

Intersectoral Approach for Mitigation of Threats and Pressures on Lakhari Valley Wildlife Sanctuary, Odisha, India

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ABSTRACT

The Lakhari Valley Wildlife Sanctuary (LVWS) in Odisha, an abode for many life forms in its dense mixed deciduous forests, have been undergoing degradation in the last three to four decades primarily due to anthropogenic activities. The sanctuary has been prone to various pressures, viz., timber/wood logging, poaching, and hunting of animals, habitat destruction, agricultural intensification, construction activities, slash and burn cultivation and natural hazards. On account of this, the present study on the LVWS was attempted to i) review the reports and articles documented, ii) analyze the forest cover change, iii) enlist the prevailing threats, iv) suggest various measures for threat mitigation, and v) list out possible conservation strategies for LVWS on a short and long term basis. The data sets and literature (published and unpublished reports) on LVWS availed from the online portals, news reports, and personal communication with different stakeholders including officials from the forest department and non-government organizations were collected and compiled. Maps of Land Use Land Cover (LULC) and Normalised Difference in Vegetation Index (NDVI) were prepared using satellite imageries. The LVWS witnessed about a 28% (50 km²) decrease in vegetation cover from 1990 to 2000 itself, an overall reduction of 20 km² vegetation cover from 1990 to 2010. During the last decade (2013-2020), the LVWS recorded a 10% reduction in forest cover, 140% upsurge of barren land, 12% increase of shrub/ agriculture land. Based on the natural and anthropogenic threats observed in the LVWS, threat mitigation measures, and intersectoral conservation strategies, ecosystem models for habitat management were compiled.

Key words: Afforestation, Biodiversity, Conservation, Deforestation, Sanctuary, Technology

INTRODUCTION

Forests are known for an array of ecosystem services rendered for the sustenance of the biosphere and human wellbeing. These include providing suitable habitats to different life forms, maintaining soil quality, regulating biogeochemical cycles, sustaining surface temperature, mitigating natural hazards, supporting livelihoods, providing food, medicines, and many such multiple benefits. Rapid urbanization, industrialization, and unsustainable extraction of forest resources are some of the major causative factors for forest degradation. The underlying and secondary threats to the forests first need to be addressed to make the citizens aware of the same, followed up by implementation of various conservation strategies at individual, social and governmental levels, which can effectively mitigate the risks and threats posing on the forest ecosystems.

As per the Millennium Ecosystems Assessment criteria and Sustainable Development Goals, efforts for conserving ecosystems must ensure both the ecosystem and human wellbeing. Despite management challenges, the importance of forest conservation along with the livelihood generation of its inhabiting human community cannot be ignored, thereby necessitating a participatory conservation approach. This should be based on sound ecological principles with the aid of spatial tools for mapping, quantifying, and monitoring the status of forest cover changes in various parts of the world (Asner 2009) and accordingly, attention is to be paid by environmentalists towards sustainable management plans (Nemani et al. 1996, Vuolo et al. 2011).

Harbouring a good assemblage of floral and faunal species, the Lakhari Valley Wildlife Sanctuary (LVWS) in Odisha has been witnessing habitat degradation for the last couple of years. Among the

21 notified Protected Areas (PAs) in Odisha, the LVWS has received comparatively lesser attention from researchers for ecological studies. The forest area has been a lesser-known habitat and has been paid less importance in conservation policies. The need is to save this forest of southern Odisha which has been home to many life forms since geological times, mainly ascribed to its decent climate, dense canopy of vegetation, and water resource availability. Factors such as rich timber plant diversity, presence of wildlife, ever-increasing road network, to this PA have been the main reasons for habitat destruction. Unregulated harvesting of bio-resources, unsustainable agricultural practices and over-exploitation of natural resources are reportedly some of the major issues associated with forest degradation. Lack of adequate and stringent actions for mitigating such losses have accelerated the habitat degradation in the LVWS. The management of such issues requires revisiting the scientific investigations, compiling the existing information, analyzing the forest cover change, enlisting and reporting the threats to the ecology of LVWS and its surroundings, suggesting measures for threat mitigation, and framing conservation strategies and action plan for the LVWS and its environs on a short and long-term basis. This would facilitate, the Forest Department in general and sanctuary management in particular, in expediting conservation efforts that would facilitate preparing a comprehensive management action plan to maintain this unique ecosystem.

The present work includes collating data sets and literature (published and unpublished reports) on LVWS to support future work in habitat change detection. The present study is attempted to i) review the reported articles on LVWS, ii) analyze the forest cover change in the LVWS, iii) examine all the threats prevailing in the LVWS, iv) suggest various measures for threat mitigation and v) list out possible conservation strategies for LVWS in the short and long term basis.

STUDY AREA

The Lakhari forest is a part of the Eastern Ghats range, covering an area of 185.86 km². Of this, 175 km² of the forest was designated as a wildlife sanctuary in 1985 (vide Notification No. 8 (F) W-

37/85-2333-FFAH dated 08.02.1985 of Government of Odisha). The declaration of the sanctuary was largely due to the presence of the elephant population and aiming at reducing the prevailing disturbances. The sanctuary is located between 84°15' to 84°25' E and 19°15' to 19°25' N, in the north-eastern parts of Gajapati district, bordering the district of Ganjam (Fig. 1). The maximum and minimum temperatures recorded in the area are 42°C and 09°C in the summer and winter months, respectively. The average annual rainfall varies from 1000 to 1800 mm in and around the Lakhari forest areas. The area has topographical uniqueness, comprising mostly of hilly tracts with altitudes ranging from 200 to 800 m ASL (Palei et al. 2012). The forest is primarily represented by a valley with small springs. The forest is predominantly a moist mixed deciduous type (Champion and Seth 1968) providing excellent habitat for a variety of animals.

The vegetation predominantly includes trees such as Sal (*Shorea robusta*), Indian Laurel (*Terminalia alata*), Mango (*Mangifera indica*), Karada (*Cleistanthus collinus*), Tendu (*Diospyros melanoxylon*), Mahua (*Madhuca longifolia latifolia*), Char (*Buchanania lanzan*), Bamboo (*Bambusa bambos*) along with other floral species. The fauna of sanctuary includes mainly Asian Elephant (*Elephas maximus*), Leopard (*Panthera pardus*), Striped Hyena (*Hyaena hyaena*), Indian Crested Porcupine (*Hystrix indica*), Sambar Deer (*Cervus unicolor*), Gaur (*Bos gaurus*), Jungle Cat (*Felis chaus*), Indian Fox (*Vulpes bengalensis*), Wild Boar (*Sus scrofa*), Barking Deer (*Muntiacus vaginalis*), Indian Wolf (*Canis lupus*), Indian Peafowl (*Pavo cristatus*), Brown Fish Owl (*Ketupa zeylonensis*), Black Kite (*Milvus migrans*) (Palei et al. 2012), Monitor Lizard (*Varanus bengalensis*), Indian Python (*Python molurus*), King Cobra (*Ophiophagus hannah*), Common Cobra (*Naja naja*) along with many other species.

