



Central India: A Nature-Based Model for Integrated Riverine Ecosystem Recovery

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Abstract

Riparian zones along the Narmada River in Central India play critical ecological roles, including erosion control, water purification, and biodiversity maintenance. However, increasing anthropogenic pressures—such as deforestation, unregulated sand mining, and agricultural expansion—have severely degraded these ecosystems. This study presents a comprehensive, community-based restoration framework implemented under the *Namami Devi Narmade* and *Narmada Pavitra Sarvada* initiatives, aimed at rehabilitating degraded riparian habitats through nature-based and participatory approaches. A stratified riparian classification model (R1–R4) was applied across 42 community-selected sites in Narmadapuram and Harda districts (Madhya Pradesh). Restoration interventions included the planting of native species, removal of invasive flora, bioengineering (coir mat installation), and vegetative propagation. Ecological indicators—such as vegetation cover, plant survival rate, and species richness—were monitored over 24 months, alongside socioeconomic parameters including employment generation and community participation indices. The research achieved an average 78% plant survival rate and a 32% increase in vegetative cover. Native biodiversity improved, with a 26% rise in riparian bird species richness and a 19% increase in pollinator abundance. Soil erosion along rehabilitated banks declined by 40%. Over 1,200 residents participated through village coordination committees, generating 18,600 person-days of employment under MNREGA. These findings demonstrate that integrating scientific riparian zoning with community stewardship can effectively restore riverine ecosystems. The Narmada framework offers a replicable, basin-scale nature-based restoration model that enhances both ecological resilience and rural livelihoods.

Keywords: Narmada River, riparian restoration, community-based conservation, ecosystem recovery, nature-based solutions, Madhya Pradesh

Introduction

Rivers function as vital ecological corridors that sustain biodiversity, livelihoods, and cultural heritage. The Narmada River, extending 1,312 km across Central India, supports more than 40 million people and encompasses diverse ecosystems ranging from the Amarkantak plateau to the Gulf of Khambhat. However, intensifying human activities—deforestation, sand extraction, agricultural runoff, and rapid urbanization—have degraded riparian habitats critical to maintaining river health and ecological balance (Malmqvist & Rundle, 2002^[2]; Naiman & Décamps, 1997)^[1].

Riparian zones act as natural biofilters that stabilize banks, reduce erosion, recharge groundwater, and maintain habitat connectivity (Bunn & Arthington, 2002)^[3]. Their degradation reduces ecosystem resilience, leading to sedimentation, loss of biodiversity, and deterioration of water quality. In response, the Government of Madhya Pradesh launched the *Namami Devi Narmade* campaign in 2016 to integrate conservation with public participation and afforestation. Building on this initiative, the *Narmada Pavitra Sarvada* program established a community-driven, scientifically guided framework for riparian restoration (The Nature Conservancy, 2022). This study documents the ecological and social outcomes of this model, implemented collaboratively by TNC, *Jan Abhiyan Parishad*, and *Indian Grameen Services (IGS)*. It quantifies ecological recovery indicators, evaluates community engagement, and demonstrates the application of nature-based solutions (NbS) for riverine ecosystem recovery in developing regions.

Objectives

1. Develop and implement a scientific, community-driven riparian restoration framework for the Narmada basin.
2. Assess ecological impacts in terms of vegetation recovery, biodiversity enhancement, and soil stabilization.
3. Evaluate social co-benefits, including livelihood generation and institutional strengthening.

Materials and Methods

1. Study Area

The study was conducted across 42 riparian sites in Narmadapuram and Harda districts, Madhya Pradesh (22°30'–22°45' N, 77°25'–77°40' E). The Narmada River basin spans approximately 99,000 km², 89% of which lies within Madhya Pradesh (Madhya Pradesh Water Resources Department, 2021)^[5]. The basin comprises 57% agricultural land, 33% forest, 6% wasteland, and 3% water bodies. The region has a tropical monsoonal climate, receiving an average annual rainfall of 1,200 mm. Forests are predominantly tropical moist and dry deciduous, hosting more than 4,000 floral and 276 avian species (Forest Survey of India, 2021)^[6].

2. Riparian Zone Classification (R1–R4)

Riparian zones were stratified into four sub-zones based on hydrology, slope, and vegetation structure:

R1 (Aquatic fringe): Periodically inundated zone (0–1 m from river edge), dominated by aquatic herbs and grasses (e.g., *Typha angustata*, *Acorus calamus*).

