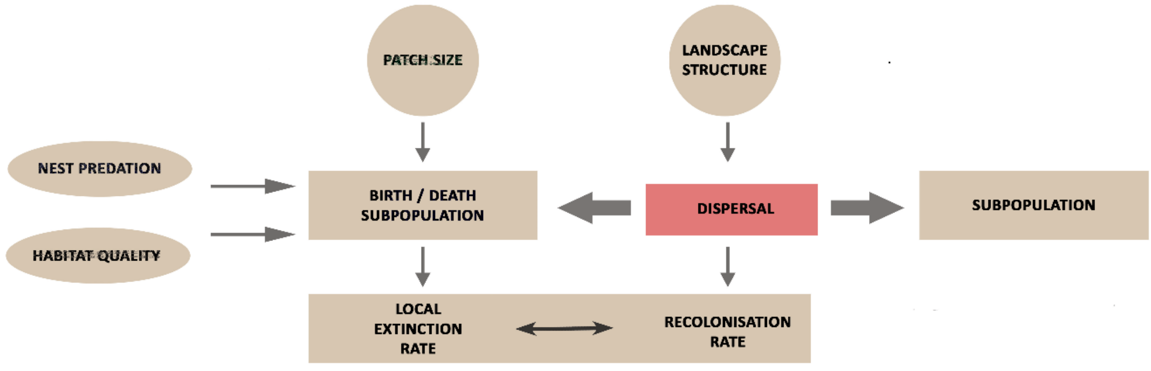


Figure 2 : Meta-population Dynamics

Each local habitat in a metapopulation is referred as subpopulations.

All local populations have a significant risk of extinction. In other words, the metapopulation is in a stochastic equilibrium between local extinctions and colonizations of currently empty land with suitable habitat patches. The migration of an individual depends on distance and spatial configuration of the landscape and affects metapopulation dynamics.

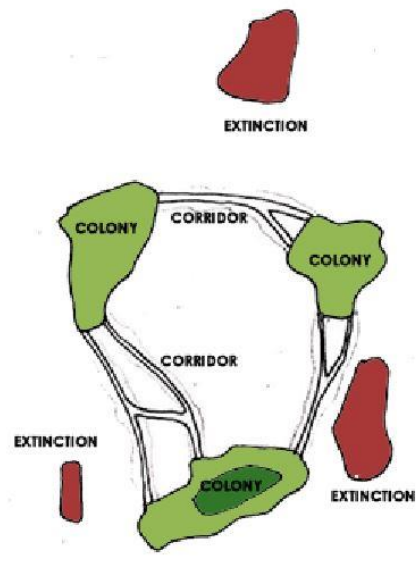


Figure 3: Spatial representation of Meta-population Dynamics

Hence, dispersal determines the rate of re-colonisation and landscape connectivity between various sub-populations through favourable environment is directly proportional to metapopulation stability.

2.5 Landscape, habitat and ecological connectivity

2.5.1 Connectivity and connectedness

Connectivity is a parameter of landscape function, which measures the process by which subpopulations of organism are interconnected into functional demographic unit.

Connectedness refers to the structural links between elements of the spatial structure of a landscape and can be described from map able elements.

Early definitions of habitat corridors approached the concept from a very literal perspective describing them as ‘linear’ or ‘narrow’ strips of land. But central to the rationale behind corridors is the capacity to facilitate movement, which occurs in different patterns and processes, and at different scales depending on the species or ecological process of interest. Thus, habitat corridors need not be linear or narrow and must be defined from the perspective of the organism or process being targeted for conservation. More recent definitions reflect a broadened understanding of habitat corridors, which are now described as components of the landscape that facilitate the movement of organisms and processes between areas of intact habitat. Implicit in this definition are two ideas: (1) corridors support the movement of both biotic processes (e.g. animal movement, plant propagation, genetic exchange) and abiotic processes (water, energy, materials); and (2) corridors are process- or speciesspecific (Jongman & Pungetti 2004). To help clarify the terminology on corridors that support biotic processes, Jongman and Pungetti (2004) distinguish between three different types:

Migration Corridor: Migration corridors are used by wildlife for annual migratory movements between source areas (e.g. winter and summer habitat). An example of a migration corridor is the Path of the Pronghorn in Wyoming.

Dispersal Corridor: Dispersal corridors are used for one-way movements of individuals or populations from one resource area to another. Dispersal is critical to the maintenance of genetic diversity within populations of species and to the persistence of fragmented populations which may require regular immigration to avoid local extinction.

Commuting Corridor: Commuting corridors link resource elements of species' home ranges to support daily movements including breeding, resting and foraging. As such, commuting corridors facilitate localized movements throughout the landscape important to daily survival and reproduction.

3. TIGER LANDSCAPES

Figure 4 : A Central Indian Tiger Landscape.

(Source: World Wildlife Fund, WWF)

3.1 What are tiger landscapes?

Tigers are magnificent big cats who sit at the top of the ecological pyramid in vast forest landscapes and depend for their survival on the existence of large, biologically rich, and undisturbed forest habitats known as *Tiger landscapes (TL)*. Hence such landscapes are always large scaled and high quality landscapes spreading over thousands of kilometres. They support tigers, their prey, and a vast amount of biodiversity. The presence of viable populations of wild tigers is a **'stamp of quality'** certifying the integrity, sustainability, and health of larger ecosystem, known as high-value Tiger Conservation Landscapes.

3.2 Over reaching benefits of tiger landscapes

They also contribute to human wellbeing, locally and globally, through the provision of many ecosystem services. (Global Tiger Recovery Programme 2010-2022, 2010).

- **Cultural services:** Tigers are highly significant symbols in Asian cultures, figuring prominently in the spiritual beliefs and cultural history of many different Asian peoples. The tiger is the national animal of many Tiger Range Countries (TRCs) and in global markets the tiger brand stands for strength and majesty.
- **Carbon Storage and Sequestration:** It is estimated that, on average, forests in TLs have nearly 3.5 times the amount of carbon than forest areas outside TLs. With 17 percent of global CO2 emissions coming from deforestation, protecting 1.2 million km2 of forest— the total area of TLs— will help mitigate climate change.
- **Poverty Alleviation:** Rural areas around protected areas in TLs contain pockets of deep poverty, with poverty levels often exceeding three times national averages. Poor people are highly dependent on forest ecosystem services including provisioning of water, food, medicine, fuel, and fiber; it is estimated that 80 percent of the income of the rural poor in Southeast Asia is derived from the local biodiversity.
- **Watershed Protection**: TLs form significant parts of nine globally important watersheds, with a total catchment area of 5.8 million km2. These watersheds supply water to as many as 830 million people and form the basis of rural livelihoods. In Bhutan, Myanmar, and Nepal, hydropower provides 74 to 100 percent of the national electricity, and a large part of the catchment area for this hydropower lies in TLs.
- **Natural Hazard Regulation:** Tiger habitats, mostly forests, ameliorate the effects of natural hazards such as floods, landslides, droughts, fires, and storms; for example, there is clear evidence that the impacts of the 2007 cyclone Sidor and the 2009 cyclone Aila were mitigated by the mangrove islands of the Sundarbans TL in Bangladesh.

- **Food Security and Agricultural Services:** Tiger landscapes support agriculture by supplying fresh surface and ground water, protecting soil from erosion, and regulating local weather; they also enhance food security by providing a source of wild genetic material for plant breeders.
- **Medicinal Services:** Tiger landscapes are repositories of herbal plant richness. Where harvest is permitted, they contribute to a global trade in medicinal and aromatic plants that is estimated at more than US$60 billion per year.
- **Tourism:** The charismatic mega fauna living in TLs are highly attractive to tourists, creating economic opportunities for local people in the ecotourism industry; ecotourism is the fastest growing and most profitable segment of the tourism industry.

Most of these benefits are not currently monetized so tiger landscapes are significantly undervalued in national and global agendas. As a result, degradation, fragmentation, and loss of natural habitats, depletion of prey animals, and poaching to supply a large illegal global trade in their body parts, have pushed wild tigers and their landscapes to the brink of extinction.

3.3 Panthera tigris

Figure 5 : Bengal tiger in wild.

Tigers have been stalking through the forests of planet earth since 2 million years. The oldest fossils that were discovered in Java date back to 1.6 to 1.8

million years ago. Once ranging widely across Asia, the range has shrunk – especially in the last century.

3.3.1 Sub- Species

Figure 6 : Tiger Sub-Species

3.3.2 Ecology

Tigers (Panthera tigris) are the largest of all living cats: a typical male can measure up to three meters in length and weigh approximately 200 kg. Tigers are normally solitary, except for females with cubs. Mating takes place year round. Gestation is approximately 103 days and an average litter is two or three cubs. Cubs reach independence at between 18 and 28 months. Females first breed after three year of age and usually reproduce every two years until they are about nine or ten years old. The average breeding life of a female is 6.1 years. Males begin breeding when they are four to five years old. Longevity of tigers in the wild is little studied but some are known to live up to 17 years (Toyne & Hoyle, 1998; Sunquist, et al., 1999).

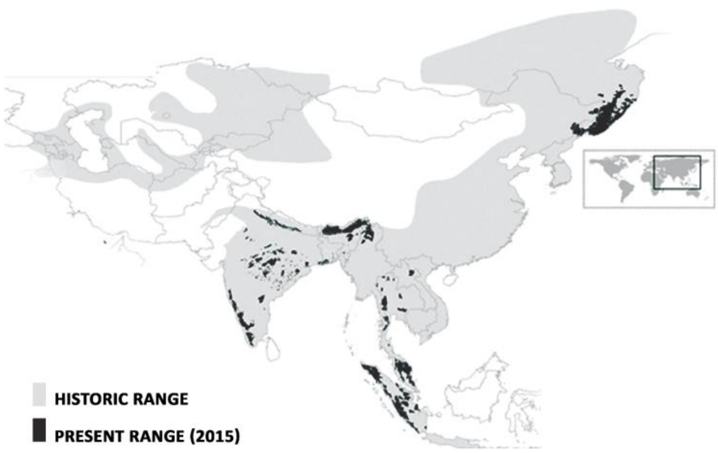
Tigers are terrestrial and occupy relatively large habitats, the size of which usually depends on the density of their prey. Their wide distribution, covering five bio-regions (the Indian sub-continent, Indo-China, South-east Asia, central and southern China, and the Russian Far East), covers eight important habitats: boreal taiga, temperate broadleaf and mixed conifer forests, alluvial grassland, subtropical moist deciduous forest, subtropical and temperate upland forest, tropical moist evergreen forest, tropical dry forests and mangroves (Wikaramanayeke, et al., 1999).

Tigers have adapted to living in each different habitat and therefore prey on wide variety of animals. In general, they feed predominately on large deer species and wild boar. Occasionally they will kill larger species such as wild cattle, elephants and rhino calves. They are also opportunistic and will kill monkeys, birds, reptiles and fish as well as more unusual prey such as crocodiles and leopards. Males have been known to kill cubs fathered by other tigers (Sunquist, et al., 1999).

Tiger density depends on the quality of the habitat and the prey it supports. Factors regulating their numbers vary in different regions, so conserving them entails protecting large areas of their habitat and sound management of their prey (Karanth & Stith, 1999).

3.4 Global tiger population distribution and status.

Wild tigers are in a precarious situation (Damania, et al., 2008). They are living in a small fraction (only seven percent) of their historical range and have lost 40% of their habitats since the 1990s (Dinerstein, et al., 2007; Damania, et al., 2008).



MAP 1 : Historical and Present range of tiger habitat in the world.

(Source: Sanderson, E., J. Forrest, et al. 2006. Setting Priorities for the Conservation and Recovery of Wild Tigers: 2005–2015.)

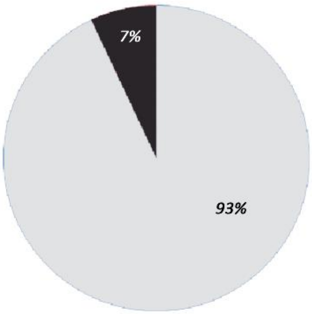


Figure 7 : Comparison of historic and present range of tiger habitats.

The global population of tigers was approximately 100,000 a century before and has declined to less than 4000 now (Damania, et al., 2008). Habitat loss and fragmentation (Wikramanayake, et al., 1998; Dinerstein, et al., 2007), depletion of prey base (Karanth & Stith, 1999; Ranganathan, et al., 2008), poaching (Nowell & Jackson, 1996; Chapron, et al., 2008), and conflict with humans (Nyhus & Tilson, 2004; Gurung, et al., 2008) is known causes of declining populations of tigers. Human-tiger conflict exists throughout its range and the intensity of conflict is high in Asia where the human population surrounding the tiger habitats is dense (McDougal, 1987; Nowell & Jackson, 1996; Nyhus & Tilson, 2004). Curtailing retaliatory killing and restoring wild prey populations are perhaps the most important needs of these big carnivores in their conservation today (Mishra, et al., 2003).

Figure 8 : Tiger sub-species extirpated in the 20th Century.

(Source: World wildlife Fund, WWF)

In the last century, three tiger sub species (two from Indonesia, the Javan tiger (Panthera tigris sondaica) and the Bali tiger (Panthera tigris balica) and one from Central Asia, the Caspian tiger (Panthera tigris virgata)) have been extirpated from the wild (Weber & Rabinowitz, 1996; Seidensticker, et al., 1999; Nyhus & Tilson, 2004).

At present, suitable habitat for wild tigers covers about 1.2 million sqkm in 13 countries in Asia: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Russian Federation, Thailand, and Vietnam. Mostly forest, this habitat has been categorized as 76 tiger landscapes.

3.5 Tiger status in India

The Indian subcontinent has the largest number of tiger landscapes (40, out of which 11 are of global priority). These tiger landscapes are a **home to 60% of wild tigers of the world** (Sanderson et al. 2006) and majority of the population is found in scattered and isolated pockets mainly in the alluvial flood plains of the Himalayan foothills, the Central Indian highlands, and forests of Western Ghats (Jhala et al. 2011).

Table 1: Tiger Population fluctuations across India

State	*Tiger Population*		
	2006	*2010*	*2014*
Shivalik-GangeticPlain Landscape Complex			
Uttarakhand	178 (161-195)	227 (199-256)	340
Uttar Pradesh	109 (91-127)	118 (113-124)	117
Bihar	10 (7-13)	8 (-)	28
Shivalik-Gangetic	*297 (259-335)*	*353 (320-388)*	*485(427-543)*
Central Indian Landscape Complex and Eastern Ghats Landscape Complex			
Andhra Pradesh (Including Telengana)	95 (84-107)	72 (65-79)	68
Chhattisgarh	26 (23-28)	26 (24-27)	46
Madhya Pradesh	300 (236-364)	257 (213-301)	308*
Maharashtra	103 (76-131)	169 (155-183)	190
Odisha	45 (37-53)	32 (20-44)	28
Rajasthan	32 (30-35)	36 (35-37)	45
Jharkhand	-	10 (6-14)	3+
Central India	601 (486-718)	601 (518-685)	688(596-780)
Western Ghats Landscape Complex			
Karnataka	290 (241-339)	300 (280-320)	406
Kerala	46 (39-53)	71 (67-75)	136
Tamil Nadu	76 (56-95)	163 (153-173)	229
Goa	-	-	5
Western Ghats	402 (336-487)	534 (500-568)	776(685-861)
North Eastern Hills and Brahmaputra Flood Plains			
Assam	70 (60-80)	143 (113-173)	167
Arunachal Pradesh	14 (12-18)	-	28
Mizoram	6 (4-8)	5	3+
Northern West Bengal	10 (8-12)	-	3
North East Hills and Brahmaputra	100 (84-118)	148 (118-178)	201 (174-212)
Sunderbans	-	70 (64-90)	76 (62-96)
TOTAL	*1,411 (1,165-1,657)*	*1,706 (1,520-1,909)*	*2226(1945-2491)*

(Source: Tiger status of india, 2014)

3.6 Conservation needs for large carnivores

Large carnivores, which comprise big cats like tigers, play an important role in maintaining the ecosystem by way of predation and inter-specific competition (Treves & Karanth, 2003). They regulate or limit the population of their prey consequently altering the structure and the function of the entire ecosystem (Schaller, 1972; Estes, et al., 1998; Berger, et al., 2001; Terborgh, et al., 2002 cited in Treves & Karanth, 2003, p. 1491). In the absence of them, trophic cascade (herbivore populations explode) will occur (Lovejoy, 2006). The presences of big cats lying on top of the trophic level are signs of good ecosystem health and acts as "umbrella species" in conservation. Protection of the big cats is consequently vital to the conservation of many other rare and threatened species as well as to sustaining essential ecosystem-services (Graham, 2003) that forests provide, including watershed protection, soil conservation, and water recharge and carbon storage. They also play a key role in a range of ecosystem processes and are often considered as icons of protected areas (Treves, unpublished). Moreover, many carnivores are important flagship species and therefore attract funding and wider conservation benefits (Linkie & Christie, 2007).

Unfortunately, large carnivores are the most threatened predators on the earth and big cats are among the line up of threatened carnivores. Long persecuted as perceived threats to livestock and humans (Lozano, et al., 2003; Mishra, et al., 2003; Duckworth, et al., 2005), hunted for their skins and purported medicinal values (Nowell & Jackson, 1996; Weber & Rabinowitz, 1996), prey depletion by hunting (Karanth & Stith, 1999; Mishra, et al., 2003), and losing critical habitat to deforestation and conversion to agriculture (Weber & Rabinowitz, 1996; Kolowski & Holekamp, 2006), big cat populations have dwindled around the world over the past century. The newest threat may be global warming which compels them to shift their range, nearly impossible, due to unsuitable habitat (corridor) in the present human dominated landscape.

4. CONTEXTUAL FRAMEWORK

4.1 Satpura-Maikal Tiger Landscape (Satpura Range)

As the name suggests this regions lies between the Satpura and Maikal hills (together known as the Satpura Range with Mahadeo hills in between). The landscape of Satpuda-Maikal range extends for a distance of about five hundred kilometer. To one side of this stretch of landscape lies the Achanakmar Wildlife Sanctuary of Chhattisgarh and on the other side lies the Melghat Tiger Reserve of Maharashtra.

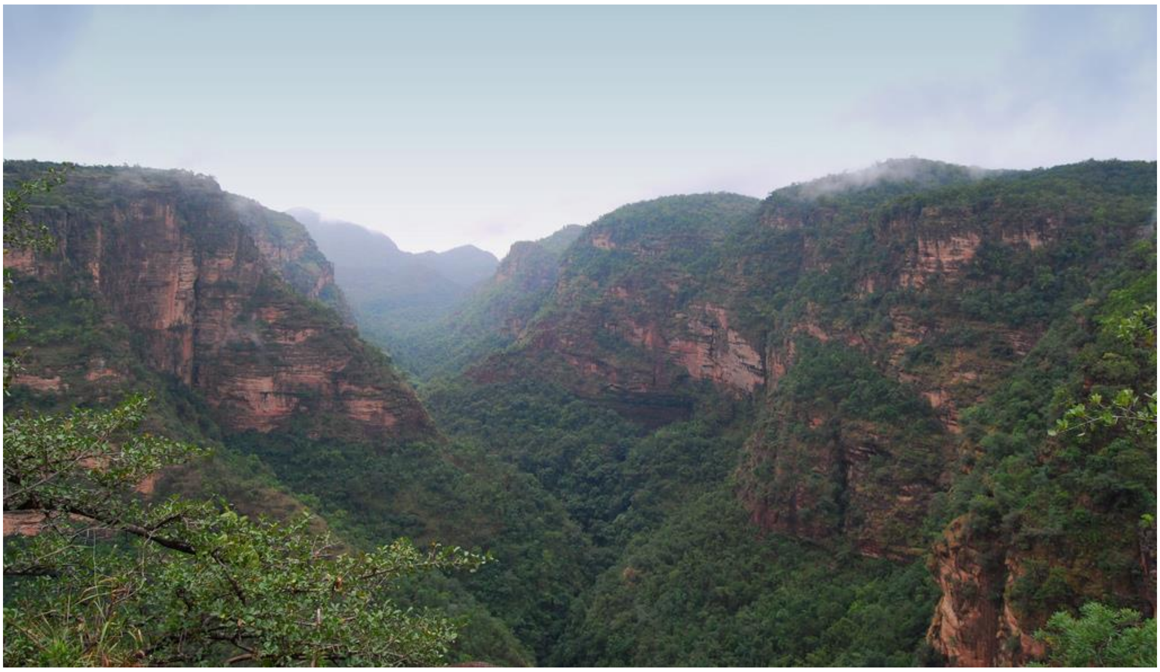
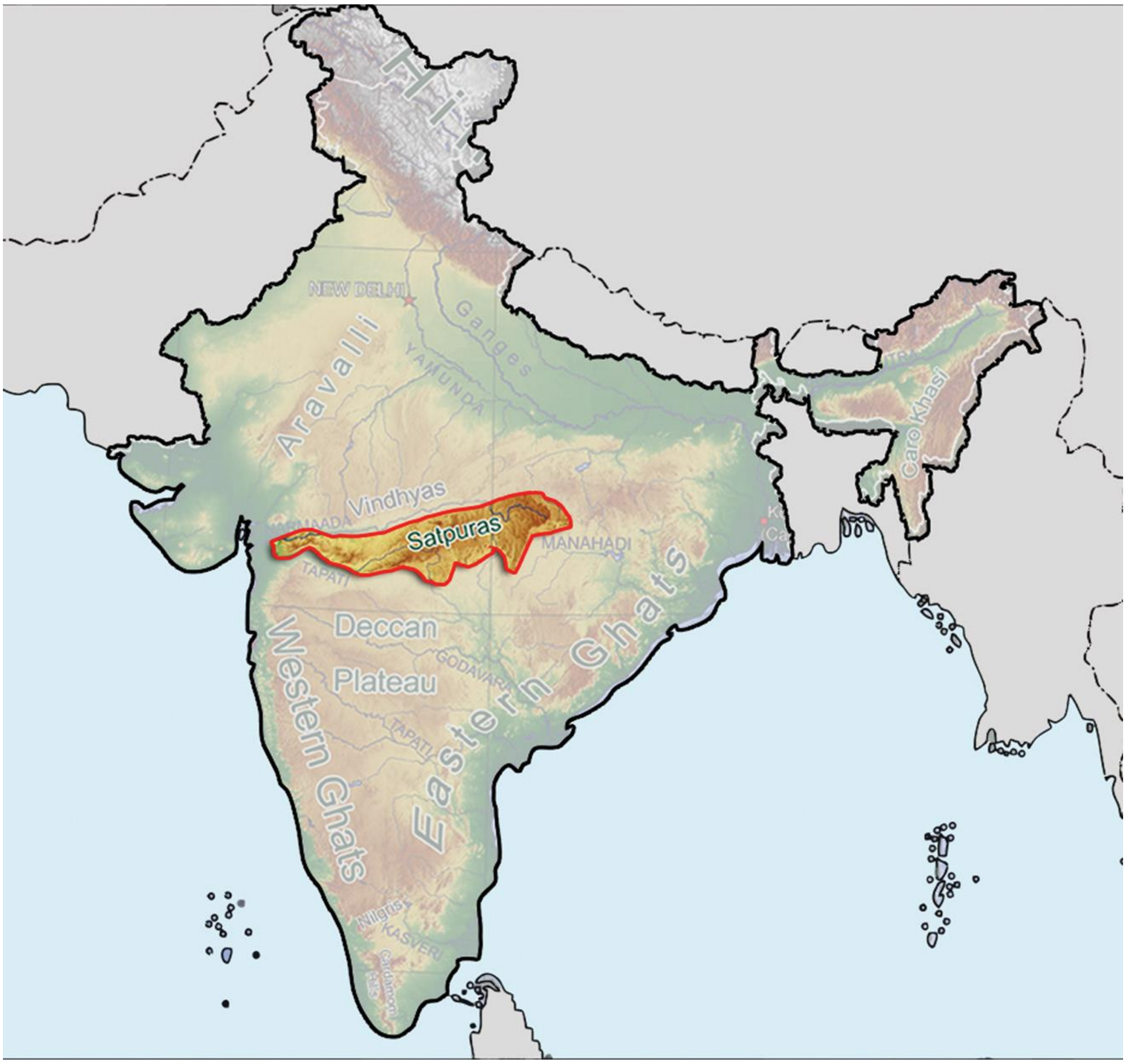


Figure 9 : Landscape of Satpura Range

The name Satpura has been derived from the Sanskrit word 'Shatpura', meaning 'Hundred Mountains'. Forsyth (1871), projects the landscape as an assemblage of sandstone blocks and few isolated peaks of granite in an ocean of basalt.