The LVWS has 06 revenue villages, 31 forest villages with a total of 515 households and an approximate human population of 2,500 (Mishra 2019). The inhabitants are primarily dependent on forest resources. In the past few decades farming has been the main source of livelihood in these villages, with cereals, pulses, and vegetables being predominantly cultivated. In addition to harvesting

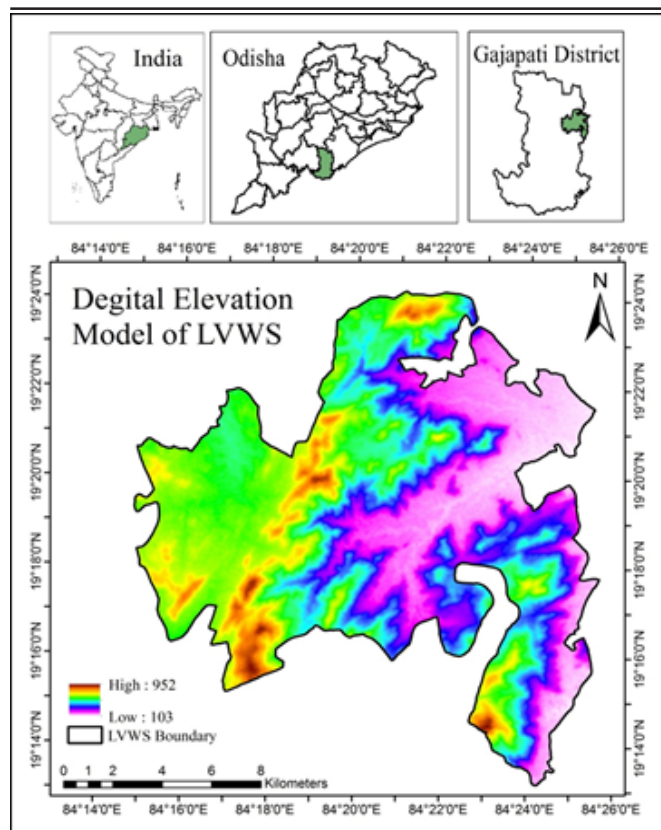


Figure 1. Digital elevation model map of LVWS

non-timber forest products, the villagers also practice livestock rearing.

METHODS

The methodology included a desk-top approach reviewing and collating datasets and literature (published and unpublished) on LVWS and its environ. The available literature (research articles and/or reports) were downloaded using different web-based search engines such as Google Scholar through a pre-defined search protocol, using a set of relevant keywords (Pullin and Stewart 2006) such as LVWS, flora, fauna, ecology, forest resources of LVWS, threats to LVWS, a conservation plan for LVWS. In some cases secondary literature, information available through the most reliable internet sources were extracted and expert opinions were also sought. Moreover, information available in the online portal of different government departments, news reports were accessed, and consultations were held with different stakeholders, frontline forest officials (stationed in different areas

of the sanctuary), and non-government organizations working for biodiversity and tribal livelihood upliftment in the area. In addition to the above, authors' periodic visit to the sanctuary area and informal interaction with some of the villagers inside and on the fringes of the sanctuary also helped in documenting the prevailing threats in and around the LVWS.

Further, for the detection of forest cover changes, Land use land cover (LULC) and Normalised Difference in Vegetation Index (NDVI) maps were prepared. For the preparation of 30 m resolution LULC and NDVI maps, satellite data of Landsat 5 and 8 were extracted from USGS earth explorer (<https://earthexplorer.usgs.gov>). The boundary file of the LVWS was digitized from the map obtained from the official website of PCCF (Wildlife) & Chief Wildlife Warden, Odisha which acted as the base map. Landsat 5 Thematic Mapper (TM) images were used for the preparation of NDVI maps of 1990, 2000, and 2010, and Landsat 8 Operational Land Imager (OLI) images were used for the preparation of LULC maps of 2013 and 2020, NDVI map of March and September 2018, and NDVI map of 2020. All the LULC maps were created using the Supervised Classification tool and the NDVI were created using the NDVI function of ArcGIS 10.5.

RESULTS AND DISCUSSION

The LVWS, a tropical forest of South Odisha, has vegetation representing moist deciduous forest and hosting varied diversities of faunal groups. There have been attempts by various researchers to report on different components of this unique forest ecosystem. The earliest scientific reporting on this sanctuary was by Palei et al. (2012) on the avifauna of LVWS and its surroundings. In addition to this, there are reporting on herpetofauna (Das et al. 2018), mammals (Das et al. 2016 and Sukumar et al. 2018) and socio-economics (Mishra 2018 and 2019). A summary of all these reportings are presented in Table 1. The LVWS has been under pressure due to many factors, which are described in brief in the following sections.

Forest degradation

This is one of the major threats to the LVWS, the consequences of which are so much that habitat

destruction has been eventually shifting from perforation to fragmentation. The degree of canopy degradation is revealed from the LULC map presented in Figure 2. The decadal change analysis of vegetation cover revealed a 28 % (50 km²) decrease in vegetation cover from 1990 to 2000 and a total reduction of 20 km² vegetation cover from 1990 to 2010, and further an increase in 6.8 % vegetation cover from 1990 to 2020 (Figure 3).

The forest cover of 2013 was 113 km² which decreased to 102 km² (about 10%) in 2020 as revealed from land-use data of LVWS (Table 2). A large area of the sanctuary remains barren and many areas have been converted to shrub or agricultural land. Further, an upsurge of 140% of barren land was recorded in LVWS during the period 2013-2020 (Table 2). As of 2020, out of the 175 km² area of the sanctuary, apart from forest cover (102.07 km²), the remaining areas included 46 km² of shrubland/ agricultural land, 16 km² of barren lands, and 11 km² of human habitations (Table 2). This occupancy of humans provided them free access into the forest leading to unsustainable utilization of the bio-resources, thereby causing degradation of the forest. Furthermore, the decadal change maps represented by NDVI (Figure 4) revealed a reduction in vegetation cover during 1990-2000, which slowly started recovering during 2010-2020. The huge degradation of vegetation seen in 2000 might have been ascribed to the devastating effects of the super cyclone in 1999 mixed with the anthropogenic actions. On the contrary, the reported increase in vegetation cover can also be ascribed to monoculture plantations and an increase in agricultural activities as witnessed from the 12.6 % surge of shrub / agricultural cover in 2020 from 2013 (Table 2).