R2 (Floodplain): Semi-aquatic zone (1–30 m), supporting grasses and water-tolerant trees (*Syzygium cumini*, *Ficus racemosa*).

R3 (Steep slope): Transitional area subject to erosion, stabilized using bamboo and coir mat bioengineering (*Dendrocalamus strictus*).

R4 (Outer upland): Dry riparian buffer (>30 m), supporting mixed native forest species (*Terminalia arjuna*, *Pongamia pinnata*, *Madhuca longifolia*).

Each site was mapped and measured using ETSM equipment in collaboration with local *Patwaris* (land surveyors).

3. Restoration Interventions

a. Vegetative Restoration

Native flora was selected based on ecological function, water tolerance, and community utility. Planting density averaged 1,200 saplings per hectare. Manure (1 kg per pit) and neem powder (100 g per pit) were applied to enhance soil fertility and pest resistance.

Bioengineering for Soil Stabilization

R3 zones received coir mat (700 GSM, 50 × 10 m) installation and bamboo reinforcement at 1-m intervals to mitigate erosion. Ankol seed balls (150 g per 500 m²) were broadcast to stimulate natural regeneration.

b. Invasive Species Management

Common invasive species—*Parthenium hysterophorus*, *Lantana camara*, and *Ipomoea fistulosa*—were manually uprooted post-monsoon and composted in controlled pits.

c. Community Participation and Governance

Village-level coordination committees (VCCs) were established in all 42 sites, comprising *Sarpanch*, *Secretary*, women's groups, and restoration champions (*Paudh Rakshaks*). Each *Paudh Rakshak* managed 2.5 acres for up to 100 MNREGA workdays.

4. Monitoring Framework

Table 1: Ecological and social parameters were monitored at quarterly intervals

Indicator	Metric	Frequency
Vegetation cover (%)	Drone-based NDVI analysis	6-monthly
Plant survival (%)	Field census	Quarterly
Bird and pollinator richness	Line transects	Biannual
Soil erosion rate (t ha ⁻¹ yr ⁻¹)	Sediment trap analysis	Annual
Community participation index (CPI)	Composite survey (0–1)	Annual
Employment generation	Person-days	Monthly

Baseline (2022) and endline (2024) data were compared using paired *t*-tests ($p < 0.05$).

Results

1. Vegetation Recovery

Average vegetation cover across all sites increased from 48.3% (baseline) to 80.4% (after 24 months), representing a

32.1% gain ($p < 0.01$). The R1–R2 zones exhibited the highest regeneration rates (Table 2).

Table 2: Mean Vegetation Cover and Survival Rates (n=42 sites)

Riparian Zone	Baseline Cover (%)	Final Cover (%)	Survival Rate (%)
R1	52.6	86.8	81.5
R2	46.1	82.2	79.8
R3	44.7	76.9	74.3
R4	49.9	76.1	76.7
Mean ± SD	48.3 ± 3.5	80.4 ± 4.8	78.1 ± 2.9

2. Biodiversity Enhancement

Riparian bird species increased from 98 to 123 species (+26%), including indicator taxa such as *Alcedo atthis* (Common Kingfisher) and *Psittacula eupatria* (Alexandrine Parakeet). Pollinator diversity (bees and butterflies) rose 19%, reflecting improved floral heterogeneity.

3. Soil and Water Indicators

Mean soil erosion declined by 40%, from 8.5 to 5.1 t ha⁻¹ yr⁻¹. Turbidity levels in adjacent water samples reduced by 18%, indicating effective sediment retention. Groundwater

recharge improved modestly (+7 cm mean rises in pre-monsoon water table).

4. Community and Livelihood Outcomes

Across the project period, 1,217 community members (48% women) participated. A total of 18,600 person-days was generated under MNREGA. The average Community Participation Index (CPI) increased from 0.54 to 0.83. VCCs institutionalized local governance, facilitating coordinated decision-making and conflict resolution.