The Satpura-Maikal landscape is a global priority tiger conservation landscape due to its potential for providing sufficient habitat that will allow long term persistence of tigers. Located to the south of the Vindhyan hills, the Satpura-Maikal landscape demonstrate one of India's finest forests. Satpura Maikal

Landscape (SML) sprawls across 19 districts in the states of Madhya Pradesh, Maharashtra and Chhattisgarh covering a total area of 1,43,551km^2. Of this, roughly 40,837km^2 is under forest cover, with some of the country's most famous tiger reserves and Protected Areas.



MAP 2 : Physical map of India highlighting the Satpura range.

4.2 Historical evolution of the Satpuras.

According to Casshyap and Khan (2000), the geologic formation of the landscape, which is essentially a **Tectono-Sedimentary evolution**, can be traced back to the early Triassic Period (251 MYA).

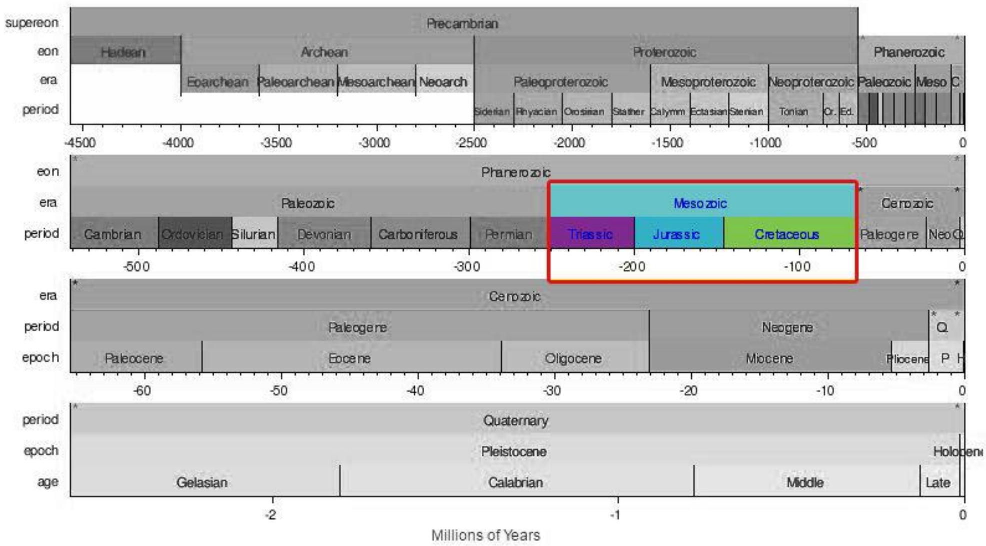


Figure 10 : Geologic time scale depicting period of evolution of Satpura range.

The presence of pre-historic rock shelters in the Satpura region suggests that humans have inhabited this place since not less than 10000 years.

In the eighth century before Christ, Munda tribes from the east climbed over the Maikal hills of eastern Mandla and Seoni to settle in the upper Son and Narmada valleys as the Kols. They later moved down the Narmada and up onto the Satpura plateau to call themselves Korkus. About three centuries after the Munda invasion other tribes entered the region. Of these the most important were the Dravidian Gonds who came from Karnataka up the Godavari and across the Maikal range (Baker 1991). Thus the two main tribes who occupied the region were the Gonds and the Korkus, who practice agriculture and hunting in the plains of the area.

The most common form of cultivation practiced by the Gonds was 'dhya' or shifting cultivation, as understood from Baker (1991):

"tribal cultivators generally lived in shifting hamlets with sufficient reserves of forest for periodic cutting and cultivation". He also projected that they *"used cattle and the plough to grow light millets for subsistence, but this deteriorated the soil necessitating frequent changes of land".*

However the Korkus practiced agriculture in a more basic form. They used neither cattle nor plough, and had no implement but the axe. They selected a hill side, cutting bushes and ringbarking larger trees to induce death. The Korkus then burnt the forest, raked the ashes over and waited for rain.

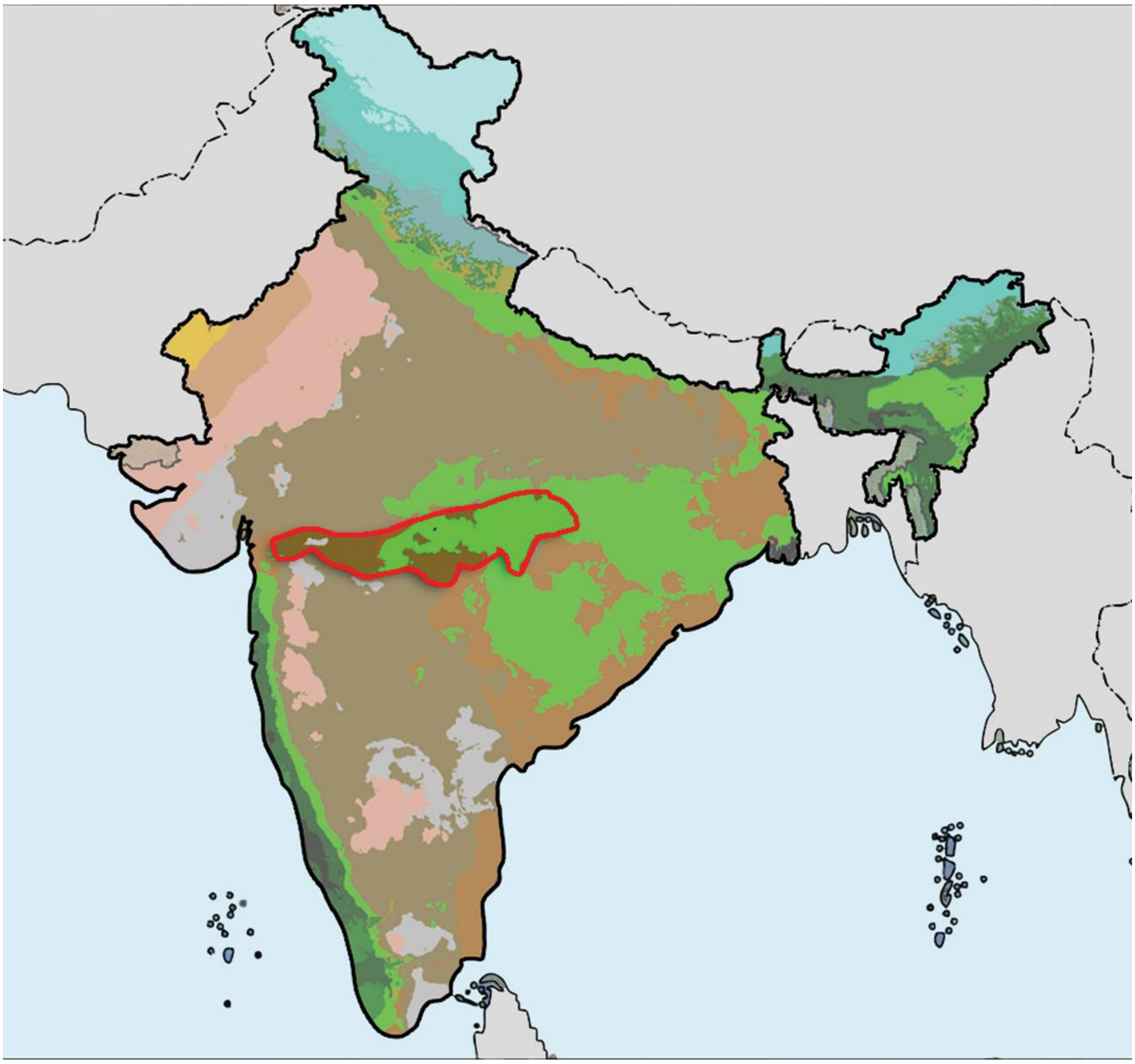
They sowed the seed by hand, using ash as fertiliser, and fenced the crop after germination to protect it against damage by wild animals (Baker 1991).

In the fourteenth and fifteenth centuries, many Rajput clans, who by Akbar's time probably had succeeded in reclaiming the Narmada valley for agriculture, infiltrated this vast land of the aborigines (EPCO 2001). They had pushed the economically weaker aborigines from the more fertile plains to the uplands, where resources were less.

The system of cultivation thus adopted by the wild tribes, which seems to a natural consequence of their want of agricultural stock, necessitates a more or less nomadic habit of life (Forsyth, 1871). Only those villages where the chief of the clan and Hindu traders resided were more stable in nature in the whole scenario.

4.3 Ecological Significance of Satpura region

The central zone of the Satpura range around the Pachmarhi peak and Mahadeo hills, where the range reaches its highest altitude, experiences the **confluence of two major biomes of the country viz. Southern Dry Deciduous Teak ecoregion and Moist deciduous eco region** and correspondingly forms the melting pot for Sal from the north and Teak from the south. This unique landscape endures high quality and wide range of biodiversity, which is rich enough to bear tiger populations that has the potential of not only sustaining themselves over a period of time but also to move out and populate other forests.



MAP 3: Eco region map of India highlighting the Satpura range.

4.4 Changing dynamics of the Landscape

Man has been manipulating and nurturing landscapes wherever he has dwelled upon it.

The ‘dhya’ (shifting cultivation) clearings of the tribes, once abandoned, speedily recovered into jungles within a year or two, but the character of the vegetation was never the same as the virgin forest that was destroyed in the first clearing.

The new cover predominantly composed of a variety of low and very densely growing bamboo, and of certain thorny bushes, which together form in a year or two, a cover almost impenetrable to man or beast (Forsyth,1871). He also added that a second growth of timber can never be expected (on abandoned 'dhya' land) if left to nature. Such bamboo dominated lands were never again cleared for cultivation as they did not produce enough coating of ashes that was sought by the dhya cutter. Hence, another new timber land was destroyed.

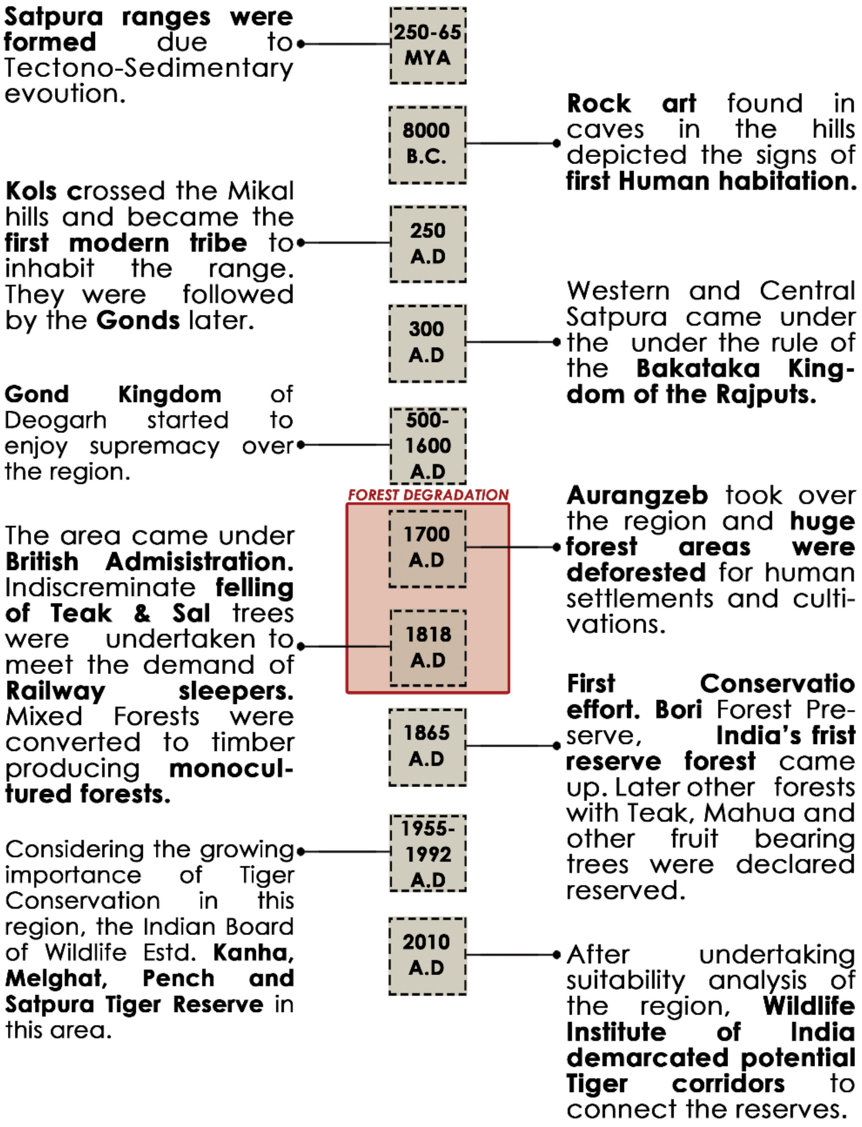


Figure 11: Historical timeline of the Satpura Region

Such practice of agriculture and unprecedented extraction of timber and other forest resources consequently saw the decline of continuous dense forest cover and the stark consequence of which can be adhered from the extinction of mega species like Elephants from the region. The forest matrix thus started to develop grains and became more permeable in nature. Principle teak forests were now found clinging to the skirts of the hills and for a long way around the settlements, forests have been hacked down to mere scrub (Forsyth,1871). Outer slopes of the plateau towards the lower plains were virtually swept of all the valuable teak.

The situation intensified in the mid-20th century when changing market demand saw the tribal giving up their traditional practices and knowledge systems. Forest produce was no more utilized for self-sustenance but was more oriented towards commercialization.

The later 20th century saw the development of a number of Coal mines in the region and also the initiation of a major thermal power plant, which changed the face of economy in the surrounding districts. Consequently, further and rapid degradation of the forest cover occurred in the forest which was once termed as *"Satpura ke ghane jungle"* by Pt. Bhawani Prasad Mishra. Such degradation of the forest cover escalated the fragmentation of the habitats of animal species, which had by this time affected the top predators, like tigers, more than others as they require large home ranges for survival.

4.5 Criticality for Tiger Conservation

This criticality of the fact that this landscape is a high priority tiger conservation landscape has been set forth by Seidensticker et al, (2013):

"Our study establishes the fact that genetic populations (of tiger) exceed the confinement of source populations and tigers require large landscapes consisting of breeding populations interconnected with forest corridors, for their long term persistence".

Although there are a handful of corridors in the landscape that are still relatively intact, the region has undergone tremendous fragmentation in the past centuries. Figure below shows the forest fragmentation of the Satpura-Maikal Landscape as studied from Landsat images of 1700CE and 2000CE by Seidensticker et al, 2013.

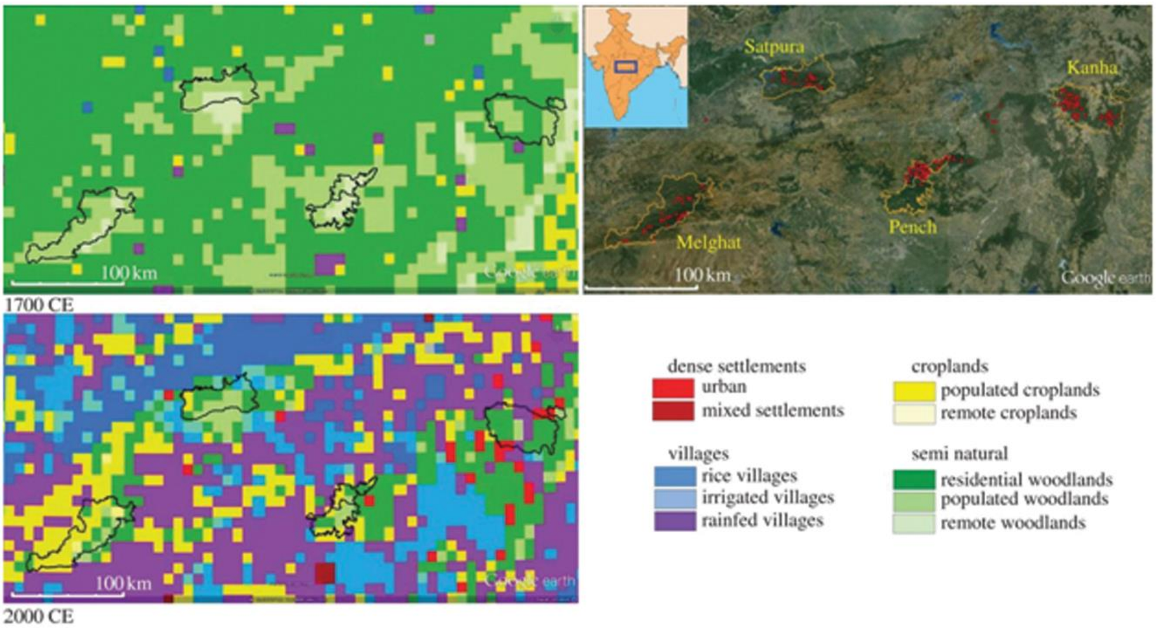
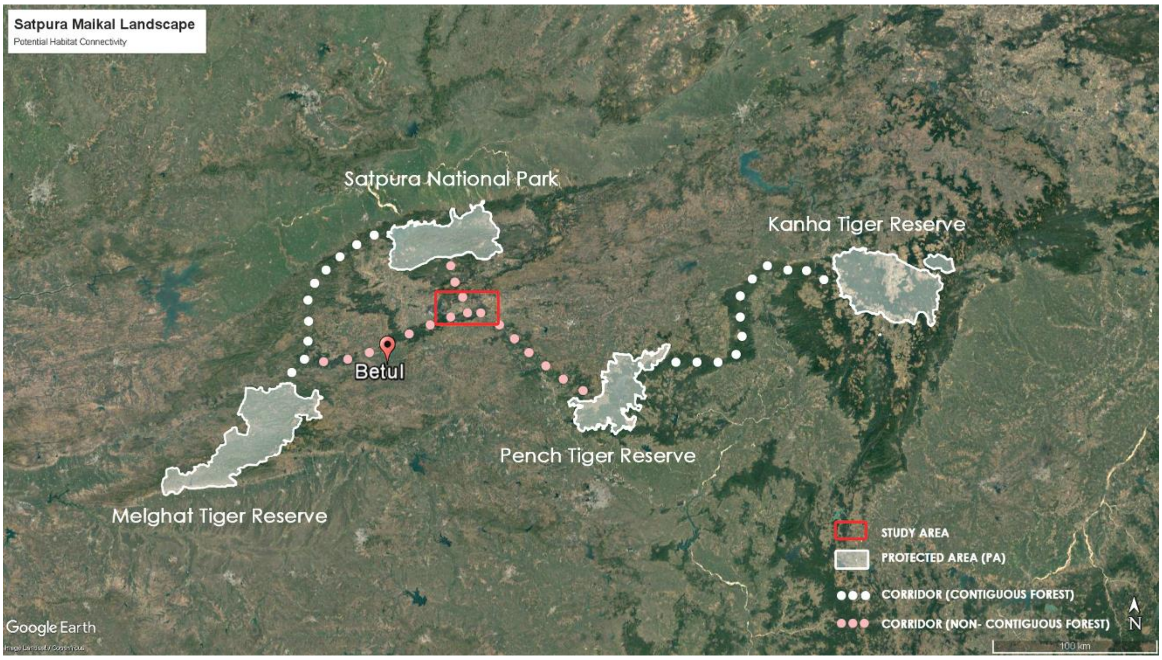


Figure 12: Landsat imageery showing forest fragmentation COMPARISION between 18th century and 21st century.