For agriculture, livestock grazing, construction, recreation, and the need for several forest-associated products, the local populace has been indulged in forest degradation by directly cutting the trees and/ or girdling or ring barking the large trees. The latter technique was more often observed and the consequence is massive as it destroys the trees even without direct notice. Since the forest is known for its timber plants, medicinal plants, and wild animals, the place has been attracting mafias for decades, who despite the presence of norms and regulations find their way to rip off many ecologically important plant

and animals of the forest for trading. This, being one of the serious concerns for the ecology of the forest, warrants stringent actions to shun illegal activities to avoid the forest degradation reaching a point of 'no recovery'.

Soil erosion

Lakhari valley, a part of Eastern Ghats, is generally mountainous and being near to the coastal region, receives good rainfall. It is apparent that upon every rainfall, the forest soil erodes to a larger extent due to reduced ground vegetation cover. Some of the major causative factors of soil erosion include shifting cultivation, land use change (conversion of forest land into farmland), agricultural intensification overgrazing by livestock, and construction works. In addition, soil erosion increases loss of upper fertile soil, leading to siltation and sedimentation of water bodies. This leads to accumulation of light and heavy minerals in water bodies, there by posing serious hazards to aquatic life and human health (Bashir et al. 2017).

Threats to forest hydrology

As the name suggests, the major source of water in the forests of Lakhari is the valley water which is accompanied by its small distributaries flowing across the landmass. Diversion of valley water for agricultural practice has been reportedly the root cause of water scarcity during the summer months, thereby causing problems to both wild animals and human beings. Moreover, the contribution of anthropogenic factors disturbing the eco-hydrology of this forest ecosystem in the LVWS can't be ruled out. Several activities such as deforestation, extensive use of agrochemicals (chemical fertilizers and pesticides) are the major reasons of contamination in the streams, rivers, and other inland water bodies. Thus, there could be possibility of elevated concentrations of nutrients, heavy metals, pesticide residues, and other oxygen-depleting substances in the aquatic ecosystems. This might jeopardize the ecological equilibrium in the LVWS.

Since the eco-toxicological and health implications of such chemical residues on wildlife and human beings are well established across the globe, this warrants attention. Due to ongoing anthropogenic activities, the likelihood of

Table 1. Ecological and socio-economic reports of LVWS

Category	Documentation / Report	Prospective / Recommendations	Reference
Avifauna	126 species of birds were documented, which includes 09 migratory species (six winter visitors and three summer visitors). Among them 71 species were common, 46 were uncommon and 9 species were rare.	Comprehensive and extensive research on the population status and distribution, ecology of rare birds, and comparative biology and behaviour of sympatric bird species such as woodpecker.	Palei et al. 2012
Herpetofauna	The status and distribution of the Indian Golden Gecko (<i>Catodactylodes aureus</i>) including their nesting sites, eggs, and calls were studied in and around the sanctuary and the associated threats and conservation challenges were enumerated. From the evaluated habitat patches of LVWS, the distribution of endemic reptile species, East-Indian Leopard Gecko (<i>Eublepharis hardwickii</i>) was confirmed.	Anthropogenic activities being the foremost threat for this species, warrant protection of the forest and abatement of activities like stone quarrying, timber logging, etc. Intensive surveys required for better understanding of the status and ecology of the species.	Das et al. 2018 Das et al. 2019
Mammals	The movements and presence of leopards in Lakhari forest evaluated through direct and indirect sighting revealed the population density of leopards to be 6±2 within an area of 300 km ² . The forests of Lakhari are known to accommodate healthy population of prey base of leopards. Asian Elephant population in the LVWS reported a 89% decline in from 1979 through 2017, apparently due to the degradation of forests in sanctuary.	The finding provides impetus on the need for conserving the herbivore (prey base) population in the forest, thereby facilitating a healthy forest ecosystem.	Das et al. 2016 Sukumar et al. 2018
Socio-economics	Loose administrative policies, ill-defined property rights, and lesser participation of locals are reportedly the main causes of forest degradation. The poor socio-economic status of people and associated unsustainable harvesting practices have been one of the major causes of forest degradation. The Forests Right Act, 2006 impacted the natural resource utilization pattern and can facilitate a shift in local denizens' attitude and cooperation in conservation practices.	Emphasis to be given on strengthening the corridors for elephant conservation and undertaking measures to improve the socio-economic condition of the local populace, through participatory conservation models. The formation of a socio-economic task force for sanctuary management could help mitigate the threats in the sanctuary. Welfare schemes meant for uplifting the financial and social conditions of locals would be crucial in saving the ecosystem of the sanctuary. Conservation programmes in sync with the livelihood generation of the people can achieve the desired goals.	Mishra 2018 Mishra 2019

agricultural runoff and domestic sewage contaminating the water bodies leading to elevated concentrations of nutrients, heavy metals, pesticide residues, and other oxygen-depleting substances could be higher.

Poaching and hunting of wild animals

Lakhari valley is one of the well-known elephant sanctuaries in India. Other wild fauna species seen in the sanctuary include Jungle Fowl, Spotted Deer, Mugger Crocodile, Sloth Bear, Leopard, Wild Boar, Sambar, Barking Deer, Black Buck (Personal communication with ground forest staff of Lakhari). The population of wild animals which were frequently seen during 1970-1990 are now rarely sighted. The hunting and poaching activities, which were once one of the major reasons for the declining population of many wild species, have now been reduced drastically, except for sporadic incidences. The poaching of Pangolins are still a cause of concern in the LVWS, as it has a high market value and its scales are used in some traditional forms of medicine. Such activities necessitate strict vigil on trade/poaching of this species.

Natural instabilities

The LVWS being located in the Gajapati district is adjacent to the coastal Ganjam district. Thus, the ecosystem of Lakhari valley is at stake for the repeated tropical cyclones of the Bay of Bengal, making landfall in the Ganjam district. The Ganjam and Gajapati districts are categorized as 'High damage risk zone' with respect to Wind and Cyclone hazard zone maps of Odisha state government. Data from the past few decades reveal an increase in the frequency of severe storms and cyclones. The Super cyclone in the year 1999, and subsequent cyclonic hazards, viz., Phailin, Hudhud, Titli, Fani, and Amphan in 2013, 2014, 2018, 2019, and 2020, respectively, have shaken the life and property in Ganjam and Gajapati districts. An NDVI analysis of LVWS done for March 2018 and September 2018 (Figure 5) to examine the impact of the cyclone Titli on the sanctuary revealed degradation of about 5 km² area of vegetation between these two time periods.