Table 3: Native Plant Species Recorded in Restored Riparian Zones of Narmada River, Central India

No.	Scientific Name	Common / Local Name	Functional Group	Ecological Role in Riparian Zone
1	<i>Typha angustata</i>	Patara	Aquatic herb	Sediment trapping, nutrient uptake
2	<i>Polygonum hydropiper</i>	Water Pepper	Aquatic herb	Root binding, nutrient cycling
3	<i>Chrysopogon zizanioides</i>	Vetiver	Grass	Erosion control, slope stabilization
4	<i>Saccharum spontaneum</i>	Kaans	Grass	Flood resistance, soil cohesion
5	<i>Tamarix dioica</i>	Jhau	Shrub	Bank stabilization, saline soil tolerance

6	<i>Syzygium salicifolium</i>	Kath Jamun	Tree	Moisture-tolerant, stabilizes banks
7	<i>Ficus hispida</i>	Katgularia	Tree	Pioneer species, fruit for fauna
8	<i>Syzygium cumini</i>	Jamun	Tree	Water-tolerant, fruit-bearing keystone species
9	<i>Terminalia arjuna</i>	Arjun	Tree	Flood-tolerant, deep-rooted, erosion control
10	<i>Ficus racemosa</i>	Gular	Tree	Fodder, soil retention, bird habitat
11	<i>Ficus benghalensis</i>	Bargad	Tree	Large canopy, carbon sink, sacred grove species
12	<i>Alangium salvifolium</i>	Ankol	Tree	Early colonizer, slope regeneration
13	<i>Dendrocalamus strictus</i>	Desi Bans	Bamboo	Bioengineering, slope stabilization
14	<i>Bambusa balcooa</i>	Bheema Bans	Bamboo	Erosion control, soil reinforcement
15	<i>Bambusa arundinacea</i>	Katang Bans	Bamboo	Slope reinforcement, bioresource
16	<i>Ficus glomerata</i>	Cluster Fig	Tree	Bird forage, soil binding
17	<i>Terminalia bellirica</i>	Bahera	Tree	Carbon sequestration, shade
18	<i>Terminalia tomentosa</i>	Saja	Tree	Timber, soil stabilizer
19	<i>Ficus religiosa</i>	Peepal	Tree	Shade, soil retention, sacred tree
20	<i>Terminalia chebula</i>	Harra	Tree	Fruit-bearing, soil improvement
21	<i>Mangifera indica</i>	Desi Aam	Tree	Fruit-bearing, canopy formation
22	<i>Manilkara hexandra</i>	Khirmi	Tree	Drought-resistant, fruit-bearing
23	<i>Pongamia pinnata</i>	Karanj	Tree	Nitrogen fixation, biofuel potential
24	<i>Madhuca longifolia</i>	Mahua	Tree	Pollinator attractant, NTFP source
25	<i>Tamarindus indica</i>	Imli	Tree	Fruit-bearing, canopy formation
26	<i>Albizia lebeck</i>	Siris	Tree	Nitrogen-fixing, soil fertility enhancer
27	<i>Cassia fistula</i>	Amaltas	Tree	Ornamental, pollinator attractant
28	<i>Schleichera oleosa</i>	Kusum	Tree	Fruit-bearing, host for lac insect
29	<i>Diospyros melanoxylon</i>	Tendu	Tree	Leaf litter, NTFP (beedi leaves)
30	<i>Dalbergia paniculata</i>	Faansi	Tree	Timber, nitrogen-fixing
31	<i>Dalbergia sissoo</i>	Sheesham	Tree	Timber, nitrogen-fixing, riparian tree
32	<i>Semecarpus anacardium</i>	Bhilwa	Tree	Pioneer species, oil-rich seeds
33	<i>Aegle marmelos</i>	Bel	Tree	Medicinal fruit, drought tolerance
34	<i>Boswellia serrata</i>	Salai	Tree	Resin source, semi-arid tolerance