(Source: Seidensticker et al, 2013.)

The intervening landscape matrix in this landscape is composed of agricultural land and fragmented forest patches, interspersed with numerous small villages and towns (Seidensticker et al 2013).

Satpura-Maikal landscape supports 30 per cent of the world's tiger population and 17 per cent of India's tiger population with some of the largest contiguous forested tracks connected through wildlife corridors. Some of the tiger reserves critical from a conservation standpoint in this landscape are Kanha, Satpura, Pench, Melghat, Tadoba and Achanakmar.



MAP 4 : Satellite Imagery of Satpura-Maikal landscape showing tiger reserves and its potential connectivity.

(Corridor connectivity data: Wildlife Institute of India)

The forests surrounding these tiger reserves are important potential corridors for the long term survival of the tiger in the landscape as they offer the space and cover for the tigers to disperse from these source populations (Seidensticker et al., 2010). Among the core tiger reserves of the region, Kanha tiger reserve lies to the western most extent of the landscape and is connected to Pench tiger reserve through a contiguous forest cover. Pench is connected to Satpura National Park and Melghat Tiger Reserve though isolated forest patches of various degrees acting as stepping stones. However the connectivity between Melghat Tiger reserve and Satpura National Park is again a fairly contiguous tract of forest cover.

5. NEED OF STUDY

The looming possibility of the tiger's extinction in the wild signals a real threat to Asian biodiversity and to the vital services provided by tiger landscapes. Because tigers are apex predators at the top of the food chain in many Asian ecosystems, they are essential to the effective functioning of other parts of these ecosystems. Tigers are an indicator species reflecting the health of the landscapes they inhabit. Tigers also serve as an umbrella species—protecting tigers and their landscapes also protects a host of other endangered species and their habitats. Most of mainland Asia's areas of highest endemism for vertebrates and richest ecoregions for vascular plants fall within the tiger range. As WWF India projects - "More than 10 percent of Birdlife International's 231 Important Bird Areas in Asia and more than 10 percent of their area intersect with TLs. Also under some part of the tiger's umbrella are six Ramsar Wetlands of International Importance in six TLs; eight natural World Heritage sites in 11 TLs; and seven UNESCO Biosphere Reserves in six TLs." Tiger landscapes contain some of the last natural forest remaining in Asia. When tigers are lost from a protected area, there is an immediate demand to convert the area to serve short-term economic purposes. Studies show that forests lacking tigers suffer from high levels of degradation and are more likely to be affected by poorly planned infrastructure.

5.1 Need for a larger habitat network

India's tiger population has risen steadily in the past decade. After it dipped to 1411 in 2007 it is now estimated to range between 2500 and 3000. (National Tiger Conservation Authority, New Delhi & The Wildlife Institute of India, Dehradun). Although conservation efforts in the past two decades has seen considerable increase in the tiger population in Asia and particularly in India, the species, *Panthera tigris* is still classified under the category of endangered species by IUCN red list of threatened species.

The rise in population of tigers in India is indeed a very positive sign but most of the population is concentrated in the isolated patches of protected areas spread across the country.

"Focusing on these isolated sites may reduce the immediate risk of population extirpation within them, but neglecting corridors in a region experiencing rapid habitat loss, will not sustain tiger ecology, behaviour, and genetics" - (Wikramanayake et al. 2010).

Moreover, the overreaching concern in this regard is that these secluded patches gravely run the risk of total extinction in the event of a natural or anthropogenic stress.

Tigers can disperse over 100 km from their natal areas to establish territories, and immigration across the landscape of contiguous, suitable habitat likely played a large role in population recovery (Sunquist et al. 1999). However, tigers are reluctant to cross more than a few kilometers of unsuitable land cover (Smith 1993).

5.2 Examples from history signifying the need for habitat connectivity

5.2.1 Sukla Phanta Wildlife Reserve and Bardia National Park, Nepal.

In Nepal, reserve protection effectively ceased between 2002 and 2006, because of civil conflict, allowing poachers greater access in Sukla Phanta Wildlife Reserve and Bardia National Park. Populations crashed in both reserves, from 27 adults in 2005 to eight in 2008 in Sukla Phanta, and from 32–40 to 18 in Bardia (Government of Nepal 2010); yet, neither population was extirpated. Both reserves are linked to tiger reserves in India via corridors used by tigers (Wikramanayake et al. 2010a; Figure 3A), which likely allowed replenishment.

5.2.2 Russian Far East and China

In the 1940s, tigers nearly disappeared from the Russian Far East. Dispersal of tigers from north-eastern China, where large numbers of tigers remained at the time, is believed to have contributed to their subsequent recovery (Miquelle et al. 2010). Recently, habitat corridors across the Sino-Russia border allowed tigers to disperse from the Russian Far East and re-establish a population in the Changbaishan Mountains of northeastern China, where they had been extirpated by the 1990s.

5.2.3 Nagarahole National Park, India

In India's Nagarahole National Park, a camera-trap program between 1991 and 2000 indicated that tiger densities ranged from 7.3 to 21.7 tigers/100 km2, marked by frequent turnover of individuals due to mortality and dispersal from and into the park (Karanth et al. 2006). Despite the threefold fluctuation, the population was considered healthy and resilient (Karanth et al. 2006). Nagarahole is embedded within a landscape across the Nilgiri range in the western Ghats and connected to other reserves by habitat used by tigers. Population resilience in Nagarahole may be maintained by metapopulation dynamics associated with its connectivity to other reserves supporting tigers in this landscape, which has close to 300 tigers.

5.2.4 The despair of Sariska and Panna, India

The extirpation of tigers from Sariska and Panna, two of India's premier tiger reserves, in 2005 and 2009, respectively (Gopal et al. 2010), is evidence of how the lack of connectivity can preclude tiger population recovery and re-colonization. Because neither is connected to other reserves through habitat corridors, the Indian government had to transport tigers by helicopter to attempt to re-establish populations in these reserves.

Hence**, a strategy that maintains connectivity will allow greater gene flow between subpopulations and mitigate further inbreeding depression in these populations without the costs of translocations. This strategy is also necessary to achieve other important conservation targets, such as, to increase the resilience of tiger populations and maintain the natural ecology and behaviour of tigers for long-term persistence.**

5.3 Aim

To prepare landscape based strategies for forging habitat connectivity in a human dominated tiger landscape.

5.4 Objectives

OBJECTIVE 1

To define the significance of the study area as a high priority Tiger Conservation Landscape.

OBJECTIVE 2

To analyse the character of the landscape and further examine its connectedness in terms of in terms of tiger dispersal.

OBJECTIVE 3

To identify the focal species crucial for tiger habitat conservation while determining and enhancing their habitat requirements.

OBJECTIVE 4

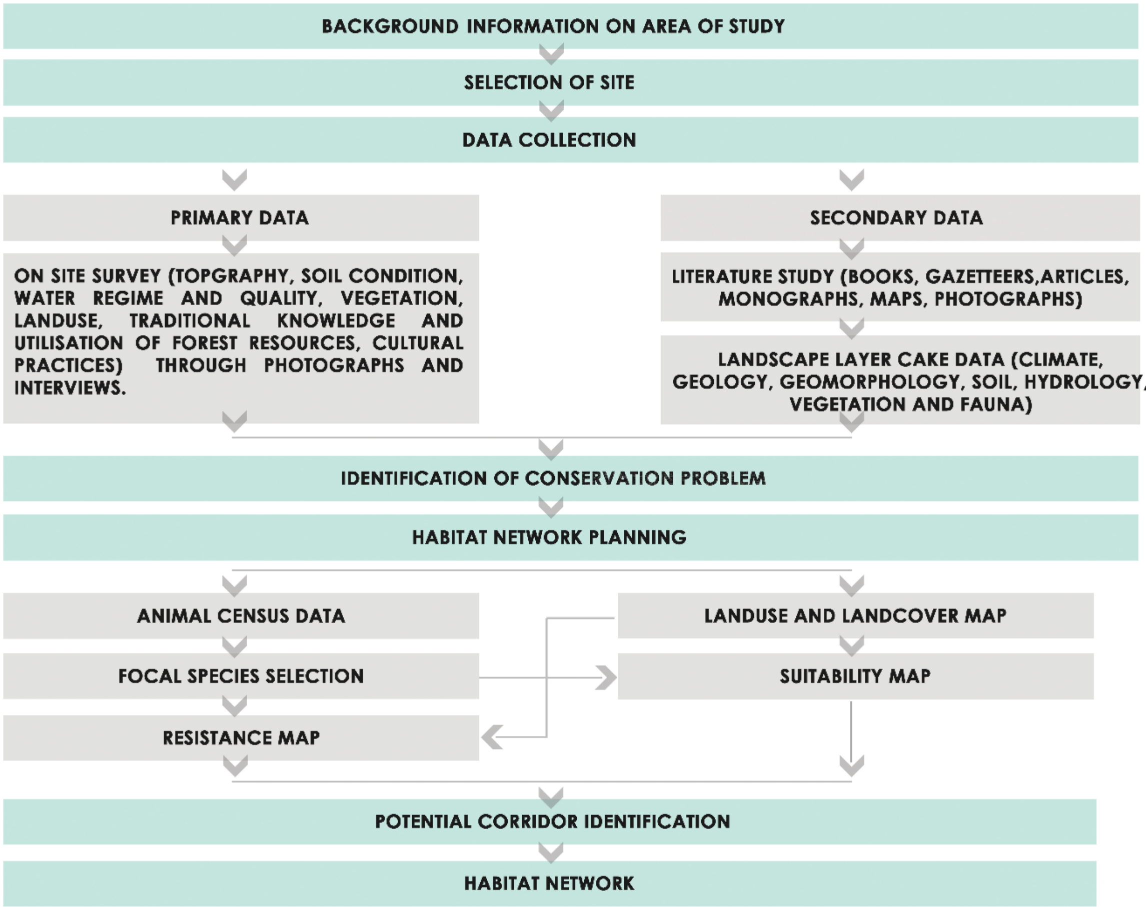
To generate habitat connectivity at critical zones and formulate strategies for holistic rejuvenation of tiger ecology in the study area.

5.5 Scope & limitations

The study is confined to the Satpura-Pench tiger corridor demarcated by the Wildlife Institute of India- WII.

5.6 Methodology

The methodology of the thesis will be as follows:



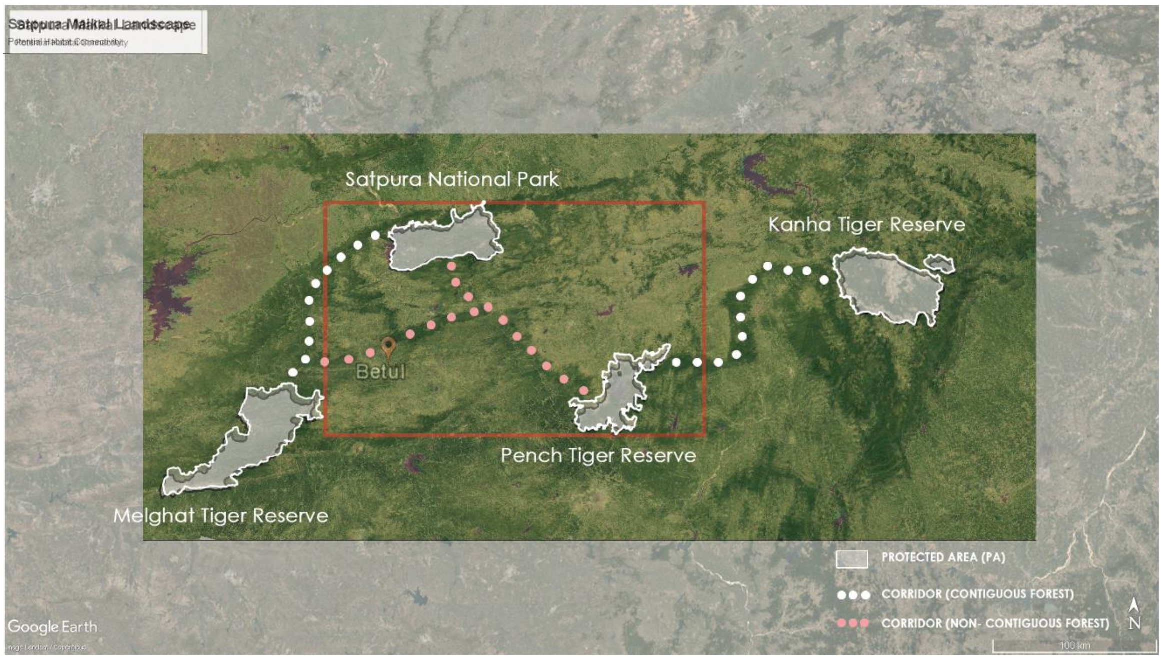
5.7 Expected Outcome

A holistic landscape conservation programme which results into recovery of lost biodiversity and thus allowing for wider tiger habitat in the region by enabling dispersal.

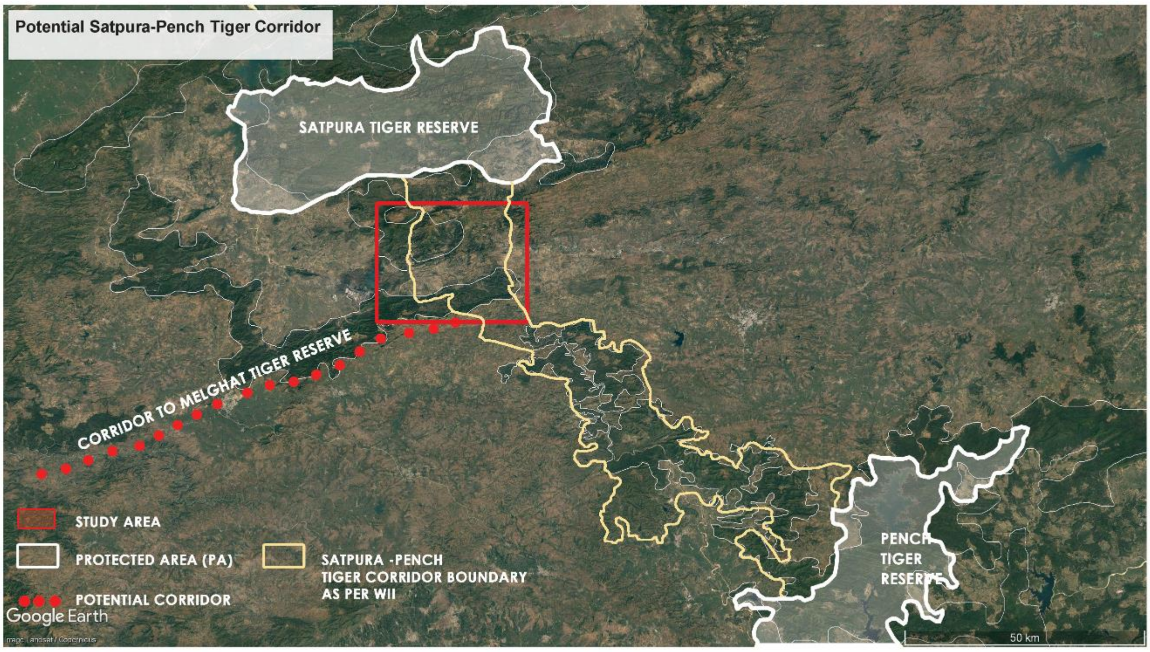
6. THE STUDY AREA

6.1 Site justification

The site selected for study falls under the **West Chindwara Forest division** in the Chindwara district of Madhya Pradesh, India. This site is a crucial part of a much larger landscape that is considered as a high-priority Tiger conservation site of international importance. As discussed earlier the Satpura-Maikal tiger conservation initiative thrives to connect four major Tiger reserves of central India, namely, Kanha Tiger Reserve, Pench Tiger Reserve, Satpura-Bori Tiger Reserve and Melghat Tiger Reseve, in order to allow gene flow among the Tiger metapopulation through dispersal. This landscape, if extended to Achanakmar and Tadoba, supports 30% of the World Tiger population and 19% of that in India with some of the largest contiguous forested tracks connected through wildlife corridors.



MAP 5 Non-Contigous forest tract in the Satpura Maikal Tiger Landscape



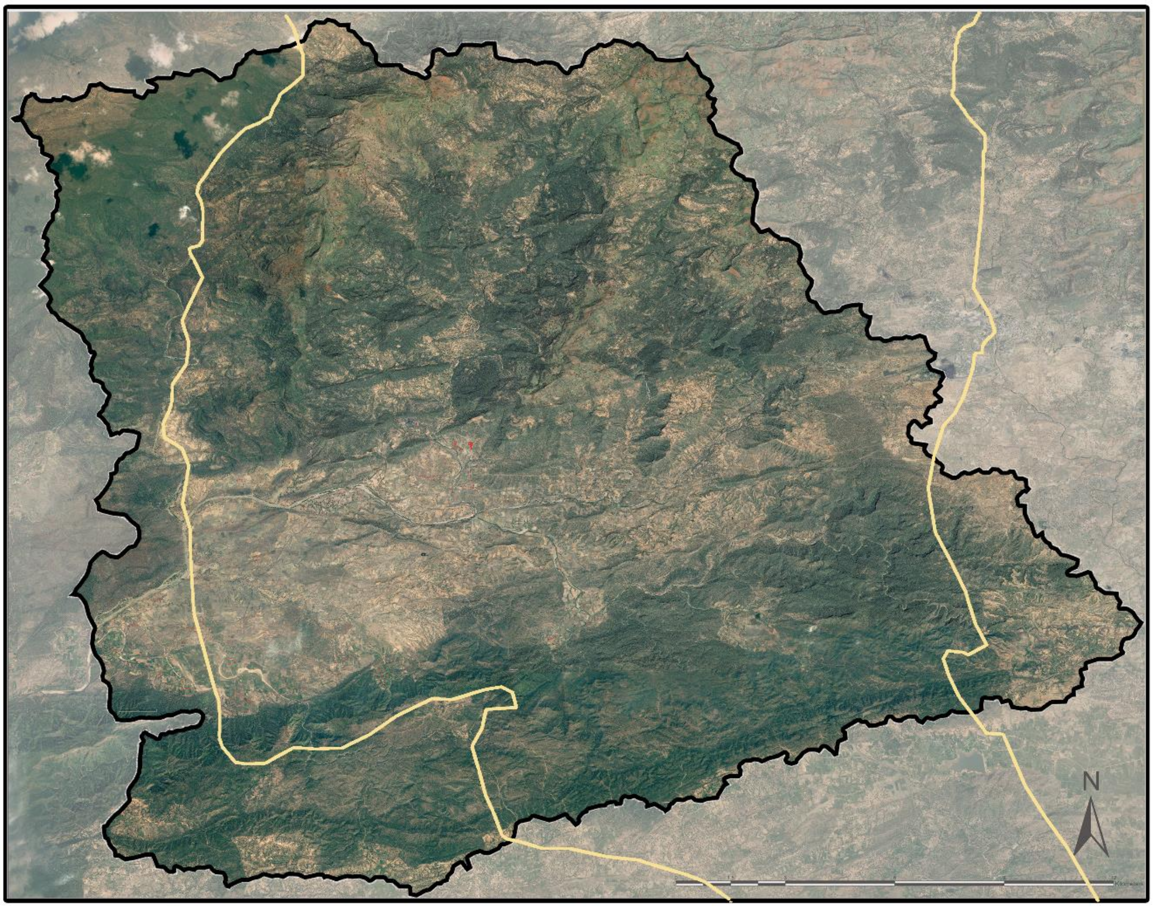
MAP 6: Demarcation of study site located at the junction of potential Satpura-Pench and Satpura-Melghat Tiger Corridor

The site under study is so critically located that it sits right at the junction of both the corridors mentioned above rendering it as a high priority site for conservation.

1. Proximity of study area to **Satpura Tiger Reserve: 20 km.**
2. Proximity of study area to **Pench Tiger Reserve: 95 km.**
3. Proximity of study area to **Melghat Tiger Reserve: 115 km.**

6.2 The site

The study area **(445 sqkms)** comprises of a constellation of hamlets, clustered in a bowl shaped depression formed by the southern limits of the Pachmarhee range of hills on the north and by a ridge formed by the vast expanse of table top highland to the south. This catchment marks the origin of the Tawa River, which flows towards the west before turning north and finally draining into the mighty Narmada flowing north of the Satpura range.