Unsustainable agriculture practices

There has been a paradigm shift in preference for

the livelihood support system in and around the LVWS. The forest dwellers of the 1980s have now been converted to farmers practising intensive agriculture activities involving (irrational) the use of agro-chemicals. In the recent decade, agriculture has become the primary source of livelihood for the residents of Lakhari. The practice of shifting cultivation, use of inorganic fertilizers, oversized clearing of forests, and monoculture-based plantations (including *Cannabis* cultivation) have shacked the structure of natural forest biodiversity.

Uncontrolled livestock grazing

Livestock rearing has been the second most preferred livelihood option in the Lakhari area. The unrestrained grazing activity in the LVWS is another serious issue for the forest. This practice of overgrazing causes definite hazards to forest shrubs, reducing their growth and productivity, causing soil erosion, and decline in soil fertility.

Human intrusion

Various reasons for human intrusion into the Lakhari forest include poaching, hunting, timber collection, extracting forest produce, land encroachment, construction works (roads, canals, electric poles). In addition, some of the stakeholders also opine tourism as another major form of human intrusion inside the forest area, particularly for recreational purposes resulting in solid waste pollution, especially plastics. Although many villagers opine intensive research experiments to be another major factor for disturbance, the actual record of an abysmally low number of studies undertaken and researchers visiting the area, don't substantiate their opinion.

Mining activities

After the declaration of the LVWS, due to the enactment of the Wildlife (Protection) Act, 1972 and the Forest (Conservation) Act, 1980, no major mining activities have yet been reported. However, localized incidences of stone quarries are common. The Odisha state, located in the mining belt, is a treasure of rich mineral reserves. The LVWS is also known for a variety of mineral reserves, viz., Quartz, Feldspar, China clay, Mica, Lime, Calc-tufa (MoEF & CC, 2018), thus intensive mining activities in the future can't be ruled out.

Forest fire

The LVWS has been witnessing fire incidents in recent decades. However, to date, no cases of natural fire have been documented, and all the fire incidents are reportedly caused by human activities such as harvesting honey, charcoal, and other forest produce. Further, the role of slash and burn cultivation, practiced in certain pockets in the area, in the fire incidents in the Lakhari forests cannot be ruled out. Much to the dismay, the forest fire spreads and causes havoc by increasing the temperature, degrading habitats, and imposing danger to the biodiversity of the forest.

Invasive species

Akin to other forest areas in the country, the Lakhari forest has also been a victim of many invasive floral species like *Lantana camara* and *Chromolaena odorata*, which has been an ecological bottleneck for the survival of native flora and fauna. These plants compete with native plants for resources such as nutrients, water, light, and space, thereby exerting an adverse impact on the ecologically fragile areas. In addition, they are potential enough to reduce the productivity of land that won't prove healthy for forestry and agriculture.

Pressures to the natives and tribal

The locals and tribes residing in the forest suffer from varied uncertainties including socio-economic insecurity, health, and nutrition problems, lack of basic facilities and proper education system, unemployment, poor roads and transport. Further, harmful activities by outsiders, threats to wildlife, human-animal conflict, and many unrated problems also add to the hardships of the local denizens. The socioeconomic status of the denizens residing in the villages in the LVWS is intricately related to the health of the forest ecosystem and resource availability. Mishra (2019) studied the factors responsible for forest degradation in PAs of Odisha including the LVWS as a case study. Due to the lack of alternate livelihood avenues, the villagers have been practicing shifting cultivation, extraction of NTFP for ages, and additionally, the ever-increasing human population in those villages have been exerting more pressure on the already strained/stressed forest habitats of LVWS.

Management challenges

Keeping an eye on the above-cited factors and drivers impacting the LVWS, the Government of Odisha declared the forest to be protected and designated as a sanctuary in the year 1985. The unauthorized access to forest resources leading to their over-exploitation; lack of awareness among locals, and loss of forest biodiversity are some of the issues suggesting less/no effective outcomes of the conservative actions (Mishra 2018). However, the welfare schemes or eco-development programs that have been carried out by the Government departments are expected to yield some results on the ground. One of the foremost issues in the forest administration is that it is being severely understaffed and unequipped to fight the menace, thereby requiring prompt actions.

Threat Mitigation Measures for LVWS

As compared to other PAs of the state, the LVWS is small in terms of area and species diversity, for which it is rather less recognized. However, it is not wise to ignore the prominence of the current threats overshadowing the diversity of vegetation and wild species of the valley. To reduce the threats as described in the earlier sections, various mitigation strategies are proposed (Table 3) for the ecosystem conservation and habitat restoration.

Conservation priorities for LVWS

The present exercise is an eye-opener for the researchers and PA managers. This compilation helped us in identifying a preliminary set of research gaps and priority areas those need to be studied and examined extensively to help maintain the ecological integrity of LVWS, its surrounding ecosystems, and catchment areas. Since the LVWS has not witnessed comprehensive ecological assessments, the research matrix (Table 4) is prepared along with the conservation priorities and anticipated benefits. A general model for forest ecosystem conservation/management is LVWS (Figure 6) is also proposed by drawing insights from Hockings et al. (2000) and Margules and Pressey (2000).

Management challenges and way forward

Although the conservation strategies for the Lakhari forest have been appropriately discussed, undertaking relevant conservation measures for

sustainable habitat management is a lot more challenging. Some of the issues which needs to be considered are as under:

- Health and life risks for the conservationists from wild animals, insects, poisonous plants, confrontation with mafias, and other mishaps.
- Prominence of naxals and maoist activities (as confirmed during a personal conversation with locals and ground forest staff) in the area is a hindrance for the developmental activities.
- Public awareness on the consequences of habitat destruction needs a larger proportion of time and energy. Further, public acceptance of conservation action programmes is also challenging.
- The impacts of developmental activities are inevitable and can be a deterrent for biodiversity conservation.
- Regular monitoring and reporting of forest parameters are tedious and would require more trained human resources deployed on regular basis.
- Threats to important wild species of plants due to physical, chemical and biological treatments in agroforestry practices.
- Upgradation of conservation infrastructure including deployment of adequate human resources would be cost prohibitive.
- Eco-development programs, remunerations, incentives, pollution abatement technologies, and related welfare schemes would be capital intensive with less than desired outcome.