35	<i>Pterocarpus marsupium</i>	Beeja	Tree	Timber, medicinal bark
36	<i>Phyllanthus emblica</i>	Amla	Tree	Antioxidant-rich fruit, soil improvement
37	<i>Ougeinia dalbergioides</i>	Tinsa	Tree	Soil enrichment, nitrogen-fixing
38	<i>Soymida febrifuga</i>	Rohini	Tree	Medicinal, native dry deciduous species
39	<i>Chloroxylon swietenia</i>	Bhirra	Tree	Timber, dry forest associate
40	<i>Gmelina arborea</i>	Gamhar	Tree	Fast-growing, timber
41	<i>Limonia acidissima</i>	Kaitha	Tree	Drought-tolerant fruit tree
42	<i>Hardwickia binata</i>	Anjan	Tree	Nitrogen-fixer, erosion control
43	<i>Bauhinia variegata</i>	Kachnar	Tree	Ornamental, early bloomer
44	<i>Bombax ceiba</i>	Semal	Tree	Pioneer, soil stabilizer
45	<i>Cordia myxa</i>	Lasoda	Tree	Fruit-bearing, medicinal
46	<i>Melia azedarach</i>	Bakain	Tree	Pest-resistant, medicinal
47	<i>Lannea grandis</i>	Moyan	Tree	Bark for tanning, drought-resistant
48	<i>Sapindus mukorossi</i>	Reetha	Tree	Soapnut, natural saponin producer
49	<i>Ziziphus mauritiana</i>	Ber	Tree	Fruit-bearing, dryland species
50	<i>Manilkara zapota</i>	Chikoo	Tree	Fruit-bearing, shade
51	<i>Azadirachta indica</i>	Neem	Tree	Pest deterrent, medicinal
52	<i>Artocarpus heterophyllus</i>	Kathal (Jackfruit)	Tree	Fruit-bearing, canopy-forming
53	<i>Terminalia arjuna</i>	Arjun	Tree	Riparian keystone, erosion control
54	<i>Dalbergia latifolia</i>	Shisham	Tree	Nitrogen-fixer, soil stabilizer
55	<i>Ficus religiosa</i>	Peepal	Tree	Air purification, sacred cultural tree
56	<i>Syzygium cumini</i>	Jamun	Tree	Fruit-bearing, high resilience
57	<i>Cassia occidentalis</i>	Chakunda	Shrub	Pioneer, soil improvement
58	<i>Vetiveria zizanioides</i>	Khus	Grass	Erosion control, groundwater recharge
59	<i>Tephrosia purpurea</i>	Sirponka	Shrub	
60	<i>Cynodon dactylon</i>	Doob	Grass	Erosion control, groundwater recharge
61	<i>Apluda mutica</i>	Tachula	Grass	Erosion control, groundwater recharge
62	<i>Cyperus rotundus</i>	Nagarmotha	Grass	Erosion control, groundwater recharge
63	<i>Cyperus alulatus</i>	Grass	Grass	Erosion control, groundwater recharge
64	<i>Cyperus niveus</i>	Grass	Grass	Erosion control, groundwater recharge
65	<i>Cyperus eleusinoides</i>	Grass	Grass	Erosion control, groundwater recharge
66	<i>Cyperus pangorei</i>	Grass	Grass	Erosion control, groundwater recharge
67	<i>Cyperus pilosus</i>	Grass	Grass	Erosion control, groundwater recharge
68	<i>Cyperus pumilus</i>	Grass	Grass	Erosion control, groundwater recharge
69	<i>Cyperus pygmaeus</i>	Grass	Grass	Erosion control, groundwater recharge
70	<i>Cyperus triceps</i>	Grass	Grass	Erosion control, groundwater recharge
71	<i>Setaria glauca</i>	Grass	Grass	Erosion control, groundwater recharge
72	<i>Setaria pumila</i>	Grass	Grass	Erosion control, groundwater recharge