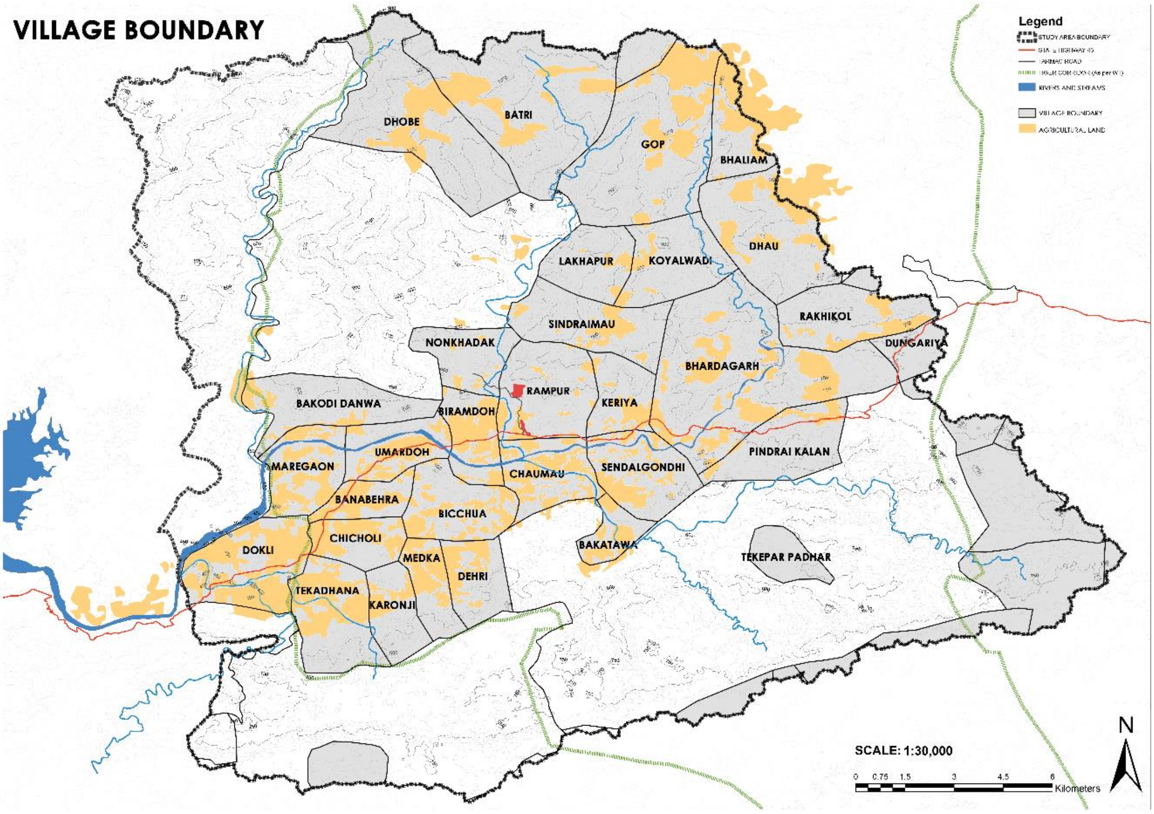


MAP 7: The Site: Headwater catchment of Tawa River

The Pachmarhee hills terminate abruptly, forming finger-like projections dropping from 1000m above msl to a rolling terrain intermitted by numerous streams fanning across its slopes. The skirts of the tabletop highland towards the south; however forms a continuous wall running from east to west along the length of the bowled valley.

6.3 Administrative setup

The area under study encompasses 30 villages lying in the Chindwara District, namely *Chandniya Koyalwadi, Kangra Sindrai Mau, Rampur, Chaumau, Keriya, Pindrai Kalan, Tekepar Padhar, Nonkhadak, Biramdoh, Bakodi Danwa, Maregaon, Dokhi, Umardoh, Banabehra, Chicholi, Tekedhana, Karonji, Medka, Dehri, Rakhikol, Dhau, Bhaliam, Gop, Batri, Dhobe and Lakhapur.*

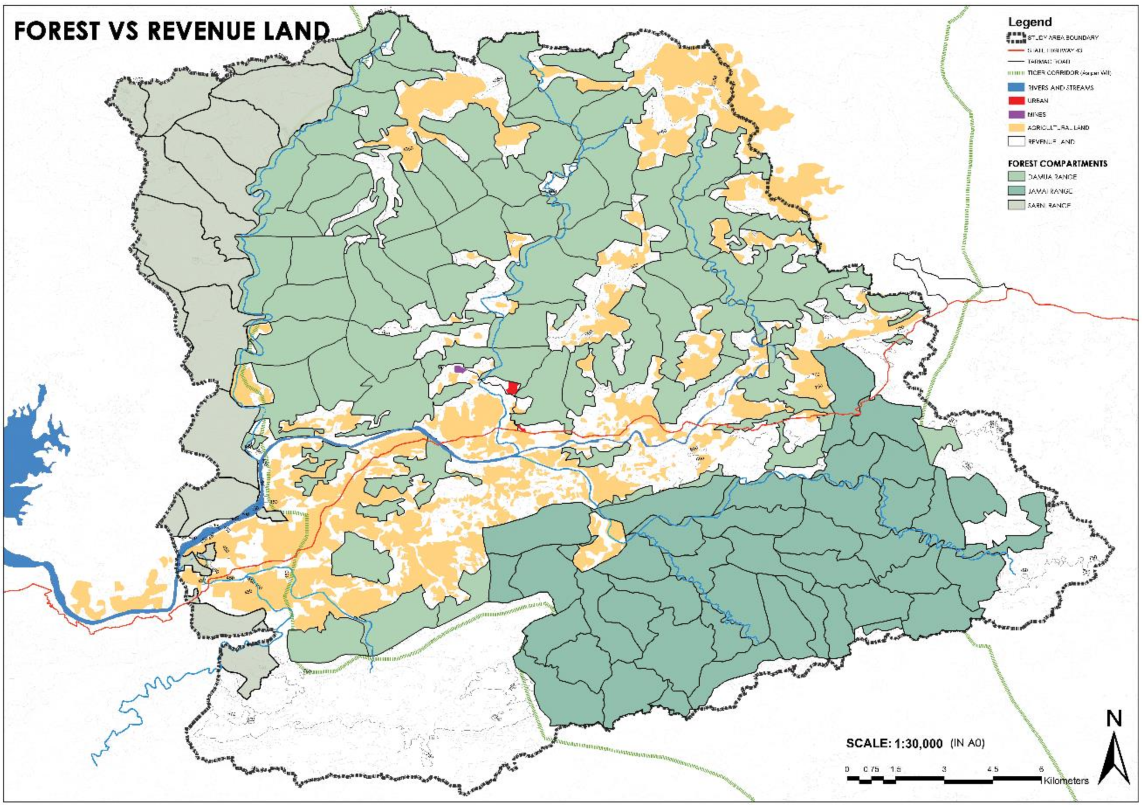


MAP 8: Village boundary

The revenue land comprises of most of the villages with vast agricultural lands in the flatter terrain and some chunks of settlements in the hills. While majority of the land in this area belongs to the West Chindwara division of Madhya Pradesh forest department, the land belonging to revenue department is located centrally and may play a major role in any policy level interventions concerning habitat connectivity.

The three forest ranges in this region area:

1. Damoa range to the north.
2. Jamai range to the south, and
3. Sarni range to the east.



MAP 9: Forest vs Revenue Land

6.4 Landuse and landcover

The area is predominantly forested with agricultural lands surrounding the settlements.

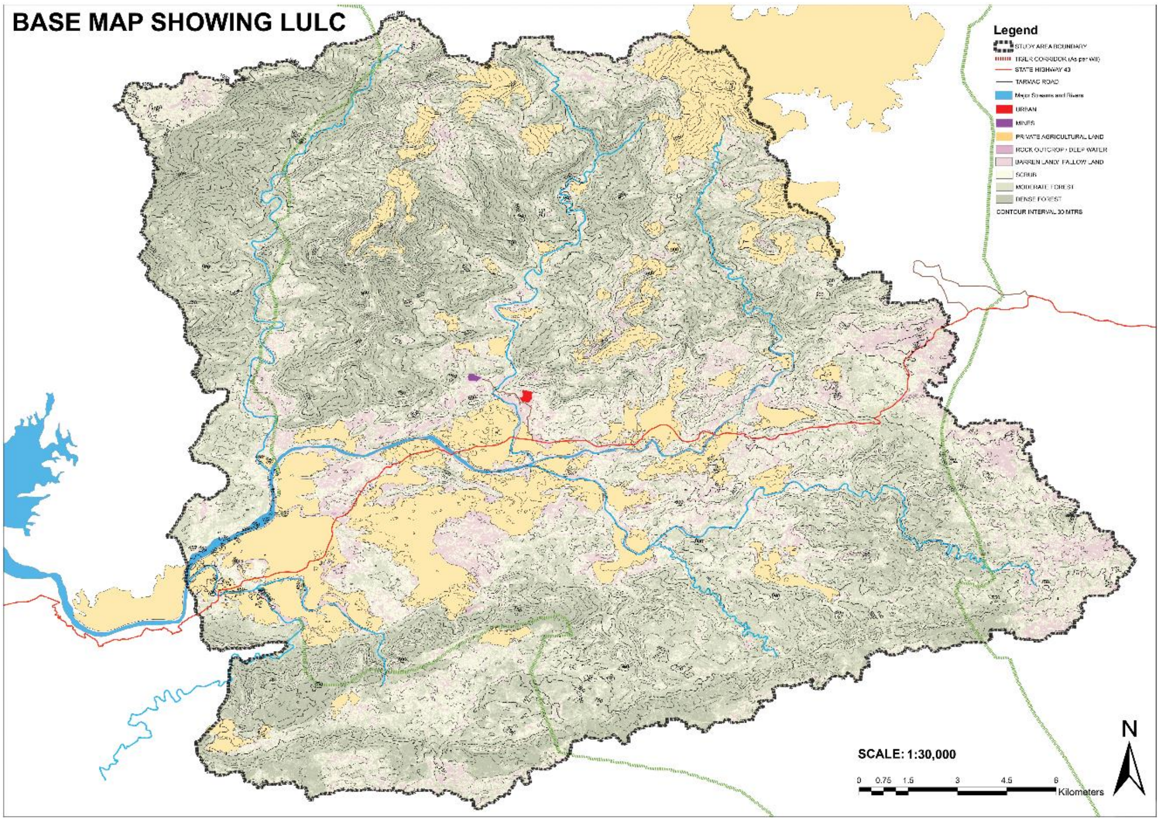
Rampur is the only semi-urban settlement hosting the Western Coalfields Coalmine and its supportive structures.

Road: State highway 19B is the only major road which cuts transversely across the spine of the study area. Villages in the plains are connected from the state highway by minor roads constructed under PMGSY (Pradhan Mantri Gram Sadak

Yojna). However the accessibility to the remote villages on the hills are poor and mainly through Kaccha roads.

Railway: There are no railway lines cutting across the study area. The railway lines terminate at Sarni to the west and Damoa to the right.

Streams: Tawa river originates in this catchment and is the biggest stream in this area. It is a seasonal stream at this reach of its course. Its receives water from two other large streams namely: Potia nala and Sanmati nala. Water from these three streams gushes in at high velocity during the monsoon and during the summers all of them are dry with some pools of water forming at intervals.



MAP 10: Landuse-Landcover (LULC)

6.1 Landscape matrix of the site

The study of the landscape grain is particularly interesting as its character changes not only in comparison to the plains and hills, but also in between the hill ranges flanking the north and south. Although forest is forming the dominant matrix of the hilly terrain, but that on the southern skirt appears to be more contiguous than that on the northern slopes, the later being higher and steeper. In the plains the forests can only be found in disconnected patches succumbed within the larger agricultural matrix. The landscape is rather more porous in the plains with other smaller patches like built-up, coal mines, stone quarry etc sprayed across its face. Landscape flows can be majorly experienced across the valley in the form of rich network of streams carrying water, sediments, minerals and certain biota, but the terrain has much higher potential for flows of energy and biota.

6.2 The people

Around 20 percent of the geographical area of the country is covered with forests and many of these forest areas have tribal or traditional communities dependent on forest resources for their subsistence and livelihoods. This study area is no exception for that matter, as majority of the folks are tribal communities, viz. Mawasi (Korku) and Gonds, dwelling in these forest for centuries. For such communities the forests are an integral part of their life with important and irreplaceable social and cultural values.

While the Gonds are settled more around the plains, the Korkus are found much within the forests. The attachment to the forest and its resources is more profound among them.

6.2.1 Culture

6.2.1.1 Korkus

Korkus have derived their name from the combination of the word ‘koru’ meaning man and ‘ku’ which makes it plural meaning tribal men (Russell and Hiralal, 1916). Korkus are initially believed to be a hunting gathering community dwelling in the forests of Satpura ranges on either sides of the river Tapti.

The Korku tribe lives in small groups of huts made of grass and wood. They socially consume liquor made from the flowers of the Mahua tree which is prepared in almost all the houses.

Korkus, like other Hindus, are atheists. They worship nature as well as Hindu god and goddess like, Mahadev, Mahavir, Ravan, Meghnad, Muthwa, Khera dev, Sun, Moon, Narmada & Tapti Mai etc.

Korku Legend: Worship and Origin of Tiger

Korkus say about the origin of tiger as follows. “Mahedeo and Parvati lived together. One day Mahadeo went to forest for wood. He delayed because of cutting wood. Parvati was waiting with preparing the meal for him. At last Parvati was getting angry and formed out of human excrements a tiger and sent him into the jungle to bring Mahadeo. Mahadeo saw an animal was coming and threw a piece of wood and said to get lost and you will remain as a jungle dog forever”

6.2.1.2 Gonds

The Gonds are among the largest tribal groups in South Asia and perhaps the world. As "hill people," they traditionally have been associated with hills and uplands in the Deccan Peninsula. Many Gonds live around the Satpura Hills, Maikala Range and Son-Deogarh uplands, and on the Bastar plateau. A typical Gond village has several hamlets. Each consists of homesteads that house extended families. Houses are usually built of mud and thatch. They consist of a living room, kitchen, veranda and a shrine for clan gods.

Like many other tribes, Gonds worship a high god known as Baradeo, whose alternate names are Bhagavan, Sri Shambu Mahadeo, and Persa Pen. Baradeo oversees activities of lesser gods.

6.2.2 Economy

Most of the men work as labourers in bigger towns and cities of Madhya Pradesh. The second major source of income is from Agriculture and Non Timber Forest Produce. But the income from both the later sources combined is only about one-third from that of labour.

Locally, the Gonds are more involved in agriculture while the Korkus depend majorly on NTFP.

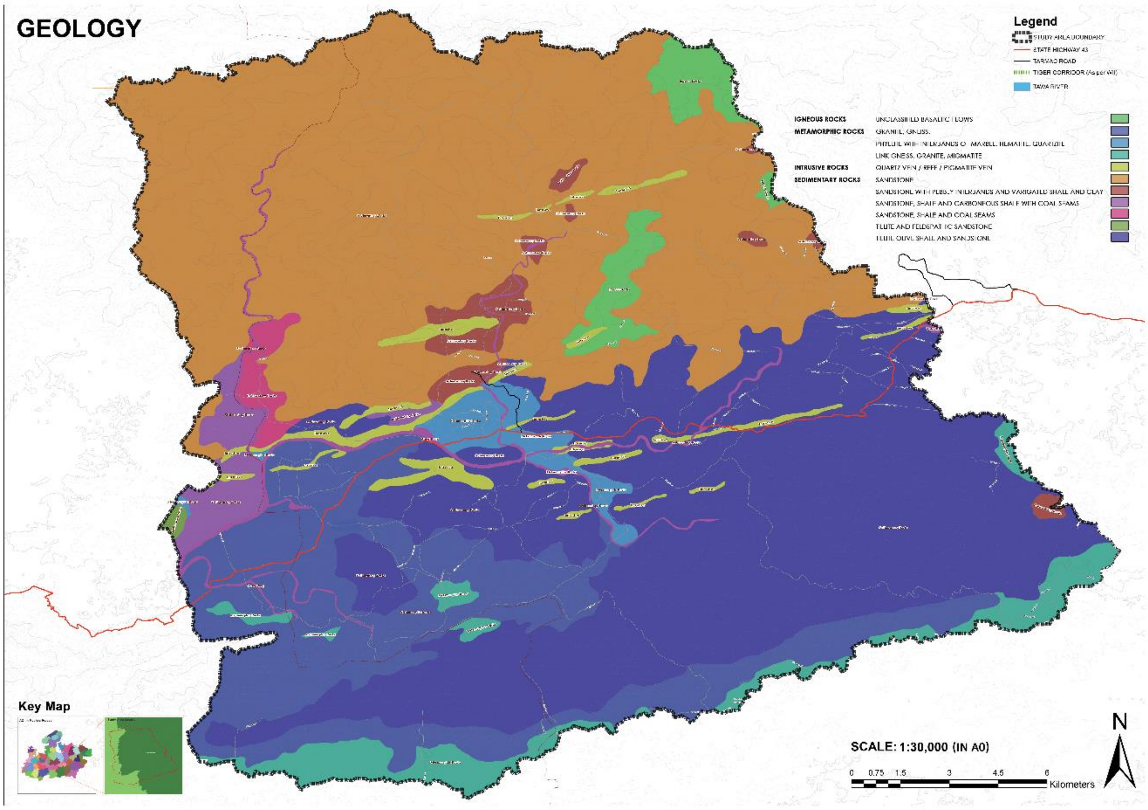
7. LANDSCAPE CHARACTER ANALYSIS

7.1 Geology

The geologic formation of the landscape, which is essentially a **Tectono-Sedimentary evolution**, can be traced back to the early Triassic Period (251 MYA).

Casshyap and Khan (2000) argue that the Gondwanan Satpura Basin of central India, comprising an approximately 1300 m thick sequence of the Pachmarhi, Denwa and Bagra Formations, was subjected to at least three major tectonic events. They further elaborate that the first tectonic event is manifested by the onset of Early Triassic **Pachmarhi sedimentation**, which is marked in the basal part by a sudden increase of conglomeratic, pebbly, gritty to coarsegrained cross-bedded sandstone. This contrasts with the underlying fine elastics of the Late Permian **Bijori Formation**. The pebbly coarse sandy facies of the Pachmarhi Formation represents a braided river assemblage, overlain by a meandering river facies of the **Denwa Formation**, with river systems flowing dominantly from southeast to northwest. The progressive change in lithofacies and grain size upward from Pachmarhi to Denwa implies that the source area became peneplained and that the basin stabilised. During the prolonged gap of non-deposition, following the Mid-Triassic break in sedimentation after deposition of the Denwa Formation, a second tectonic event resulted in the widespread faulting and uplift of Permo-Triassic Gondwana sediments and basement rocks, respectively, to the south and north of the Narmada-Son Lineament Zone of Peninsular India. A third tectonic event is manifested by Late Jurassic-Early Cretaceous **Bagra conglomerate** and sandstone-shale facies in the northern part of the Satpura Basin.

This formation, which unconformably overlies the Precambrian, and Permian and Triassic Gondwana formations, represents proximal and distal facies of an alluvial fan deposit in a rifted basin with uplifted highlands to the north. This tectonism, representing the termination of continental Gondwana sedimentation, preceded the widespread eruption of the Deccan Traps (65 Ma) after the break-up of India from Antarctica. As a consequence, a northward sloping, peninsular craton was tilted southward and small rift basins developed along peripheral parts to the north, west and along the east coast of Peninsular India.



MAP 11: Geology

The upper pleatue is majorly composed of the bagra formation with sandstone as the major component accompanied by shale.

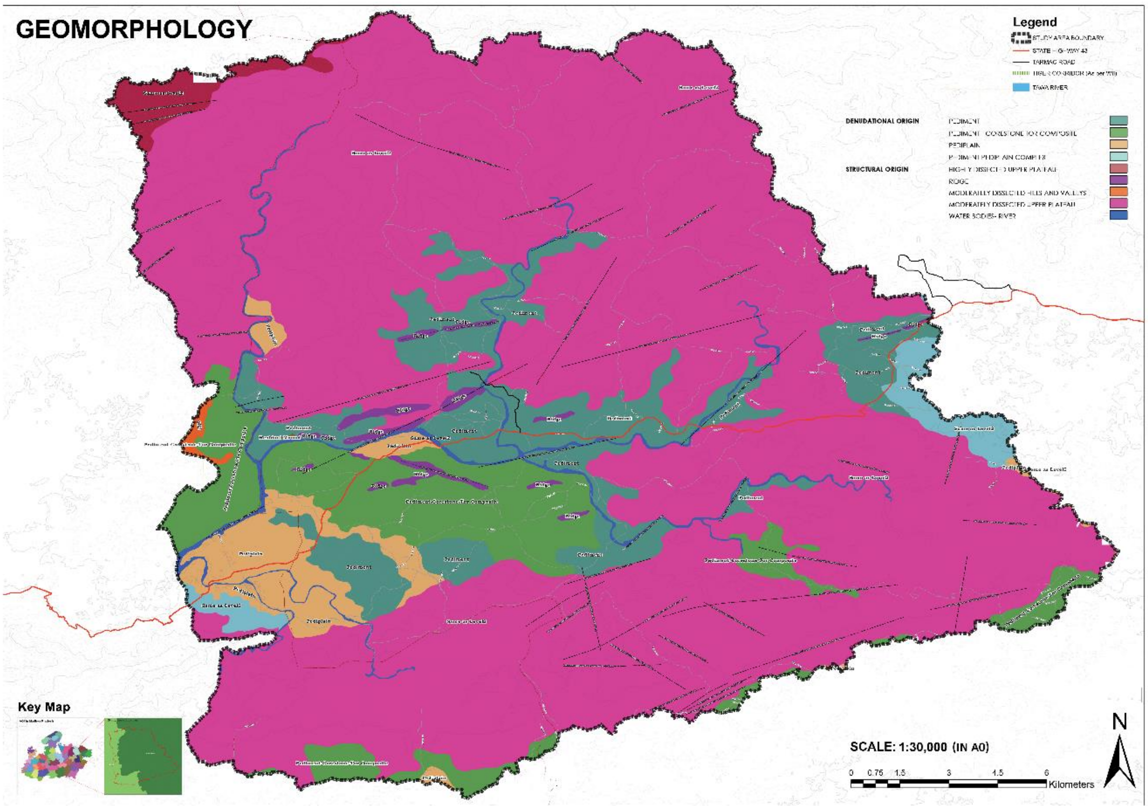
Metamorphic and intrusive igneous rocks of the Denwa formation can be seen, mainly in the low lying areas.