The conservation challenges and threats as described in earlier sections hold good not only for LVWS but for many other PAs across the country. The present exercise calls for the ecological

protection of LVWS paralleling with the lifestyle upliftment of local populace in Lakhari to achieve sustainable development goals. The finding of the present study advocates for a participatory approach with the involvement of the public, government, and relevant stakeholders. On the whole, sound policy framework, channelizing funds and incentives for participatory conservation and threat mitigation practices, support and education for sustainable livelihood, strategic agro-forestry practices, citizen science programme and use of spatial tools in conservation actions are some of the major inter-sectorial approaches and initiatives services required for ecosystem restoration in LVWS. Moreover, conservation and sustainable use of the existing natural resource base and their rejuvenation; awareness among the public, socio-economic aids to locals, strong administrative action, and regulated management of forest treasure are some of the aspects those are to be adopted for holistic management of LVWS and its surrounding areas.

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Table 2. Land-use change analysis of LVWS during 2013 – 2020

Land Use	Area (km ²)		Change (%)
	2013	2020	
Barren Land	6.67	16.02	+ 140.1
Forest Cover	113.08	102.07	- 9.7
Human Habitation	13.76	11.05	- 19.6
Shrub Land / Agriculture	41.39	46.64	+ 12.6
Water Body	0.95	0.07	- 92.6
Total	175.85	175.85	

Table 3. Threat mitigation matrix for LVWS

Areas of intervention Sector / domain		Objectives / Action to be initiated	Outcomes
Land resources	Forest management	<ul style="list-style-type: none"> · Primary surveys and assessments of ecological variables · Mapping of resources and threats in the forest · Policy formulation for conservation including its timely execution, encompassing employments and training 	<ul style="list-style-type: none"> · Conservation of forest resources · Sustainable harvesting of bio-resources
	Planned afforestation	<ul style="list-style-type: none"> · Forest canopy and landscape analysis · Preparation of land and selection of plant species · Protection of wild and endemic floral species · Regulated plantation and monitoring of plant growth · Check over forest tree clearance and selective cutting of old trees and re-plantations · Provisions for apiculture and horticulture · Conservation of habitat (trees with a significant requirement for animal survival and soil conservation) 	<ul style="list-style-type: none"> · Habitat restoration · Reduction in soil erosion · Enhancement in soil fertility · Improvement in the hydrological cycle
Forest resources	Smart agriculture	<ul style="list-style-type: none"> · Integration of conventional agriculture with agro-forestry · Crop management using organic fertilizers · Promoting hydroponics and incentivising the practice · Plantation of ecologically important timber species · Livestock management: Strategies for limiting herd size, livestock feed arrangements, controlled grazing, health monitoring, and veterinary services · Soil profile monitoring through routine soil health assessment · Promoting use of organic fertilizers · Safe disposal of wastes and sewage · Promoting afforestation and reforestation · Regular monitoring of water quality · Setting up of artificial ponds/ water holes in the forest · Selective plantation of native cyclone-resistant trees 	<ul style="list-style-type: none"> · Increase in the socio-economic status of forest dwellers · Better ecological connectivity to the forest mass.
	Protection of forest soil	<ul style="list-style-type: none"> · Promoting use of organic fertilizers · Safe disposal of wastes and sewage · Promoting afforestation and reforestation · Regular monitoring of water quality · Setting up of artificial ponds/ water holes in the forest · Selective plantation of native cyclone-resistant trees 	<ul style="list-style-type: none"> · Enhanced soil quality conducive for ecosystem · Minimization of soil erosion
Disaster control	Hydrological regime	<ul style="list-style-type: none"> · Regular monitoring of water quality · Setting up of artificial ponds/ water holes in the forest · Selective plantation of native cyclone-resistant trees 	<ul style="list-style-type: none"> · Reduction of water scarcity · Ensuring quality water to humans and wildlife · Minimization of soil erosion, · Protection of life and property · Causality mitigation related to forest fires · Protection of life and property
	Cyclones	<ul style="list-style-type: none"> · Regulated cutting of trees especially discarding unwanted logs · Permits for burning in forest premises · Fire vulnerability mapping and zonation · Installation of fire-fighting gadgets in forest · Arrangements for emergency telephone numbers for better communication and coordination 	<ul style="list-style-type: none"> · Information generation on measurable indicators and secondary data
Research and conservation	Forest fires	<ul style="list-style-type: none"> · Regulated cutting of trees especially discarding unwanted logs · Permits for burning in forest premises · Fire vulnerability mapping and zonation · Installation of fire-fighting gadgets in forest · Arrangements for emergency telephone numbers for better communication and coordination 	<ul style="list-style-type: none"> · Information generation on measurable indicators and secondary data
	Research activities	<ul style="list-style-type: none"> · Assessment of water quality, biodiversity indices, soil characteristics, varied species demography, agricultural surveys, anthropogenic impacts · Habitat mapping for flora and fauna · Monitoring forest climate parameters · Grant support for research activities · Mobilizing capitals towards the development, assessment, conservation, and supporting volunteers · Participation of scholars, environmentalists and local community for research and conservation 	<ul style="list-style-type: none"> · Understanding the species distribution pattern · Primary data collection
Research and conservation	Ecological surveys	<ul style="list-style-type: none"> · Habitat mapping for flora and fauna · Monitoring forest climate parameters · Grant support for research activities · Mobilizing capitals towards the development, assessment, conservation, and supporting volunteers · Participation of scholars, environmentalists and local community for research and conservation 	<ul style="list-style-type: none"> · Maintenance and protection of forest resources · Incentivising people's contribution towards environment conservation
	Project funding	<ul style="list-style-type: none"> · Mobilizing capitals towards the development, assessment, conservation, and supporting volunteers · Participation of scholars, environmentalists and local community for research and conservation 	<ul style="list-style-type: none"> · Maintenance and protection of forest resources · Incentivising people's contribution towards environment conservation

Areas of intervention Sector / domain		Objectives / Action to be initiated	Outcomes
Participatory approaches	Community-based works	<p>Awareness among locals:</p> <ul style="list-style-type: none"> · Traditional Ecological Knowledge (TEK) · Vocational education for students <p>Power to locals:</p> <ul style="list-style-type: none"> · Alternative livelihood generation for locals · Provision of Access and Benefit Sharing (ABS) mechanism for harvesting of forestry resources · Implementation of the Biodiversity Management Committee (BMC), in accordance with Biological Diversity Act 2002, for conservation <p>Local youth membership:</p> <ul style="list-style-type: none"> · Encouraging educated youth for participating in forest protection · Volunteering activities to be organized by educational institutes, individuals, groups, government or non-government organizations · Assisting in adult education through awareness programs in connection with health and the environment. · Donations to the unprivileged and village adoption · Tree plantations and cleanliness works <p>Public cooperation:</p> <ul style="list-style-type: none"> · Assistance for tribal and forest welfare · Upholding ecologically beneficial practices through the ban on plastic use, conservation and regeneration of habitats. · Supporting ecological organizations and promoting the use of forest-friendly products and actions. · Practicing the 3 R - reuse, recycle and reduce for waste management <p>Compensation, Incentives:</p> <ul style="list-style-type: none"> · Arrangement of competition for conservation · Awarding with monetary grants and recognition · Creating alternative sources of livelihood to reduce dependency on forest <p>Administrative policies:</p> <ul style="list-style-type: none"> · Proper implementation of forest laws through regular inspection and stringent action against violators. · Revenue management for land and agricultural properties · Regulations for entry into the forest and collection of forest produce · Prohibitions on mining activities, including stone quarries. · Establishing a cordial relationship between forest officials and locals · Provision of high-end GIS and remote sensing tools (Newton 2007), Internet of Things (IoT) (Salam 2020), Artificial Intelligence (Kourtz 2011), Big Data Analytics (Zou et al. 2019) for data generation, monitoring, and identification of forest health (Shah 2020, Singh et al. 2021) 	<ul style="list-style-type: none"> · Conservation and sustainable use of natural resources and equitable sharing of benefits among the local denizens. · Enhanced socio-economic conditions of local denizens · Peaceful co-existence with wild-animals · Monetary rewards · Honouring the youths at district carnivals · Improved ecological awareness among locals · Effective conservation of forest ecosystem · Mitigation of the multiple threats in the sanctuary · Economic assistance to conservationists · The attraction of many locals for conservation practices · Effective and ease of conservation · Alternative usage of forest products · Wildlife and habitat protection · Ease in conservation practices by gaining real-time updates on status of forest resource
Technological support	Use of advanced technological tools/ aids		

Table 4. Priority research matrix for LVWS

Major categories /domains	Works to be carried out	Short term	Long term	Frequency of intervention/assessment	Components to be investigated and/or anticipated benefits
Forest ecology aspects	Seed bank for LVWS	✓		Decadal	Assess the minimum ecological requirements of seeds of plants, and investigate the carrying capacity w.r.t. specific groups of animals
	Vegetation pattern and soil quality assessment	✓		Regular	Examine the changes in vegetation pattern and soil quality w.r.t. the ongoing forest degradation. Investigate the role of Lakhari forests in carbon sequestration.
	Strategic agroforestry practice		✓	Regular	Per capita income increase, forest connectivity
	Planned afforestation	✓		Regular	Ecological restoration
	Plantations along the water bodies (biofilter approach)		✓	Regular	Buffer area to filter the runoffs from agriculture, prevention of floods
	Setup of artificial ponds in the sanctuary	✓		Decadal	Water supply to wild animals at the time of scarcity
Socio-economic attributes	Co-existence and Resource Partitioning		✓	Regular	Co-existence and resources partitioning among the wild and domesticated species that could help in habitat management.
	Natural Resource Economics	✓		Decadal	Assessment of Ecosystem Services of LVWS and its economic evaluation
	Circulation of organic fertilizers	✓		Regular	Stable soil health, Good crop productivity
	Vocational education for all age groups		✓	Regular	Betterment of life and livelihood of locals
	Self-employment for women individuals	✓		Regular	Socio-economic upliftment of households
	Property supplementation in association with conservation agreements		✓	Regular	Ecosystem preservation with bound legal jurisdiction
Technical perspectives	Volunteering activities	✓		Regular	Awareness programs, Fundraising activities for ecological and local benefit
	Solar appliances to villages/ natives		✓	Decadal	Solar lights for village streets and homes, hassle-free energy
	Solar panels to every house		✓	Decadal	Less dependence on wood products for energy
	Provision for induction based cooking		✓	Decadal	Less risk on timber collection for cooking
	Camera setup inside forests		✓	Decadal	Real-time monitoring of animal and human movements and activities

Major categories /domains	Works to be carried out	Short term	Long term	Frequency of intervention/ assessment	Components to be investigated and/or anticipated benefits
	Fire extinguisher provision in forests	✓	✓	Decadal	Control over forest fires
	Satellite telemetry for wildlife tracking	✓	✓	Regular	Update gain on the movement and presence of wildlife
Research inputs	Research cum survey for primary data collection of forest resources	✓	✓	Regular	Provide a base for conservation works
	Impact Assessment	✓	✓	Regular	Cumulative Impact Assessment of land-use changes, intensification of agriculture, hydrology and water regime, infrastructure development, groundwater extraction and tourism.
	Indicator species studies	✓	✓	Regular	Identification of indicator species and their ecology needs to be studied for the long-term habitat conservation
	Bioacoustic monitoring	✓	✓	Regular	For ecosystem supervision
	Surveillance through technology: IoT, AI, Remote Sensing, Drones	✓	✓	Regular	Handy tools for transparent, on-time updates of ecosystem
	Research database	✓	✓	Regular	Creation of research database and analysis on research-management interface