Small segments of extrusive igneous rocks of the trap formation are present, which have surfaced due to volcanic eruptions.

7.2 Geomorphology

The geologic evolution of the region has given rise to a geomorphologic configuration like a bowl. The predominant geomorphologic signatures in the study region are mainly comprised of two origins:

1. Structural origin: formed by tectonic or volcanic events.
2. Denudational origin: formed by the erosion of elements of structural origin.



MAP 12: Geomorphology

The plateaus of structural origin form a ring of elevated mass around the plains which are formed due to denudation.

The course of tectono-sedimentary processes have led to the uplifting of deep forming igneous rocks on to the surface, upon which long period of sedimentation have resulted in massive sandstone layers. These sandstone layers were again elevated due to further tectonic events. The later period of volcanic eruptions had pushed the layers upwards forming table top highlands. Magma had leaked through the cracks within the rocks to cover the peaks with basalt. But basalt being highly erosive have flowed down the slope due to climatic agents of erosion (wind and water) and thus revealing the much harder igneous and sedimentary rock structures.

The major geomorphologic signatures seen in this area are:

1. Plateau
2. Pediment
3. Pediplain
4. Intrusive ridges.

7.2.1 Plateau

A plateau, also called a high plain or tableland, is an area of highland, usually consisting of relatively flat terrain that is raised significantly above the surrounding area, often with one or more sides with steep slopes. Plateaus can be formed by a number of processes, including upwelling of volcanic magma, extrusion of lava, and erosion by water and glaciers. Magma rises from the mantle, causing the ground to swell upward; in this way, large, flat areas of rock are uplifted. Plateaus can also be built up by lava spreading outward from cracks and weak areas in the crust.

Figure 13 Upper Plateau at site

The sandstone formations comprises the most widespread geomorphologic unit of structural origin of the region in the form of the upper plateau.

7.2.2 Pediment

A pediment is a very gently sloping (.5°-7°) inclined bedrock surface. It typically slopes down from the base of a steeper retreating desert cliff, or escarpment, but may continue to exist after the mountain has eroded away. It is formed by erosion of elements of structural origin. It develops when sheets of running water (laminar sheet flows) wash over it in intense rainfall events.

Figure 14 Pediment area at site

The pleatue of sandstone is moderately dissected in nature, therefore its continuous erosion has led to the formation of broad gently sloping expanse of rock debris known as pediments, extending outwards from its slope. As the scarps retreated over geologic time the pediments made way for vast pediplain areas.

7.2.3 Pediplain

A pediplain is a concept in geology and geomorphology that describe an extensive plain formed by the coalescence of pediments. The processes through which pediplains forms is known as pediplanation.

Pediplanation is linked to scarp retreat in the following way: as scarps retreat over geological time pediments migrate and extend over large areas. The result is that the surface is eroded chiefly backward and that downward erosion is limited.

Figure 15 Pediplain area at site

7.2.4 Intrusive ridges

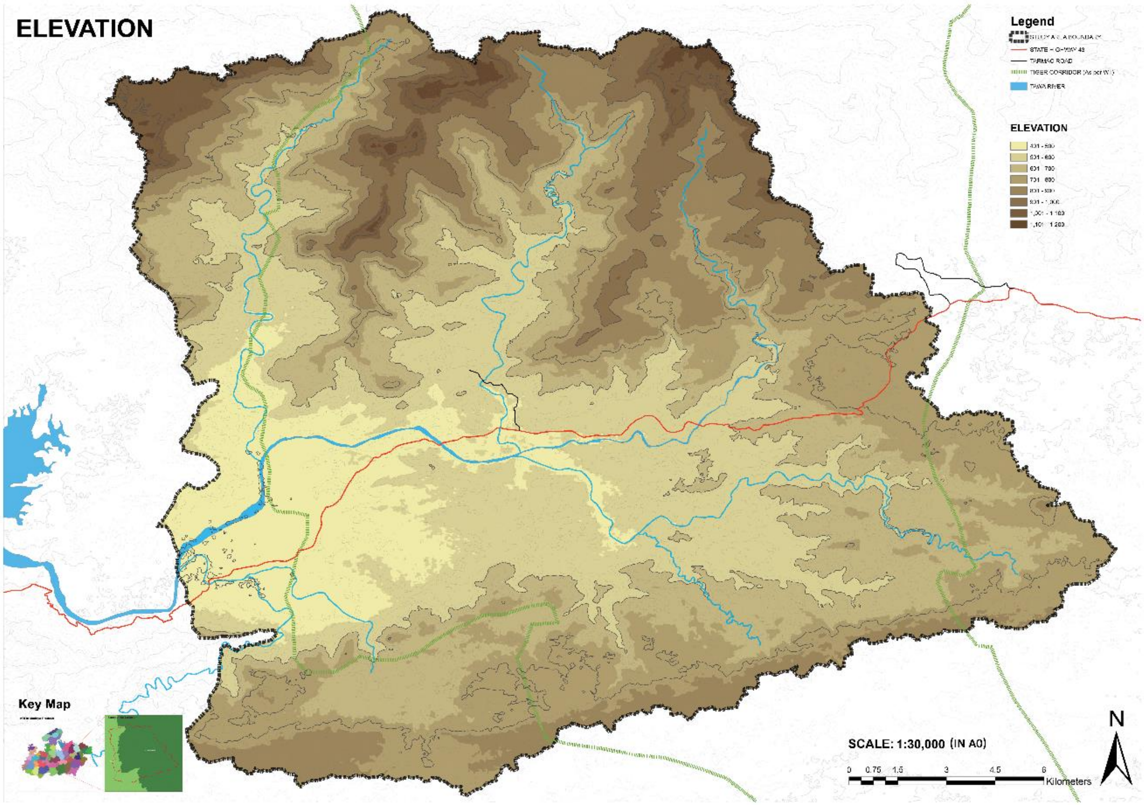
Igneous rocks which form by the crystallization of magma at a depth within the Earth are called intrusive rocks. As the cooling down of the magma beneath the surface of the earth is a slow process hence the rocks formed are very hard. When such rocks come above the surface of the earth due to uplifting by tectonic events or further volcanic uplifts, they form ridges known as intrusive ridges.

The surfaced intrusive formations are chiefly composed of quartz. Being highly resistant to weathering due to its crystalline structure, the quartz zones have remained untouched as ridges sitting on lowering and retreating pediments.

Figure 16 Intrusive ridge at the backdrop

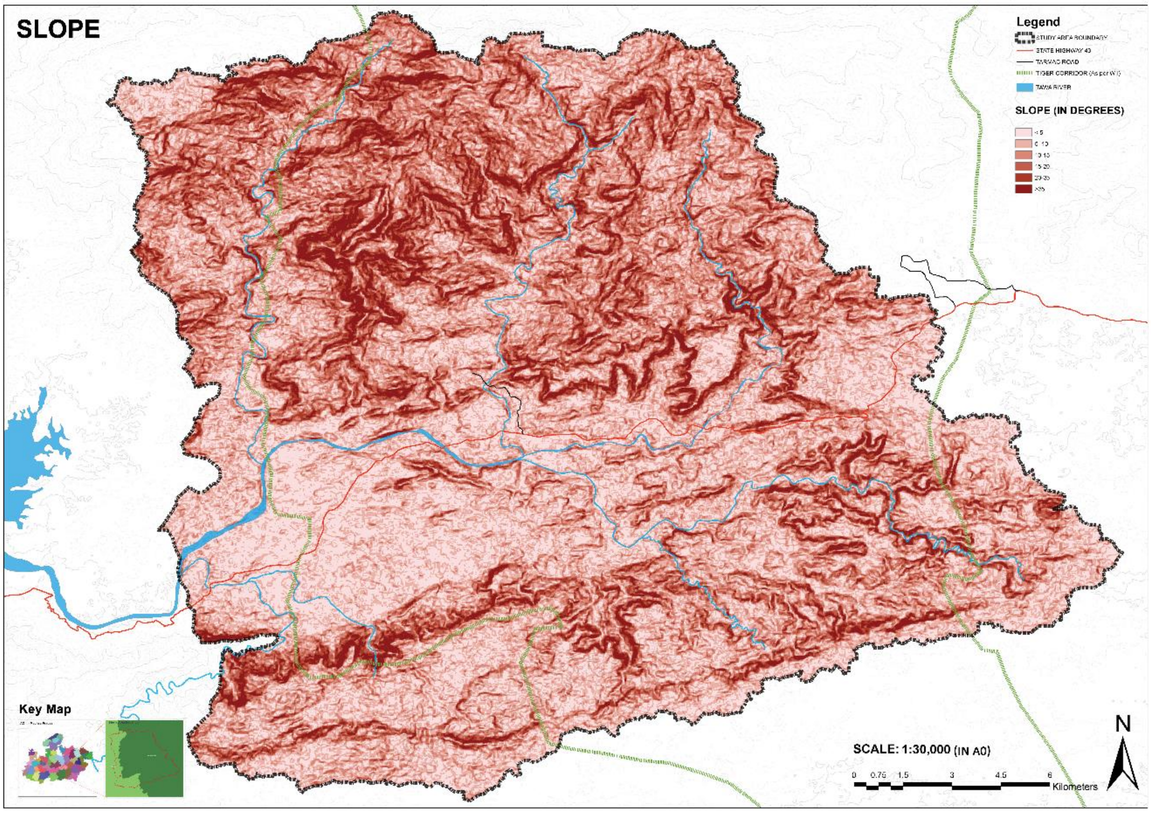
7.3 Elevation and slope

The geomorphologic evolution of the region has led to the formation of the plateau with steep edges and finger-like projections on the north. These masses drop down from 1000m above msl to a gently undulating terrain which rolls down towards the west.



MAP 13: Elevation

The slope at the shoulder of the plateau range from 35 degrees to 48 degrees. Although it doesn't render it as an escarpment but is prone to severe erosion.



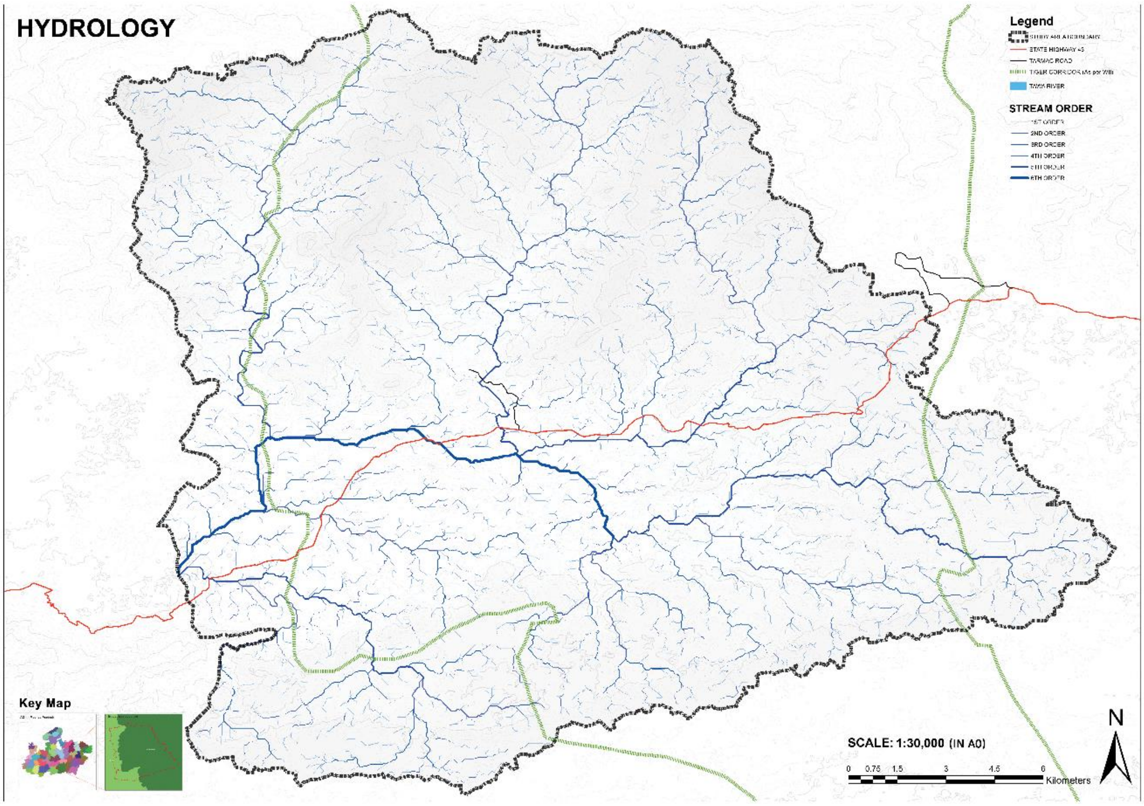
MAP 14: Slope

7.4 Hydrology

The bowl shaped depression at the center receives quantum of water as streams from all directions accumulate through the valleys formed between the finger-like projections of the plateau. High elevation areas have more number of streams (more drainage points) for water to drain quickly ; while low lying areas have less number of streams leading to slow drainage.

The predominant drainage pattern is dendritic. Such patterns arise when to the streams are flowing down a slope due to the terrain which has uniform lithology, and where faulting and jointing are insignificant. Hence, in the study region the dendritic pattern is significantly observed in the plateau and pediment regions.

The streams in this area are of order 1 to 4 and hence are seasonal in nature. They form in V-shaped valleys; and have high velocity. Erosion and transportation of matter is high.



MAP 15 Hydrology

In the more gentle pediplain area the drainage pattern is either braided or slightly meandering. Here the rate of flow is variable and braiding gives signs of coarse sediment deposition during slower flows.

The order of the streams washing the pediplain area is 5 and 6, which suggests that it is partially perennial in nature.

From source to mouth, substrata of the stream varies at different points, from rocky to gravel to silt due to gradual breakdown of parent material.

7.5 Geohydrology

Stream orders observed on site are between 1 and 6 which indicates the streams area annual (1 to 4) and slightly perennial in nature.

Factors controlling ground water storage depend on the following parameters:

1. Rainfall availability as the source of water.

2. Drainage characteristics have a role in the distribution of runoff and indicate an infiltration scheme and it governs the behavior of water flow on terrain surface vertically and horizontally.

3. Rock type for which the lithological character governs the flow and storage management

4. Slope is another influencing factor, and it controls water flow energy, which plays a role in facilitating water flow in the basin.

5. A dendritic drainage pattern indicates homogenous subsurface strata of the study area. The drainage pattern replicates mainly structural/litho-logic controls of the underlying rocks. They are generally characterized by a treelike branching system, which indicates the homogenous and uniformity.

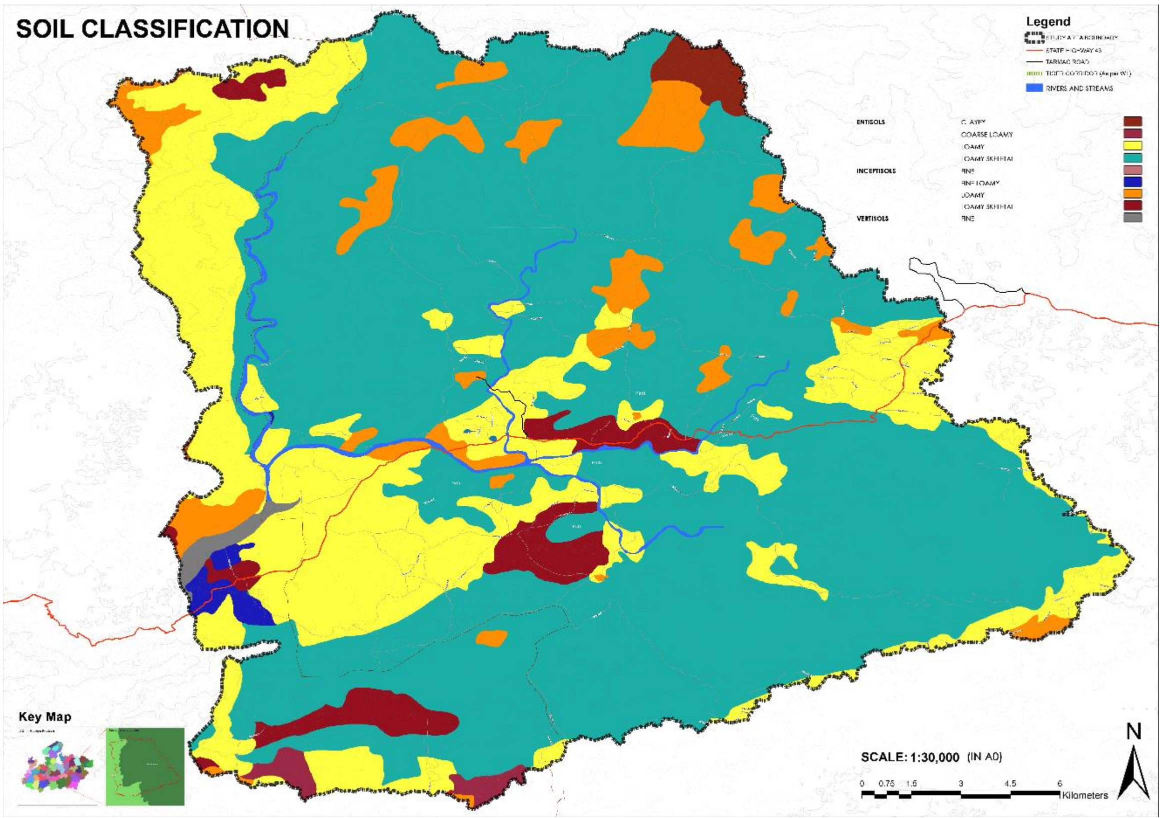
6. The topography plays a major role in ground water percolation. In steep slopes i.e. >35%, runoff speed is higher resulting in less infiltration , while in shallow areas the runoff speed is decreased increasing the infiltration rate.

This region receives average rainfall of 850-1000mm but the ground water in the study area is very low. This is because the slope is steeper at the areas where water-absorbing substrata of sandstone is available. And where the slope is gentle the substrata is mainly of metamorphic rocks. The structural lineaments running across the ridges and the streams are the main sources of ground water percolation.

7.6 Soil

The soil in this region are broadly classified into three broad orders:

1. Inceptisols
2. Entisols
3. Vertisols



MAP 16: Soil Classification

7.6.1 Inceptisols

A soil of an order comprising freely draining soils in which the formation of distinct horizons is not far advanced,

They are often found on fairly steep slopes, young geomorphic surfaces, and on resistant parent materials. Land use varies considerably with Inceptisols. A sizable percentage of Inceptisols are found in mountainous areas and are used for forestry, recreation, and watershed. They form quickly through alteration of parent material.

7.6.2 Entisols

Entisols are defined as soils that do not show any profile development other than an A horizon. An entisol has no diagnostic horizons, and most are basically unaltered from their parent material, which can be unconsolidated sediment or rock.

They are characterized by great diversity, both in environmental setting and land use. Many Entisols are found in steep, rocky settings. However, Entisols of large river valleys and associated shore deposits provide cropland and habitat for millions of people worldwide.

7.6.3 Vertisols

A vertisol in the Soil Classification is a soil in which there is a high content of expansive clay known as montmorillonite that forms deep cracks in drier seasons or years. Alternate shrinking and swelling causes *self-mulching*, where the soil material consistently mixes itself, causing vertisols to have an extremely deep A horizon and no B horizon.

Vertisols typically form from highly basic rocks, such as basalt, in climates that are seasonally humid or subject to erratic droughts and floods, or that impeded drainage. Depending on the parent material and the climate, they can range from grey or red to the more familiar deep black.

The upper plateau is covered by loamy-skeletal entisols owing to moderately high erosion. This soil is somewhat excessively drained and the surface stoniness is moderately high.

Streams drain these soils into the valleys where they are broken down and temporarily deposited as loamy entisols. However, wherever these soils got the opportunity to remain for a longer period, horizons have developed and hence loamy inceptisols were formed. These loamy soils can retain nutrients and water while allowing excess water to drain off. Stoniness is much less in loamy soils and depth is slightly more.

Figure 17: Stony eroded soil of upper plateau

Figure 18: Entisols at Pediplains; No horizons

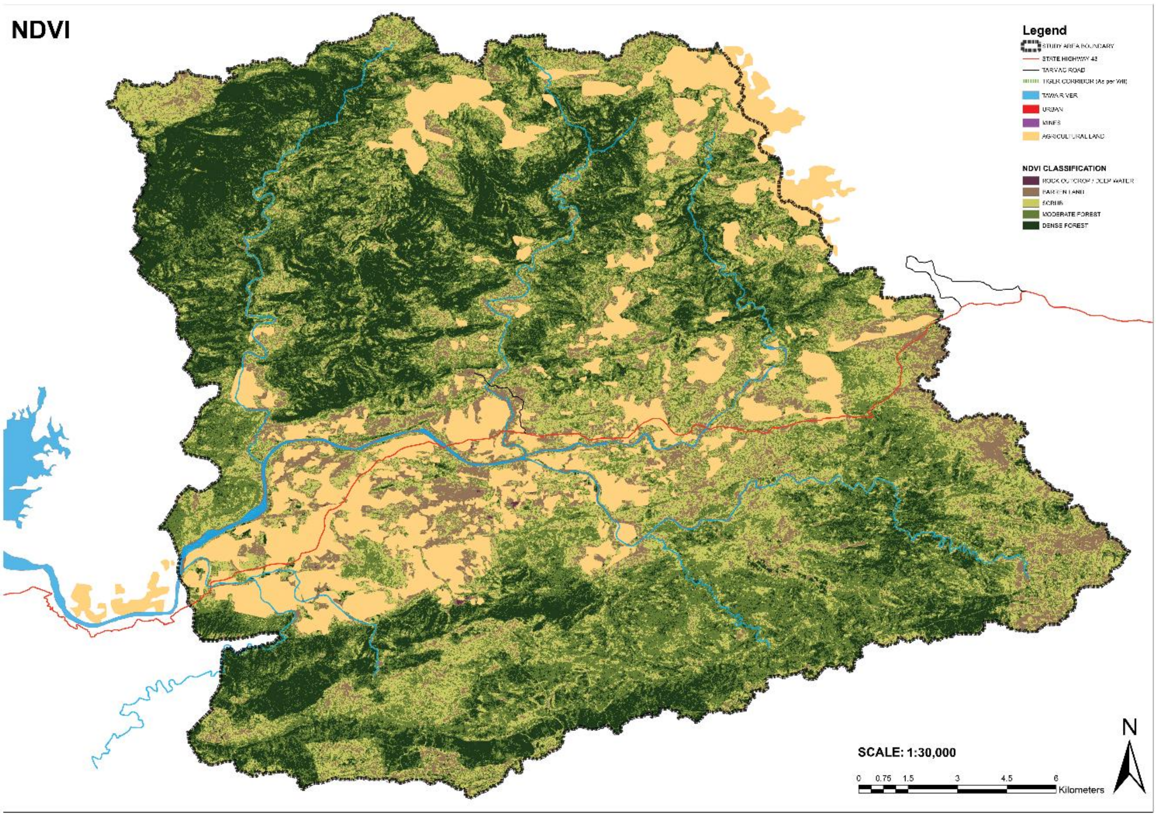
Towards the mouth of the satpura reservoir fine inceptisols are seen due to furthur breakdown of the loamy soil and continous deposition by the tawa river in the dam locked flatter land.

7.7 Flora and fauna

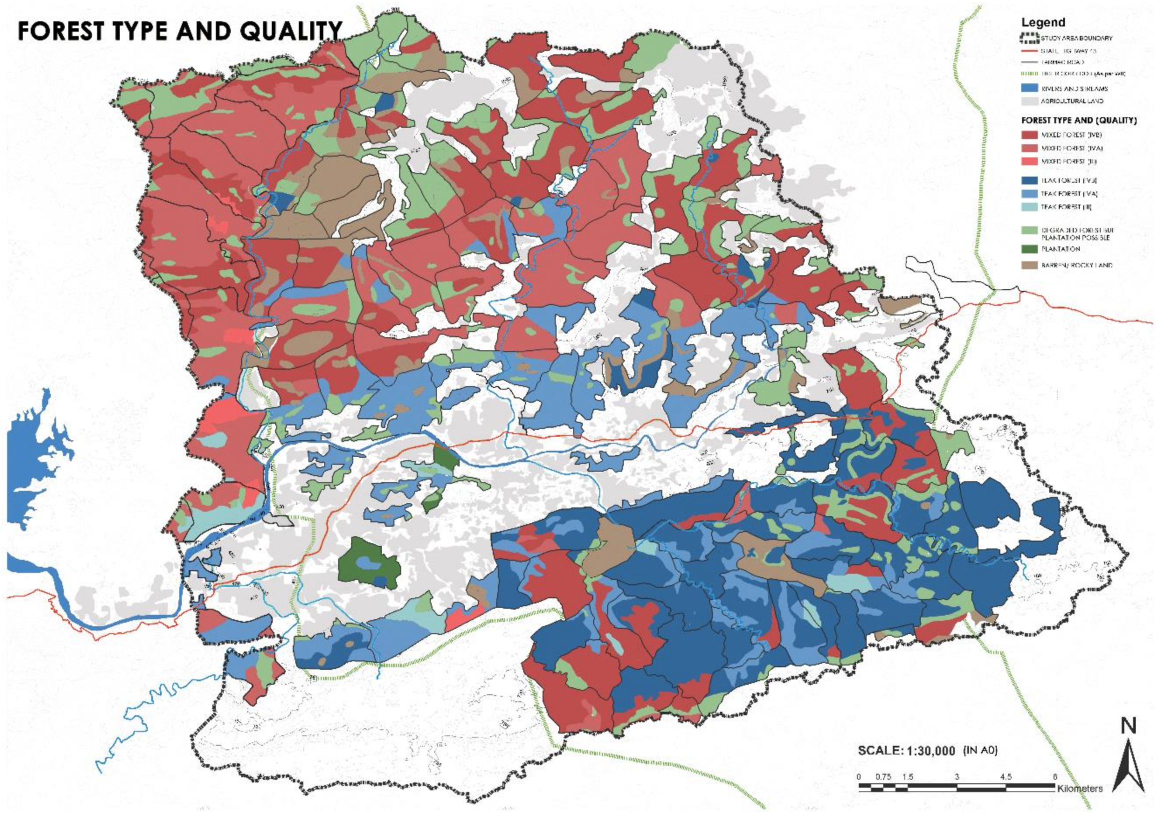
7.7.1 Vegetation

As mentioned earlier the region experiences the confluence of two major biomes of the country: The moist deciduous ecoregion and southern dry deciduous ecoregion.

The study site however experiences more of the southern dry deciduous ecoregion.



MAP 17: Vegetation Density (NDVI)



MAP 18: Forest type and quality

The two main forest type of the study area are:

- **Dry Teak Forest** and **Southern dry mixed deciduous forest.**

1. DRY TEAK FOREST(5A/C1b) [>50% teak]

The teak forests are confined to relatively deeper soils which are well drained. These forests are associated with:

UPPER CANOPY

- Dhaura (Anogenissus latifolia)
- Tendu (Diospyros melanoxylon)
- Amaltas(Cassia fistula)
- Faldu (Mitragyna spp.)
- Salai (Boswellia serrata)

LOWER CANOPY

- Nyctanthus arbortitis
- Woodforida fruiticosa
- Helicteres isora
- Grewia hirsuta
- Indigofera pulchella
- Carissa spp.
- Holarrhena antidysenterica

2. SOUTHERN DRY MIXED DECIDUOUS FOREST (5A/C3):

Species which can grow on thin stony and well drained soil constitute majority of the mixed forest and are found in areas with very steep slopes. Certain degree of low quality teak is also available here.

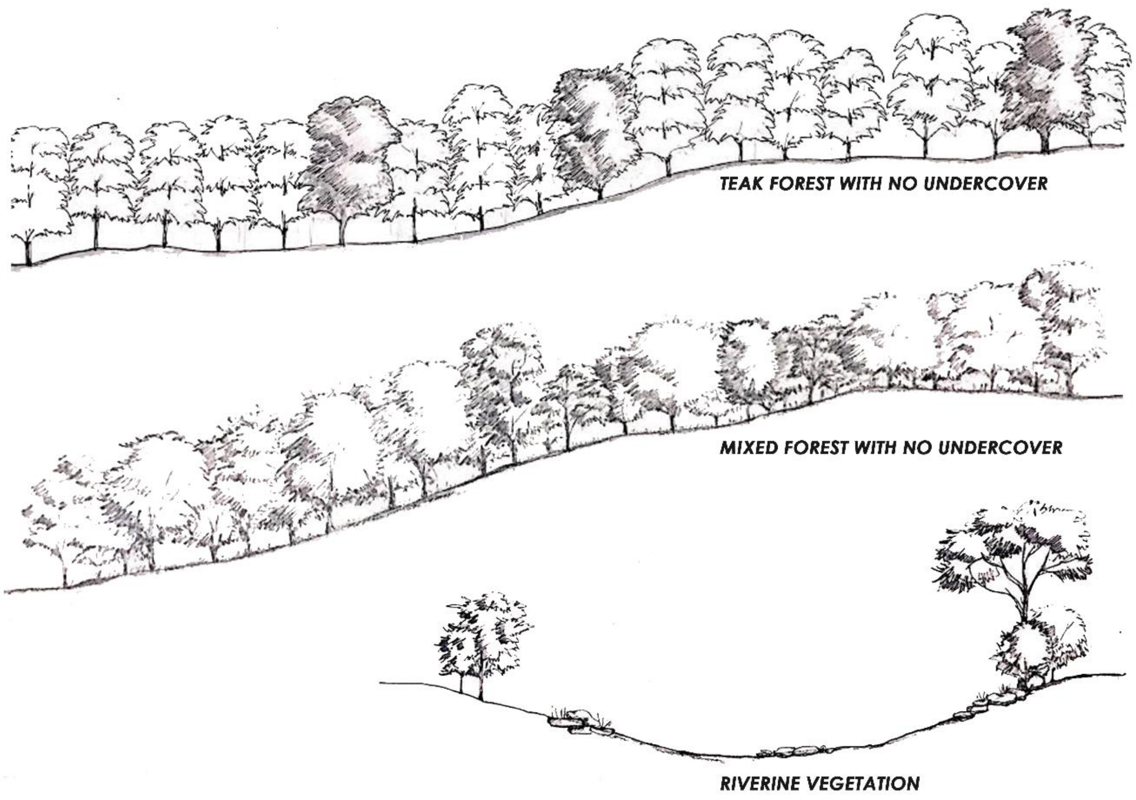
Many species growing in this forest type are common to the moist deciduous forest.

- Dhaura (Anogenissus latifolia)
- Terminalia tomentosa
- Diospyros tomentosa
- Choloxylon swietenia
- Hardwikia binata
- Boswellia serrata
- Soymida febrifuga
- Mitragyna parviflolia
- Mahuka indica
- Lagerstromia parviflora
- Aegle marmelos
- Butea monosperma

Riverine forests are found in valleys and are mainly composed of Arjun, Jamun, Mango, Amla, Khair.

Key Characteristic of the forest:

- Dominant stands attain height of 18-20m.
- Rich diversity can be seen in the upper and middle storey but the lower storey suffers in this region as no perennial grasses are present. Though annual grasses and weeds appear during monsoon.
- The canopy is comparatively open allowing good percentage of grass and herb to grow.
- The forest floor is thickly covered with dry twigs and leaves in flatter lands but totally barren on slopes.
- Forest is prone to fire due to anthropogenic activities.



MAP 19: Sections of typical forest structures at site

Table 2: Major tree species on site and their habitat

MAJOR TREE SPECIES PRESENT ON SITE

MAJOR TREE SPECIES AVAILABLE	HABITAT
Tectona Grandis **Sagon / Teak**	Well drained soils derived from sandstone or black cotton soil on slopes.
Madhuca longifolia **Mahua**	*Grows on stony ground but does best on deep loamy soil.*
Terminalia elliptica **Saaj**	*Badly drained, binding clay soils.*
Pterocarpus marsupium **Beeja**	*Deciduous forest, on soils derived from sandstone or metamorphic rock.*
Schleichera oleosa **Kosam**	*Low hills with dry, boul-dary, well drained soils*
Phyllanthus emblica **Aamla**	*Open Forest. Thrives best on Deep loamy soil but will tolerate poor, gravelly, even alkaline soil.*
Buchanania cochinchinensis **Achar / Chironji**	*Prefers open areas but also found in mixed deciduoud jungle.*
Butea monosperma **Palash**	*Badly drained clay soil. Pioneer species, does not prosper under shade.*
Ziziphus mauritiana **Ber**	*Does best in savannah woodland or disturbed land on sandy loam or gravel.*
Acacia catechu **Khair**	*Open forest on dark soil or gravelly sandstone. Ideal habitat is riverine tracts.*
Terminalia chebula **Harra**	*High plateaux (1000m above) on iron rich yellow soils.*
Syzygium cumini **Jamun**	Grows in moist places like river banks.
Mangifera indica **Aam**	*Well watered well drained sandy or gravelly soil.*
Desmodium oojeinense **Tinsa**	*Well drained hilly terrain. clearly prefers soils from sandstone.*
Terminalia arjuna **Arjun**	*Moist tracts especially riversides in Central India*

7.7.2 Fauna

Due to the lack of perennial grasses in the study area, the presence of Ungulates is very rare. However the undisturbed ranges just north of the site shows considerable rise in ungulate numbers.

The rich upper canopy is a home hoards of Langoors and decent number of peacocks.

Among others Wild Boars, Chinkaras, Rabbits and Foxes are the noteworthy species in the region. Very occasional Leopard and Tiger kills are also seen, mainly during the winter months.

Although Tigers do not regularly tread this area but the rare incidents of presence of Satpura tigers in Pench confirms the dispersal of tigers through this region by choice.

8. ECOLOGICAL ANALYSIS

8.1 Identifying critical landscape flows in the study region

A holistic landscape ecological restoration would require identification of appropriate potential landscape flows which would be most representative of the general ecosystem type and will use a significant part, if not all, of the landscape under study.

The landscape flows can be broadly categorised under

1. Abiotic and;
2. Biotic

On the basis of the landscape character analysis, the more significant Abiotic Landscape Flows that would impact the process of ecological restoration in the region are:

- Water (Streams),
- Soil,
- Nutrients and Organic matter.

And the critical potential Biotic Landscape flows identified in the region are:

- Umbrella Species- Here, a specie placed high on the food web and with significantly large area requirement is chosen. In, this study the priority specie Panthera tigris, Tiger, is chosen. If natural resources are managed to ensure the range and distribution of these species, then species at the lower trophic levels will also benefit.

- Indicator Species- To target the Umbrella specie, here Tiger, we need to target the habitat restoration of Indicator Species. These focal species mainly form the prey base for Tiger and any good tiger habitat has flourishing number of these indicator species.

8.1.1 Abiotic flows

According to Spiralling Concept of River System by Webster (1975), strong interactions between the streams and the riparian systems represents important exchange and flow of nutrients, matter and species.

Owing to this transport mechanism, rivers and streams should be key systems in the development of ecological networks.

The site features numerous streams fanning down the slopes on three sides and flowing out on the west.

Hence this system of streams is the most widespread abiotic flow and promoting or arresting this flow would regulate the dynamics of movement of nutrients, organic matter and species.

8.1.2 Biotic flows

The biotic flows in the study region is the primarily narrowed down to Umbrella species and indicator species movement.

8.1.2.1 UMBRELLA SPECIE – Panthera tigris

BEHAVIOURAL CHARACTERISTICS

Tigers are primarily territorial and solitary animals having large and owned territories. The size of these territories vary according to prey base availability. For abundant prey base availability the territory sixes are as small as 5sqkm for male and 2sqkm for females. However these territory sizes may expand upto 150sqkm for males and 20sqkm for females. Generally several female territory overlay upon a male territory, but two alpha male territories will never overlap.

The only time tigers roam as a pack is while raising the young. When the young come of age they disperse up to 100- 250kms form new territories, but if the landscape structure is not favourable for a stretch of 4-5kms dispersal will be

Table 3: Behavioural Characteristics of Tiger

Social Structure	Territory	Dispersal	Succesive Day Movement
Territorial and solitary except during mating season and when with cubs.	Size of territory depends largely up on prey availability. **Male 5 - 150 sqkm** **Female 2 - 20 sqkm** One male territory include several female territory	Can disperse **100 - 250 kms** if landscape structure is favourable but if only **5 - 10 kms are unfavourable** migration will stop.	**Male 4.2 - 1.7 kms** **Female 2.9 - 0.6 kms**

(Source: An ecology based method of defining priorities of large mammal conservation: Tiger as case study. Wikramanayake 1998)

restricted by choice. Successive day movement can be around 4kms for males and 3kms for females.

The movement areas for tigers are generally open areas like grasslands, dried riverbeds and stream banks. Stream banks are particularly preferred for dispersal because they dehydrate very quickly and need to replenish their water requirements. Also is hot climates like in the study area, tigers like to soak inside water bodies and are excellent swimmers by nature.

8.1.2.2 INDICATOR SPECIES SELECTION

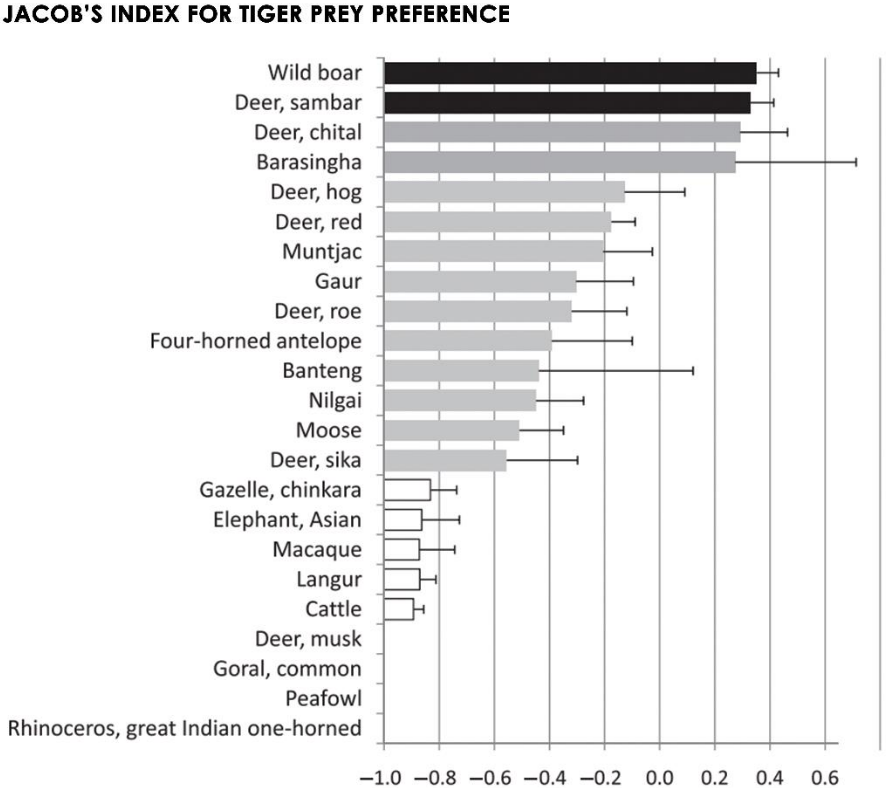
The first step towards the selection of indicator species to understand the preferred prey base of the umbrella specie.

TIGER PREY PREFERENCES

This study compares two other studies for identifying the preferred prey base for Tiger.

The first table shows the Mean Jacob's Index for tiger prey preference. The mean Jacob index was calculated on the basis of worldwide collection of tiger scat samples and kill information over a period of time.

Table 4 Mean Jacob's Index for Tiger prey preferences.



(Source: Prey preferences for the Tiger, Panthera tigris. Hayward et al. 2011)

Table 5: Prey preference for tiger of Dry Deciduous forest

PREDATOR	PREY BASE		PERCENTAGE	CONFIDENCE INTERVAL
TIGER *Panthera tigris* 	**CHITAL**	*Axis axis*	*32.66*	*28.38–36.71*
	SAMBAR	*Cervus unicolor*	*22.30*	*18.24–26.35*
	CHINKARA	*Gazella gazelle*	*0.45*	*0.1- .62*
	WILD BOAR	*Sus scrofa*	*9.01*	*6.17–11.71*
	MUNTJAC	*Muntiacus muntjak*	*2.48*	*1.13–3.83*
	FOUR HORNED ANTELOPE	*Tetracerus quadricornis*	*1.13*	*0.23–2.03*
	LANGUR	*Semnopithecus entellus*	*2.25*	*0.90–3.60*
	GAUR	*Bos gaurus*	*23.87*	*19.90–27.93*
	OTHER SMALL PREY		*5.87*	*5.87*

(Source: Prey abundance and food habit of tigers (Panthera tigris tigris) in Pench National Park, Madhya Pradesh, India. Biswas 2002)

The successive table indicate the tiger prey preference study done at dry deciduous forest of Pench national park.

TIGER PREY SPECIES FOUND IN THE SATPURA REGION

The major tiger prey species found in the Satpura landscape are:

- Chinkara *Gazella gazelle*
- Chital *Axis axis*
- Four horned antelope *Tetracerus quadricornis*
- Gaur *Bos gaurus*
- Muntjac *Muntiacus muntjak*
- Sambar *Cervus unicolor*
- Wild Boar *Sus scrofa*

SELECTION FOR PRIORITY INDICATOR SPECIES FOR HABITAT RESTORATION

Interpolating the prey availability in the Satpura region and the conclusion derived from analysing tiger prey preferences, it is well resolved that that there is a clear preference for Sambar, Chital and Wild Boar and Gaur.

Gaur, being a species is confined to the moist deciduous tracts of the Satpura region is discarded from this selection process due to its inability to adopt to dry deciduous tract which the study area experiences.

Wild Boar has the ability to adapt to a wide range of environments and no major mediation is required to sustain its propagation.

Hence **Chital (*Axis axis*) and Sambar (*Cervus unicolor)*** are the two pioneer indicator species (referred as Ungulates from here on) chosen for habitat restoration for the umbrella specie, the **Tiger *(Panthera tigris).***

8.2 Factors influencing umbrella specie movement

8.2.1 Tiger habitat requirements

Table 6: Tiger habitat requirements

PREY BASE	WATER	COVER
The most important criteria is the availability of Prey base.	Tigers need to drink rapidly and reduce their body heat by entering into water bodies especially in hot climates.	Needs cover to hide while hunting and to protect cubs.