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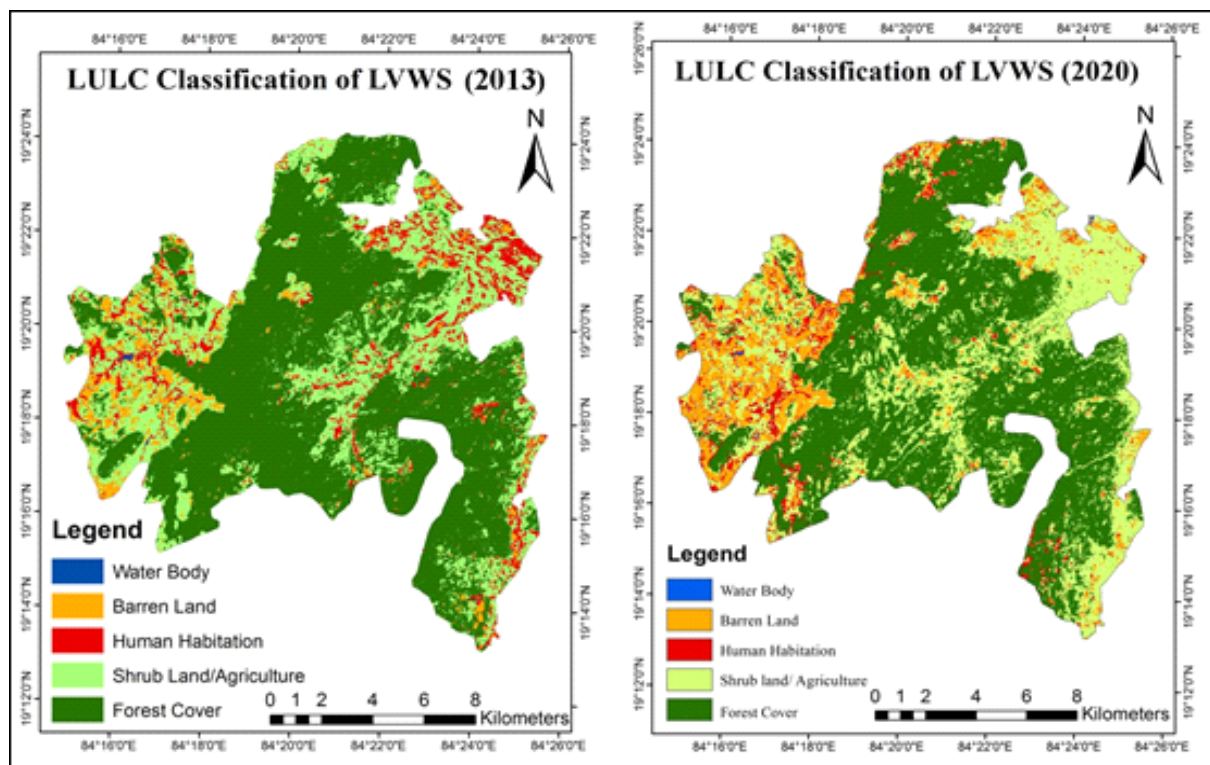


Figure 2. Land use land cover map of LVWS of the year 2013 and 2020

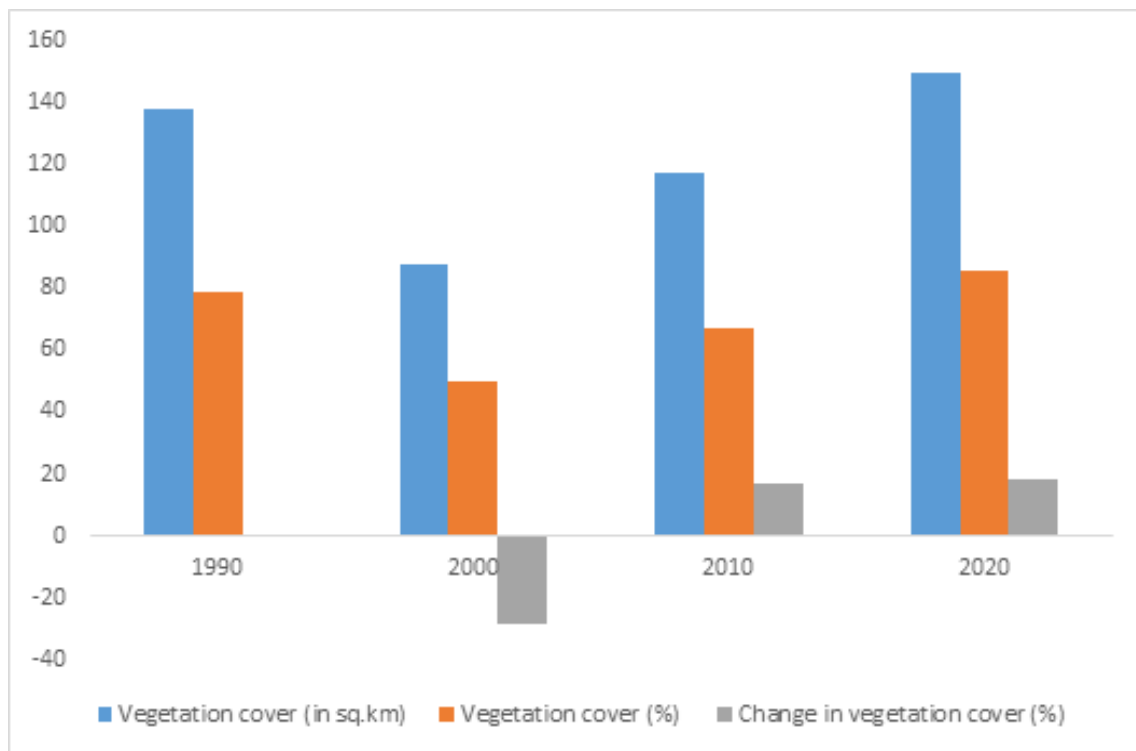


Figure 3. Decadal change analysis of vegetation cover in LVWS (Note: Total area of LVWS = 175 km²)