8.2.2 Factors impeding tiger movement in study area

PREY BASE	WATER	COVER
NO	NO	MARGINAL
LACK OF PALATABLE GRASSES AND SHRUBS.	EXCESSIVE RUNOFF	ADEQUATE FOREST COVER BUT LACK OF UNDERSTOREY
INDUCED FOREST FIRES OVER GRAZING	SLOPING TERRAIN WHICH DRAINS WATER AWAY FROM THE ZONE	

8.3 Factors influencing priority indicator species movement

8.3.1 Ecology of Chital and Sambar

Chital and Sambar have distinctive optimal habitat requirements that is unique to each specie.

Table 7: Ecology of Ungulates found at Satpura region

UNGULATES IN FOUND IN SATPURA REGION			BEHAVIOUR				OPTIMAL HABITAT	WATER REQUIREMENT	DIET CHOICE
			DISTANCE FROM WATER	FORAGE AVAILABILITY	VARIANCE IN SLOPE	HUMAN IMPACT			
	CHITAL	*Axis axis*	NEGETIVELY IMPACTED	POSITIVELY IMPACTED	NEGETIVELY IMPACTED	NEGETIVELY IMPACTED	*Short Grassland close to Water source.*	*Highly dependent and continous drinkers.*	*Highly dependent and continous drinkers.*
	SAMBAR	*Cervus unicolor*	NEGLIGIBLE IMPACT	POSITIVELY IMPACTED	POSITIVELY IMPACTED	NEGETIVELY IMPACTED	*Forest with shrubs and tall grasslands.*	*Moderate and drinks at intervals*	*Moderate and drinks at intervals*
	CHINKARA	*Gazella gazelle*	NEGLIGIBLE IMPACT	POSITIVELY IMPACTED	POSITIVELY IMPACTED	NEGETIVELY IMPACTED	*Open woodlands and scrublands.*	*Long period with-out water.*	*Long period with-out water.*
	WILD BOAR	*Sus scrofa*	NEGLIGIBLE IMPACT	POSITIVELY IMPACTED	NEGLIGIBLE IMPACT	NEGLIGIBLE IMPACT	*Woodland, Marsh and Farmland*	*Moderate*	*Moderate*
	MUNTJAC	*Muntiacus muntjak*	NEGETIVELY IMPACTED	POSITIVELY IMPACTED	NEGLIGIBLE IMPACT	NEGETIVELY IMPACTED	*Dense Forest with good understorey*	*Highly dependent*	*Highly dependent*
	FOUR HORNED ANTELOPE	*Tetracerus quadricornis*	NEGETIVELY IMPACTED	POSITIVELY IMPACTED	POSITIVELY IMPACTED	NEGETIVELY IMPACTED	*Short Grassland close to Water*	*High and continous*	*High and continous*
	GAUR	*Bos gaurus*	NEGETIVELY IMPACTED	POSITIVELY IMPACTED	NEGETIVELY IMPACTED	NEGETIVELY IMPACTED	*Moist Deciduous forest. (Not aplicable in study area)*	*High and continous*	

SOURCE -
JHONSON ET AL (2002). MOVEMENT PARAMETERS OF UNGULATES AND SCALE-SPECIFIC RESPONSES TO THE ENVIRONMENT.
KILLEEN ET AL (2014). HABITAT SELECTION DURING UNGULATE DISPERSAL AND EXPLORATORY MOVEMENT AT BROAD AND FINE SCALE WITH IMPLICATIONS FOR CONSERVATION MANAGEMENT.
BAGCHI ET AL. (2003) HABITAT SEPARATION AMONG UNGULATES IN DRY TROPICAL FORESTS OF RANTHAMBHORE NATIONAL PARK RAJASTHAN.
BAGCHI ET AL (2003) NICHE RELATIONSHIPS OF AN UNGULATE ASSEMBLAGE IN A DRY TROPICAL FOREST. BEN, CLEMENT, HABITAT CONSERVATION OF CHINKARA HABIT (GAZELLE GAZELLE) IN PROTECTED AREAS OF MAHARASHTRA AND GUJARAT.

POSITIVELY IMPACTED (green)
NEGETIVELY IMPACTED (red)
NEGLIGIBLE IMPACT (yellow)

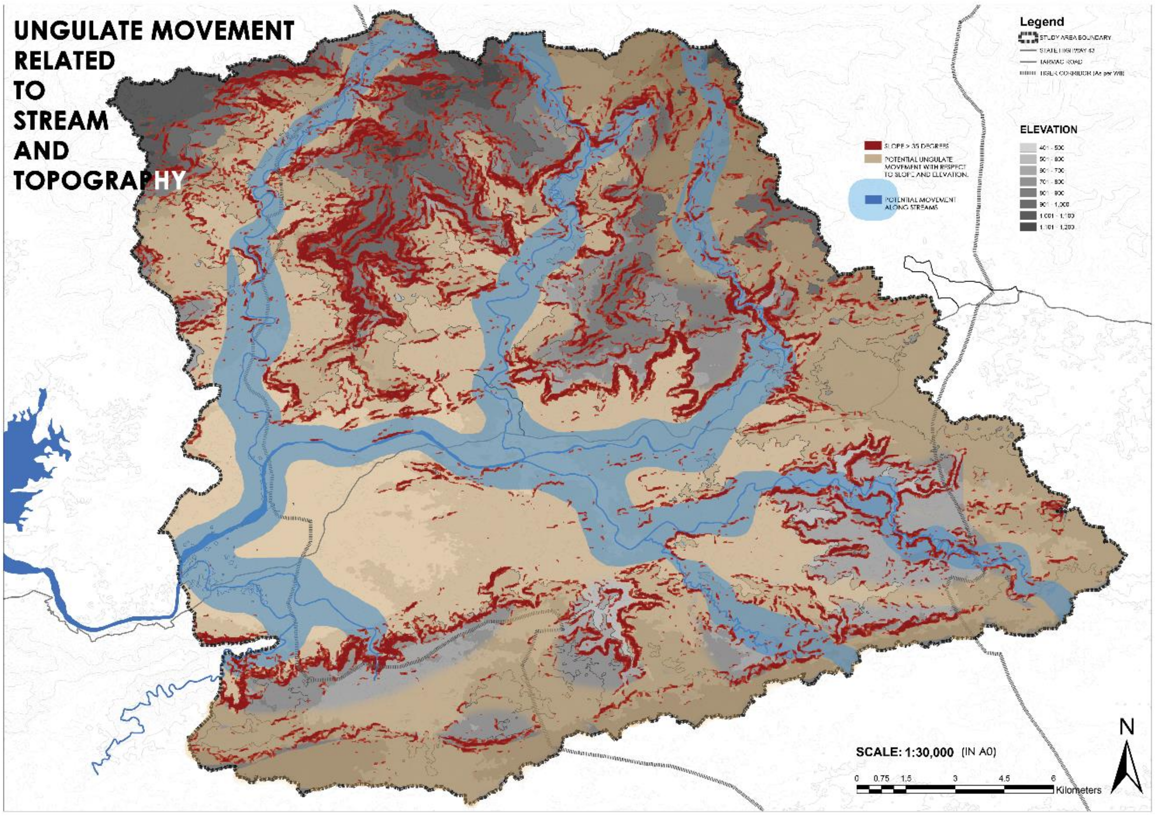
Chital is a preferential grazer specie which favours short grasslands and stay very close to water sources.

Sambar on the other hand is a preferential browser favouring forested areas with shrubs and tall grasses. They are not as much dependent on water sources as chital but frequent water sources at intervals.

Topographically Sambars can be understood to favour the hill slopes whereas chital strictly restrict themselves to stream banks and valleys.

Both these species however maintain distance from anthropogenic influences.

8.3.2 Potential ungulate movement possibilities with respect to physical factors.

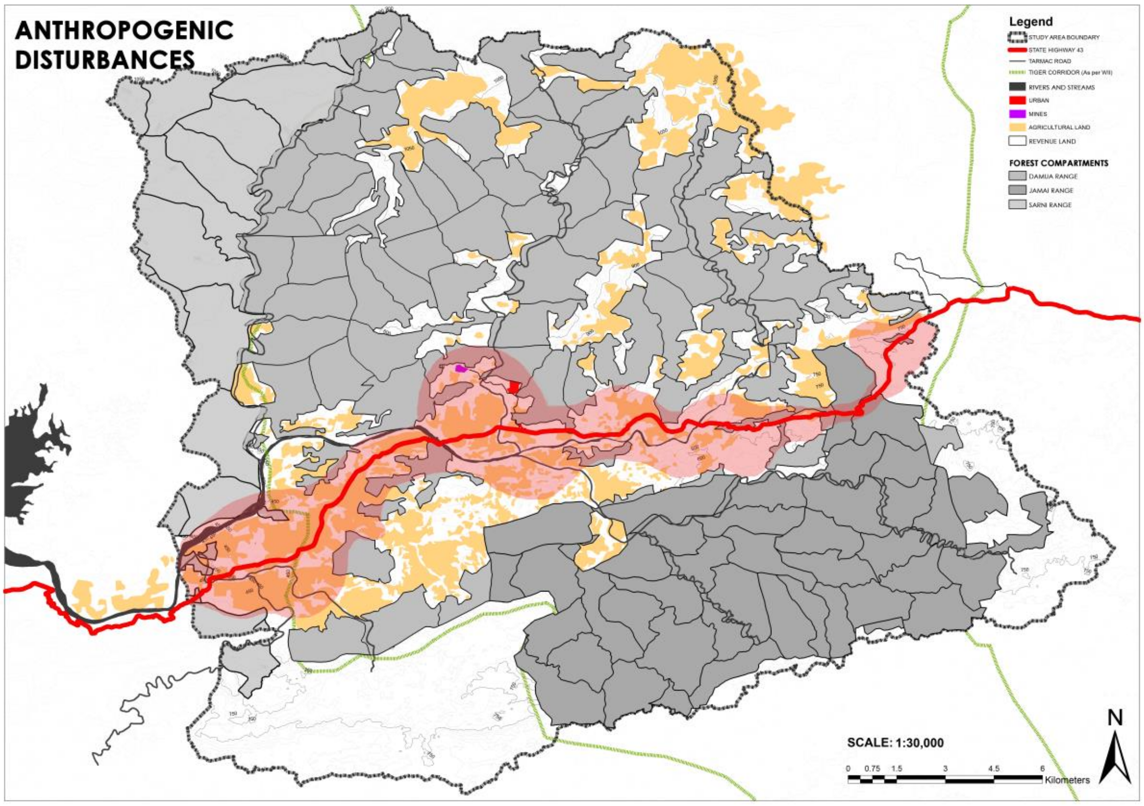


MAP 20 Potential ungulate movement with respect to physical factors.

- STREAM: The streams form the prime corridors of movement as per the spiralling concept of river systems and behavioural analysis of Chital and Sambar.

- STEEP SLOPE: Although Sambar prefers browsing on slopes, but slopes greater than 35 degrees are considered a limiting factor for the dispersal of both the ungulates.

8.3.3 Disturbances restricting potential ungulate movement



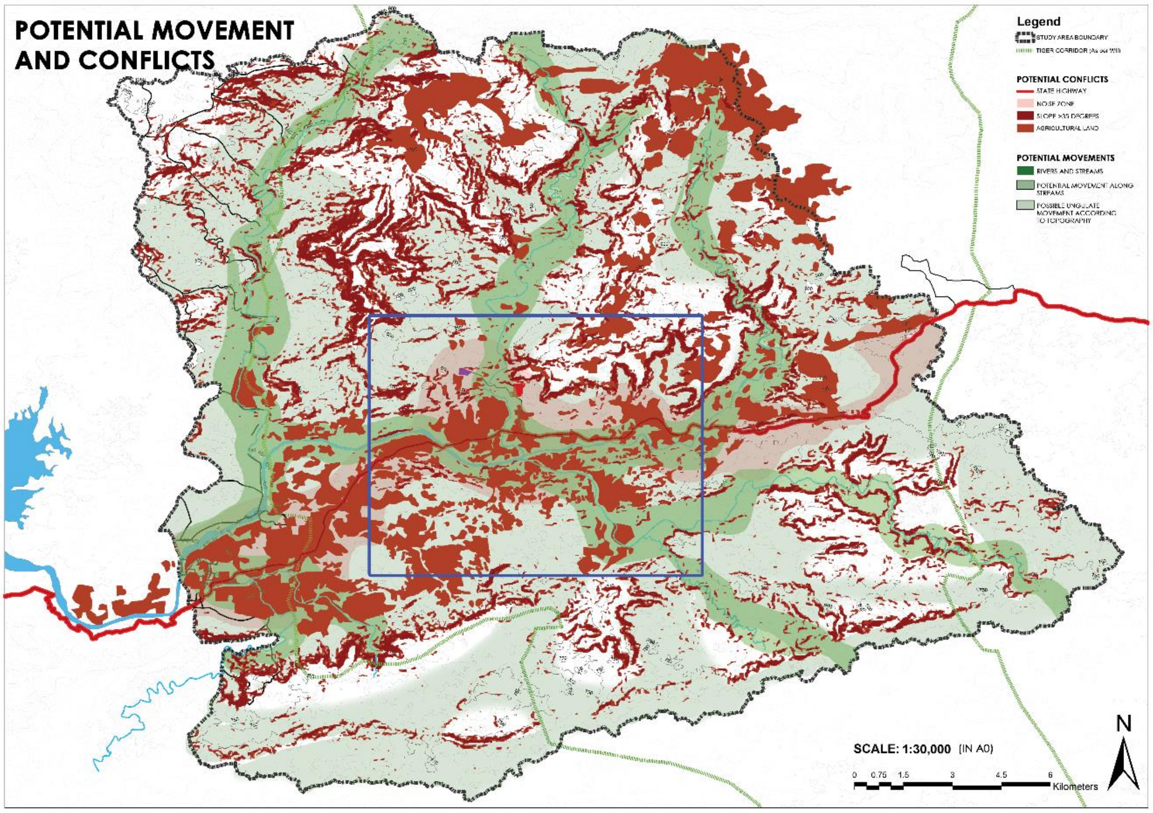
MAP 21: Anthropogenic disturbances restricting ungulate movement

- The state highway dividing the forest ranges act as the paramount fragmenting agent in the landscape. The disturbance is both in terms of moment of vehicles and also the noise generated in the process.
- Since both the ungulates and also the umbrella specie have negative tolerance for human habitation, all private agricultural lands act as barriers in movement. During unavailability of wild palatable grasses agricultural lands may suffer crop raiding by ungulates.
- The Coal mine create disturbance by generating of noise and dust and also by the volume of transportation of goods involved.

8.3.4 An overlay of disturbances and possibilities

In the overlay map, all the factors encouraging movement are shown in shades of green and all the restricting factors are shown as shades of red.

It is clearly understood that the possibilities of dispersal congregate at the Triveni area, much at the centre of the study area. However the disturbances are also loom large here in the form of the Coal Mine and its auxiliary facilities, State highway and agricultural lands.



Hence, the Triveni area renders itself extremely critical for the management of the landscape with respect to aiding habitat connectivity.

8.3.5 Random habitat assessment of ungulates in the study area

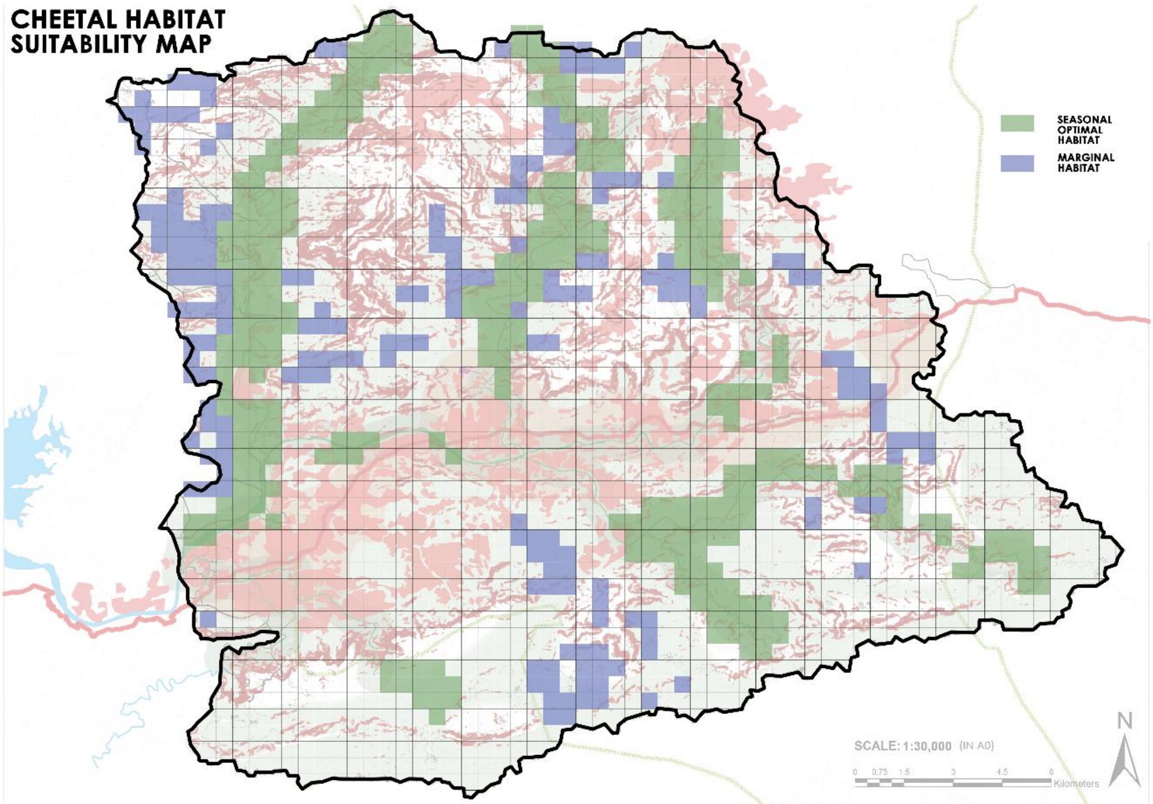
Using random habitat assesment method the site has been divided into grids of 500mts.

Base information used for defining habitat suitability were:

- Existing Vegetation
- Habitat use by individual species.
- Topography
- Disturbances

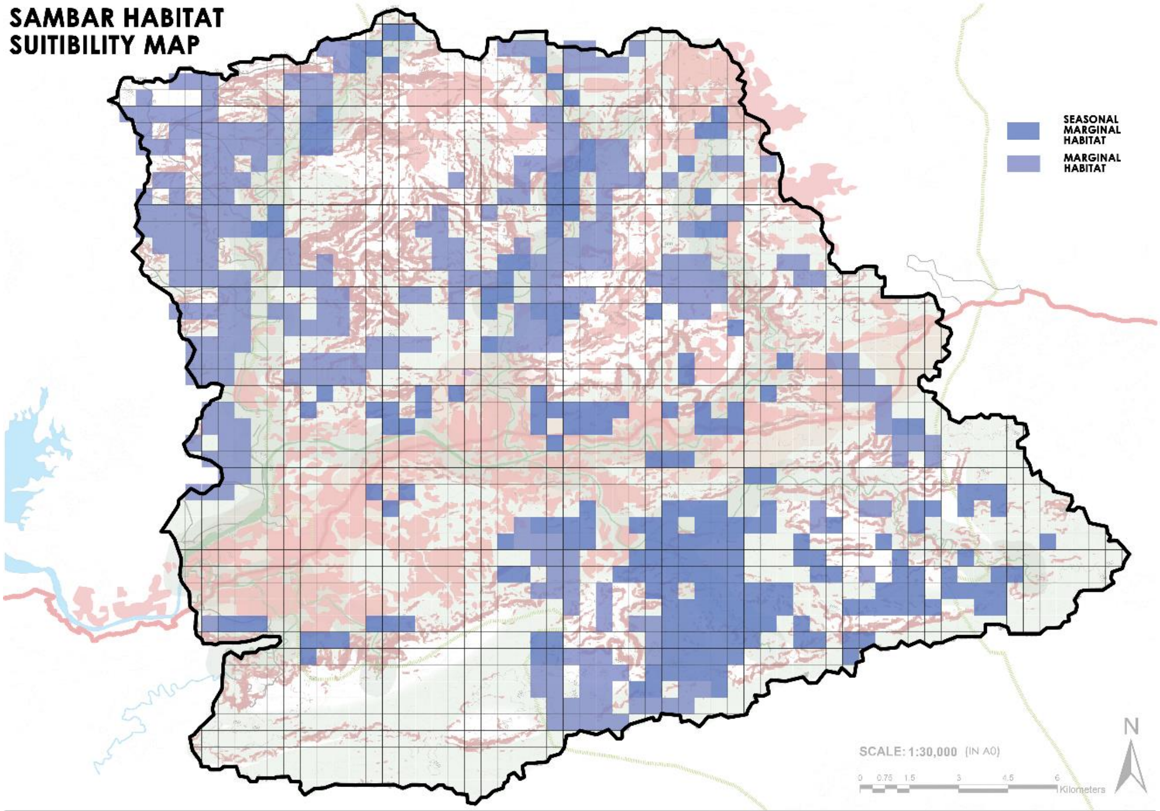
At present there is no optimal habitat for either of the two Ungulates.

Chital has potential to develop optimal seasonal habitat along streams when annual grasses come in the wet season and being an oppertunist browser it may develop seasonal marginal habitat in mixed forests, when forage trees come to fruit.