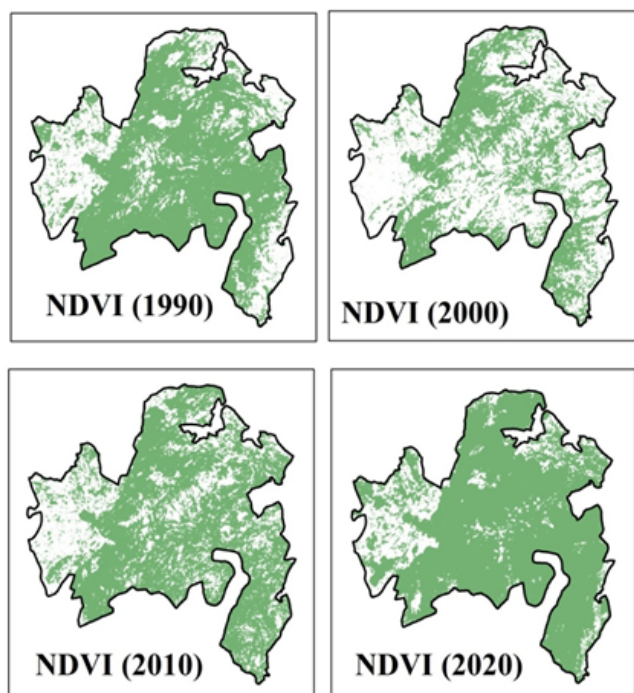


Figure 4. Decadal change in vegetation cover (NDVI) of LVWS

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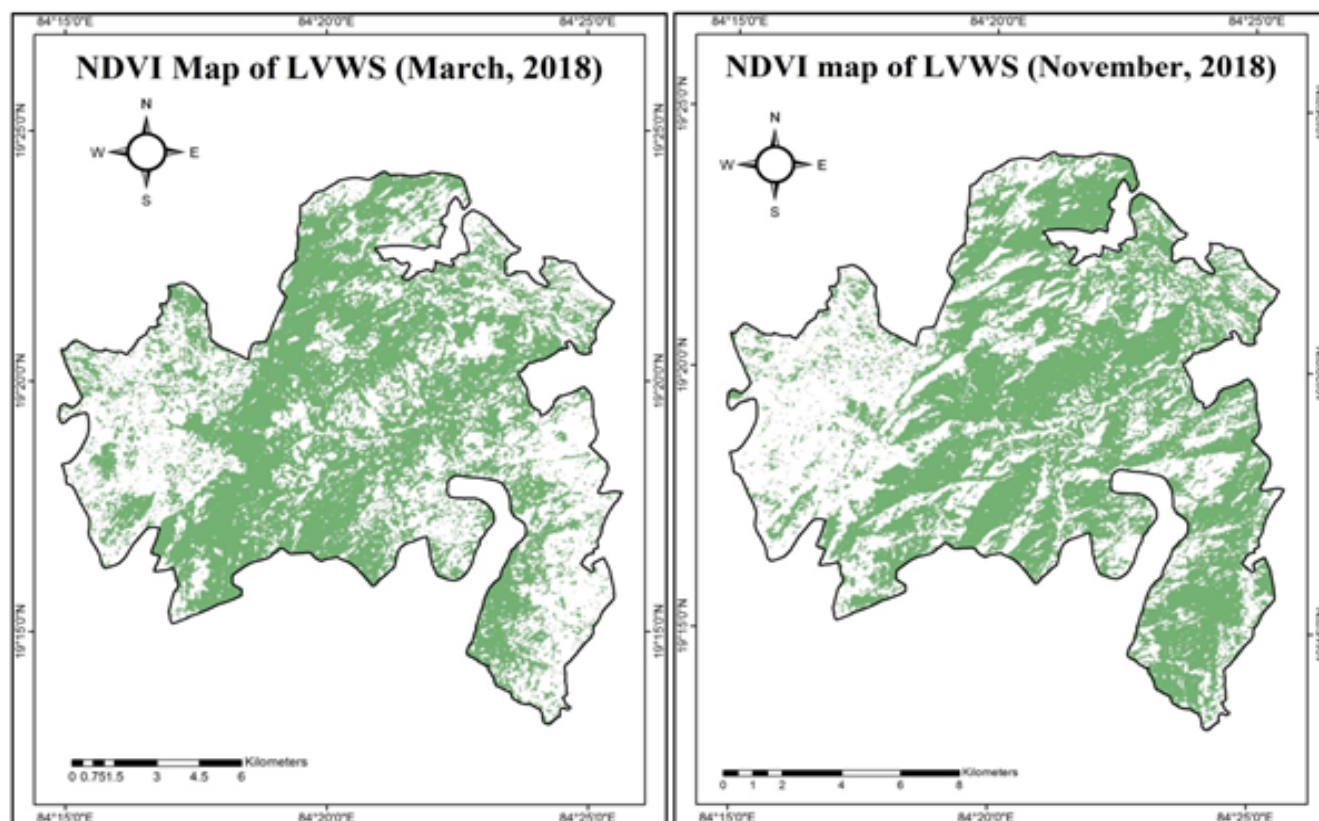


Figure 5. NDVI map of LVWS during March 2018 and November 2018

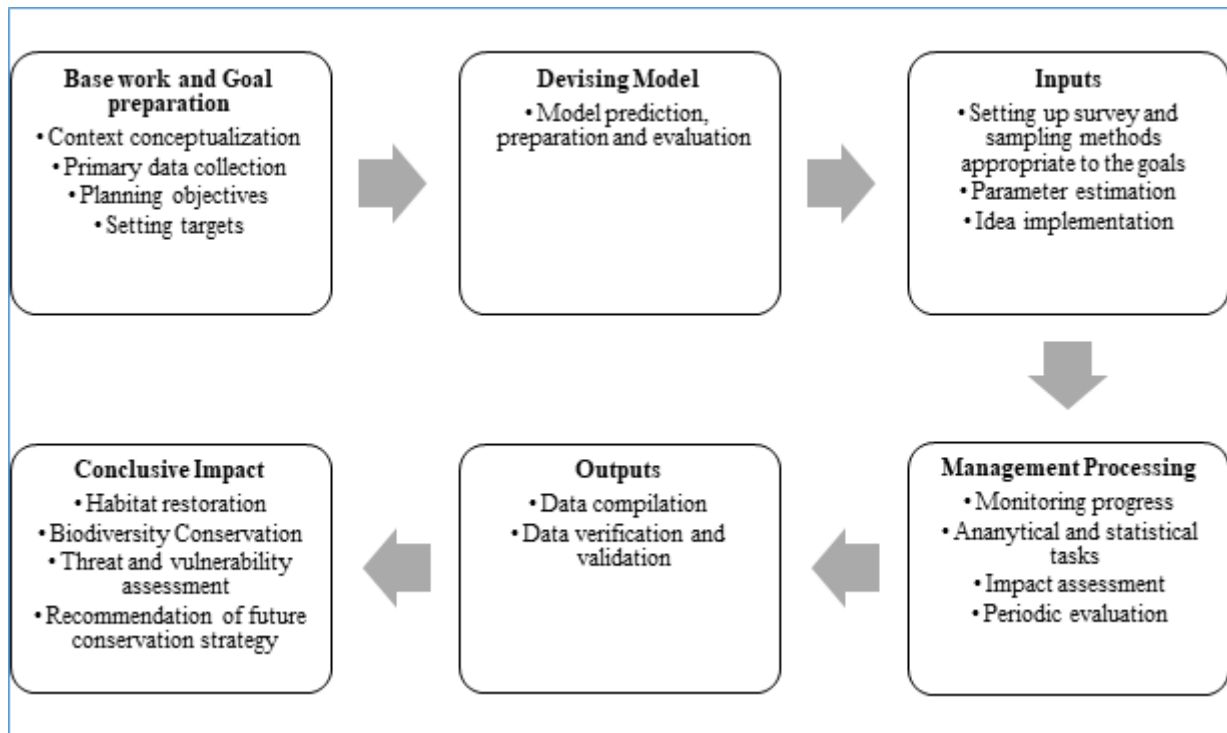


Figure 6. Model for effective ecosystem management in LVWS

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