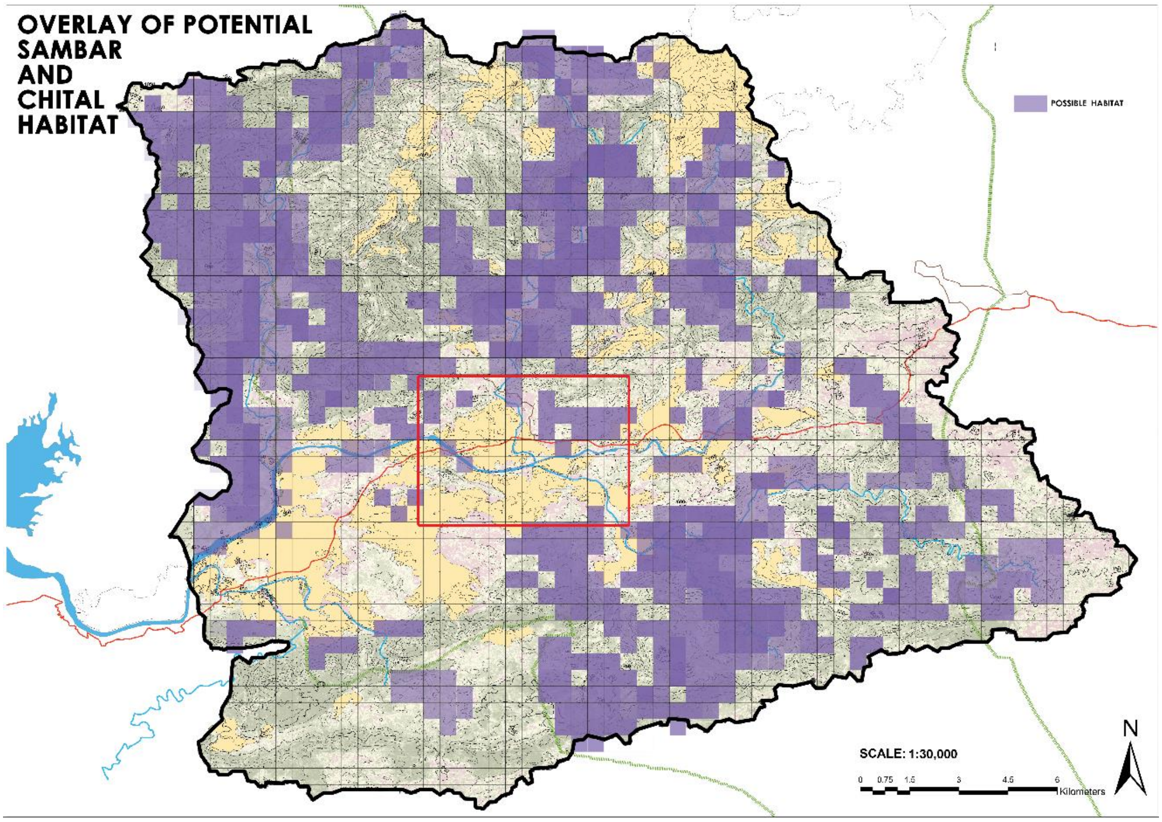
MAP 22: Habitat suitability assessment of Chital

Sambar being a browser is more confined to the mixed forest areas where it is likely to find marginal habitat whereas the teak forest will provide seasonal marginal habitat, sambar love to feed on the bark of teak trees when no other forage is available. It is also an oppertunistic grazer so in wet season it is likely to be found near the streams feeding on fresh grasses.



MAP 23: Habitat suitability assessment of Sambar

The overlaid habitat assessment map of Chital and Sambar, suggest that the potential favourable habitats converge at two points, the Triveni area at the centre and the hilly terrain in the east, where both the habitats face large fragmentation.



MAP 24: Chital and Sambar habitat assessment overlay

8.3.6 Conclusion

The Disturbance and Possibilities map converge at the Triveni area and the Random Habitat Assesment map converge at the triveni area as well as the eastern hilly terrain.

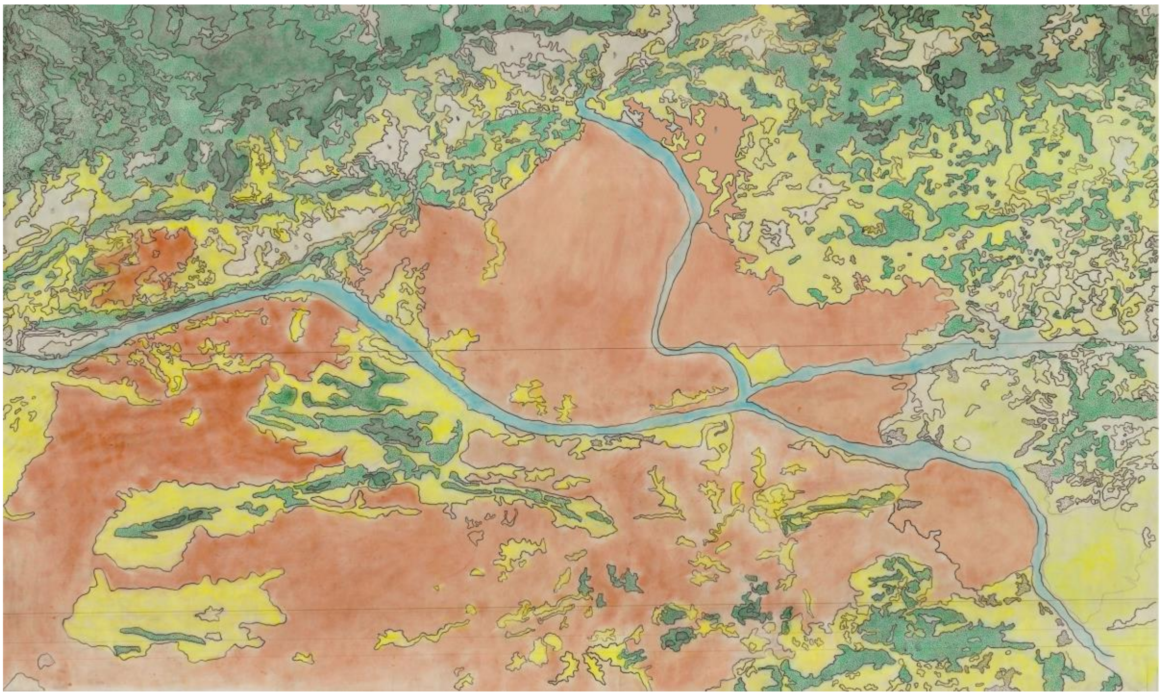
The eastern hilly terrain consists of slopes greater than 35 degrees that impede favourable movement of ungulates.

Given the above mentioned conditions, it is inferred that the **Central Triveni area is rendered extremely critical in terms of continuity of abiotic and biotic flows through the study region** *(termed as critical area from here on)***.**

9. STRATEGIES

9.1 Critical area (micro level)

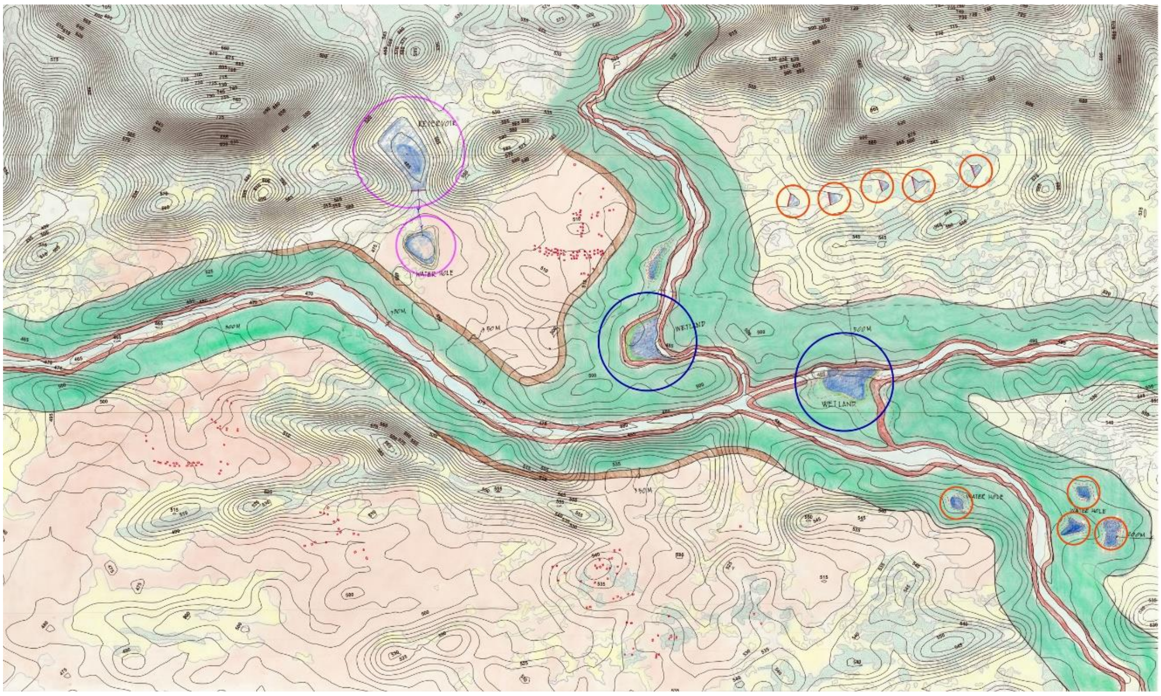
9.1.1 Matrix analysis



MAP 25: Landscape mosaic evaluation of Critical Zone

PATCH	FRAGMENTATION due to consolidated agricultural land between forest patches on both sides.	Habitat discontinuity leading to higher extinction probability for lesser species and dispersal discontinuity for wide ranging species.
	GRAIN SIZE: Coarse patch fragmentation.	Discontinuity to most terrestrial species

EDGE	Forest edges are Fine GRAINED	Considered continuous by most wide ranging species.
	Edge shape - Convoluted	More interaction possibility with surrounding edge.
	Edge width and bio-diversity	Good for supporting edge species like Chital
CORRIDOR	For terrestrial animals no corridors exist between the two disconnected forest patches, however, the river network creates the possibility of corridor management.	



MAP 26: Spatial interventions at Critical zone

Table 8: Strategy interventions at Critical zone level

INTERVENTIONS	BENEFITS
1. **BUFFER STRIP**	• Dispersal of Terrestrial Wildlife especially wide-ranging species. • Checking stream bank erosion. • Regulation of water quality of streams. • Generation of Local income through Non Timber Forest Produce(s).
2. **Wetlands**	• Creation of Micro-Habitat for interior species like Chital, thus at certain nodes the species richness is higher than elsewhere in the network (stepping stones in terms of tiger dispersal). • Flood Sequestration. • Ground water recharge. • Soil moisture improvement. • Downstream sediment trapping.
3. **Gully Plugs/Bunds**	• Erosion control. • Water availability during dry season. • Trapping Sediments and organic matter. • Improving Ground water regime.

BUFFER DEMARCATION

The primary function of this buffer strip is to facilitate wildlife movement with primary consideration to tiger.

According to study by yale university the minimum width of buffer strip for terrestrial wildlife movement should be between 10mts to 500mts. But as per Seidensticker (2010), the minimum width of sub-regional tiger corridor should be minimum 300mts if not more.

Table 9: Buffer widths according to Yale University

	Effective Width of Buffer (in feet)							
Author	**Aquatic Wildlife**	**Terrestrial Wildlife**	**Stream Temperature**	**Litter/Debris input**	**Nutrient Retention**	**Sediment Control**	**Bank Stabilization**	**Pesticide Retention**
Wenger 1999		220-574 ft.	33 – 98 ft.	50 ft.	50 – 100 ft.	82 – 328 ft.	–	> 49 ft.
Army Corps 1991	98 ft.	30 – 656 ft.	33 – 66 ft.	66-102 ft.	52 – 164 ft.	33 – 148 ft.	49 – 98 ft.	49 – 328 ft.
Fisher and Fischenich 2000	> 98 ft.	98-1,640 ft.	–	10 – 33 ft.	16.4-98 ft.	30-200 ft.	30 -66 ft.	–
Broadmeadow and Nisbet 2004	33 –164 ft.	–	49 – 230 ft.	82 – 328 ft.	16.4-98 ft.	49 – 213 ft.	–	–

Hence, the width of buffer strip is maintained as **300 mts along streams and 500 mts around wetlands** which act at micro habitats for interior species.

The buffer strip have been divided into 3 functional zones.

- **Zone 1: 30mts structural zone**

Functions: stream bank stabilization. Water temperature regulation.

Plant species used: Arjun, Jamun, Acacia, cynodon dactylon grass.

- **Zone 2: 280 mts dispersal zone**

Function: movement of species.

Plant species used: acacia, zizyphus

- **Zone 3: 50 mts livelihood improvement zone**

Function: Generation of economy and livelihood needs of villagers.

Plant species: Mahua, Acchar, Mango. Palatable grasses for grazing domestic animals on a rotation basis

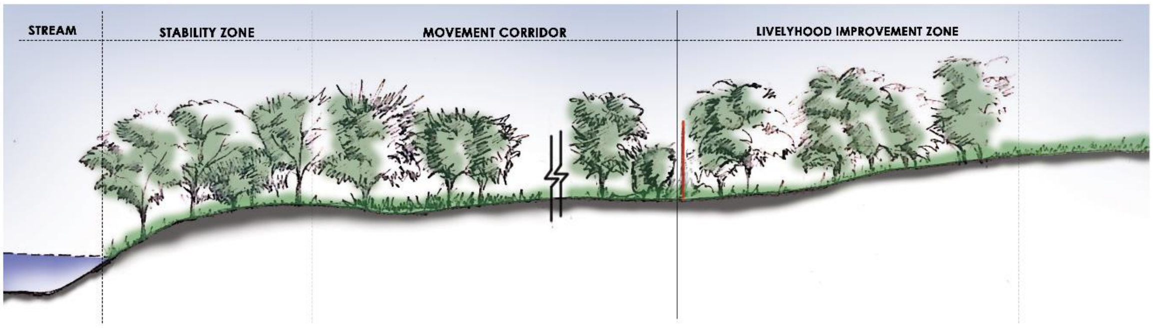


Figure 19: Zonal Division of Buffer Strip

9.2 Study region level

Table 10 Strategy interventions at study region level

CRITICAL ZONES	PROBLEMS	INTERVENTIONS
Steep Slopes	• Sheet Erosion and Mass Movement of particles.	• Brush Layering • Gabion retaining walls
	• Barren and Thin Soil.	• Introduction of Legumes like *Atylosia scarabaeoides, Rhyncosia minima Vigna trilobata*
Gradual Slopes	• Sheet Erosion and Mass Movement of particles.	• Brush Layering. • Contour Bunding.
	• Devoid of ground cover and palatable grasses and shrubs.	• Seeding palatable perennial grasses like *Heteropogon contortus, Sehima Nervosium*.
	• Low Water availability and low Soil moisture.	• Gully plugs across streams and Furrow and Gully method of water harvesting

Headwater streams (1 to 3)	• Gully erosion	• Planting Arjun trees along the stream edges (Its roots hold the soil and spreading roots act as natural bunds slowing the flow of water and by holding water at regular pockets). • Brushwood gully plugs.
	• No water during dry season.	
Higher Order Streams	Stream Bank erosion	• Rock Armouring • Planting Trees with spreading root system.
	Flash Flooding during monsoon and shallow water level to dry otherwise due to quick runoff.	• Small Wetlands at regular intervals that will act as cushions during monsoon and as water holding pools during the dry season.
	No Fodder plantations.	• Species like *Syzygium cumini, Acacia nilotica* to be planted along the stream in addition to *Terminalia arjuna.* Perennial palatable grasses like *Cynodon dactylon, Isielema laxum* should be seeded along the

		streams.
Plains	• Shortage of water. • Very deep ground water table. • Low Soil moisture and soil humus content.	• Small Wetlands and percolation ponds at regular intervals and preferably over lineaments of the existing impermeable base strata.

9.2.1 Policy level interventions

- Shifting of Coal Mine and its allied facilities as it sits right at the critical zone of dispersal.
- No traffic movement through the highway from 9 PM to 6 AM
- Agriculture should be completely stopped on top of the hills, which primarily fall under forested region. More focus should be put on economy based on Non Timber forest produce and tourism.
- Collection of firewood and logging of teak should be done with permission in zones that require density thinning for propagation of understory.
- In plains focus should be upon agricultural intensification (dual crop cycle) rather than agricultural extensification.
- Grazing should be strictly limited to the third zone of the proposed buffer strip.
- Economy should shift towards Eco Tourism and revival ethno medicinal knowhows.

9.2.2 Planting strategy for introduction of perennial palatable species and soil texture and moisture improvement

Table 11 Strategy for use of perennial grasses to be introduced for landscape restoration and forage

	PALATABLE GRASSES	ANNUAL / PERENNIAL	HEIGHT	SOIL	REMARKS
	*Heteropogon contortus*	PERENNIAL	750cm	Loamy, sandy, clay loam. Well Drained. Tolerates poor fertility	Erosion control upto 20° slopes. Fire is a useful tool in management of H. contortus stands, and can be used to restore pasture composition, especially if an area is burnt two years in row. Tolerates Part Shade
	*Chrysopogon fulvus*	PERENNIAL	90cm	*Eroded, shallow and gravelly / stony soils of medium texture.*	---
	*Themeda quadrivalvis*	ANNUAL	140cm	*Sandy loam soil with a pH from 7.0-8.5*	*Also used for thatching*
	*Dichanthium annulatum*	PERENNIAL	120cms	*Adapted to most textures of soil from coralline sands to heavy black clays.*	*One of the best grass for forage. Also good for soil conservationStands very heavy grazing, forming an open turf. Although not considered shade tolerant.*
	*Dichanthium caricosum*	PERENNIAL	4-20cms	*It prefers dry, sandy soil. Drainage can be poor under high rainfall.*	*It prefers dry, sandy soil. Drainage can be poor under high rlt has low fertility requirement, tolerant to waterlogging, tolerant to heavy grazing and good ground cover for the control of erosion and weeds.ainfall.*
	*Cynodon dactylon*	PERENNIAL	15-30cms	*Heavier silt and clayey. Resistant to a great extent to drought and tolerant to salinity and alkalinity.*	*Most nutritive Fodder. Easiest and earliest in establishment. Checking soil erosion, gully plugging on check dams, embankments .*
	*Sehima nervosum*	PERENNIAL	100cm	*Eroded, red gravelly / stony to medium sandy loamy soils. Rock crevices of undulating topography and on hill slopes*	*Eroded, red gravelly / stony to medium sandy loamy soils. Rock crevices of undulating topography and on hill slopes*
	*Digitaria stricta*	PERENNIAL	75cm	*Any type of Soil.*	*Any type of Soil.*
	*Iseilema laxum*	PERENNIAL	90cms	*Thrives best in black clayey soils and heavy loams, though it can grow on almost all types of soils in low lying areas, ditches, ponds along canals and river banks.*	*Highly Nutritous fodder grass. Riparian grass.*

Table 12: Planting strategy for introduction of Chital and Sambar based forage.

PALATABLE PLANT SPECIES	CHITAL		SAMBAR	
	PART EATEN	DEGREE OF USE	PART EATEN	DEGREE OF USE
Acacia catechu	L + F	■■	F	■
Acacia leucophloea	L + S + P	■■■	L + S + P	■■■
Acacia nilotica	L + S + P	■■■	L + F	■■■
Acacia Senegal	F	■	- -	
Adina cordifolia	- -		B	■■■
Aegle marmelos	L	■	- -	
Agaveingens	L	■	- -	
Albizia procera	L	■	- -	
Balanites aegyptica	L + F	■■■	- -	
Barleria prionitis	L	■■■	- -	
Bauhinia racemosa	L + F	■■■	L + F	■■■
Bombax ceiba	- -		B	■■■
Butea monosperma	L + S	■	- -	
Capparis sepiaria	L	■■■	L + S	■■■
Carissa carandas	L + S + F	■■■	L + B	■■■
Cassia fistula	F	■■	B	■■
Cassia tora	P	■■	L + P	■
Dichrostachys cinerea	L	■■■	L	■■■
Diospyros melanoxylon	L + F	■■■	L	■■
Ehretia laevis	L	■■	- -	
Embilica officinalis	L + F	■■■	L + F + B	■■■
Ficus benghalensis	- -		L	■
Ficus religiosa	L	■	L	■
Flaucortia indica	L	■■	- -	
Helicteres isora	L	■■■	L + S	■■■
Holoptelea integrifolia	L	■■	- -	
Holarrhena antidysenterica	L	■■	- -	
Ixora arbórea	L	■	- -	
Morinda tinctoria	L	■	L	■
Mitragyna parvifolia	- -		B	■■■
Sapindus emarginatus	L	■	- -	
Securinega leucopyros	L	■	- -	
Syzyguim rubicundum	L + F	■■	L	■
Tectona grandis	L	■	B	■■■
Terminalia bellirica	F	■■	F	■■
Terminalia crenulata	L	■	B	■■
Wrightia tinctoria	L + F	■■	B	■■■
Xeromphis spinosa	L + F	■■■	L + B	■■■
Xeromphis uliginosa	- -		B	■■■
Zizyphus mauritiana	L + F	■■■	L	■■■
Zizyphus nummularia	L + F	■■■	- -	
Zizyphus oenoplia	L + F	■■■	L	■■■
Zizyphus xylopyrus	L + F	■■■	L	■■■

PALATABLE CLIMBER SPECIES	CHITAL		SAMBAR	
	PART EATEN	DEGREE OF USE	PART EATEN	DEGREE OF USE
Asparagus racemosa	L + S	■■■	--	■■■
Comberatum roxbergii	L + S	■■■	L + S	■■■

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