5. Floral Composition and Functional Diversity

A total of 72 native plant species were recorded across the restored riparian zones of the Narmada River (Table 3). These included 46 tree species (72%), 10 shrub and grass species (16%), and 8 herbaceous and aquatic species (12%). This diversity reflects a balanced, multi-strata vegetation structure essential for riparian stability and ecological function.

1.1 Species Richness and Functional Groups

The dominance of tree species underscores the project's focus on establishing long-term canopy cover and structural resilience. Key riparian trees such as *Terminalia arjuna*, *Syzygium cumini*, *Ficus racemosa*, and *Pongamia pinnata* were identified as keystone species, providing bank stabilization, fruit and nectar resources, and nitrogen enrichment. The inclusion of grasses like *Vetiveria zizanioides* and *Saccharum spontaneum* supported rapid soil binding and reduced erosion in R1–R3 zones.

Herbaceous and aquatic species (*Typha angustata*, *Acorus calamus*, *Polygonum hydropiper*) enhanced sediment trapping and nutrient cycling in periodically inundated areas, reinforcing biophysical recovery along the floodplain. Shrubs such as *Tamarix dioica* and *Cassia occidentalis* contributed to soil fertility and served as early colonizers in degraded sites.

1.2 Dominant Plant Families

Species were distributed across 22 plant families, with Fabaceae (9 species) emerging as the most dominant, followed by Moraceae (5 species), Combretaceae (4 species), and Euphorbiaceae and Poaceae (3 species each). The prominence of Fabaceae highlights its crucial role in nitrogen fixation and soil enrichment, fostering secondary succession and ecosystem resilience (Gregory *et al.*, 1991) [7].

1.3 Ecological Functionality

The restored vegetation exhibited significant functional diversity; 14 species displayed nitrogen-fixing properties (e.g., *Pongamia pinnata*, *Albizia lebbek*, *Dalbergia sissoo*). 19 species served as food sources (fruits, nectar, foliage) for birds and pollinators, contributing to a 26% increase in avian richness. 7 species produced non-timber forest products (NTFPs) such as fruits, resins, and leaves, strengthening local livelihood incentives. Canopy height increased to an average of 6.4 m after 24 months, enhancing microhabitat stratification and improving overall ecosystem complexity.

These outcomes demonstrate that a strategically designed, multi-strata planting scheme using native species can rapidly restore riparian structure and function. The inclusion of culturally significant trees such as *Ficus religiosa* (Peepal) and *Madhuca longifolia* (Mahua) also enhanced local acceptance and stewardship, reinforcing the social-ecological integration of the restoration model.

1.4 Ecological Insights

Overall, the restored riparian corridors exhibited marked improvement in structural integrity, soil retention, and habitat diversity. The multi-strata design—combining deep-rooted trees, erosion-controlling grasses, and moisture-adapted aquatics—mirrored natural riparian succession processes (Bunn & Arthington, 2002 [3]; Strayer & Dudgeon, 2010) [10]. This integrated vegetative matrix contributed to a

32% increase in vegetative cover, 40% reduction in soil erosion, and a measurable enhancement in pollinator and avian diversity.

These findings affirm that locally adapted native vegetation forms the ecological foundation for nature-based riparian recovery, supporting the long-term resilience of the Narmada River ecosystem.

Discussion

1. Ecological Effectiveness

The Narmada restoration framework demonstrated significant ecological gains, corroborating global findings that multilayered vegetation buffers enhance riparian resilience (Gregory *et al.*, 1991 [7]; Dwire & Kauffman, 2003) [8]. The R1–R2 interface exhibited optimal vegetation recovery due to sustained soil moisture and dense root networks. Bioengineering interventions effectively stabilized R3 slopes, consistent with outcomes observed in the Mekong Delta and Ganga restoration projects (Pham *et al.*, 2020) [9].

2. Biodiversity and Ecosystem Services

Enhanced vegetation heterogeneity supported higher bird and pollinator diversity, emphasizing the ecological value of native species in habitat restoration. Increased canopy complexity likely improved microclimatic regulation, litter deposition, and soil carbon sequestration—key components of riparian resilience (Strayer & Dudgeon, 2010) [10].

3. Community Engagement and Socioeconomic Benefits

Community participation was central to the project's success. Empowering *Paudh Rakshaks* and incorporating MNREGA labor ensured accountability and continuous engagement. Women's participation notably enhanced monitoring effectiveness, aligning with community forestry models in Nepal and Uttarakhand (Agrawal & Chhatre, 2006) [11]. This synergy between ecological restoration and livelihood generation fostered enduring social capital.

4. Policy Integration and Replicability

The Narmada model aligns with India's *National River Conservation Plan (NRCP)* and *Green India Mission* (MoEFCC, 2019) [12], demonstrating how NbS can complement infrastructure-based river rejuvenation. The modular R1–R4 framework allows site-specific adaptation, enabling replication in similar basins such as the Tapi and Mahanadi.

Conclusions

This investigation validates a scientifically grounded, community-led framework for riparian restoration along the Narmada River. Integrating traditional ecological knowledge with modern NbS techniques achieved significant ecological recovery within two years, evidenced by increased vegetation cover, biodiversity, and erosion reduction. The participatory governance model also strengthened livelihoods and community ownership. The Narmada framework thus provides a replicable, nature-based template for basin-scale river restoration in India, effectively addressing intertwined ecological and socioeconomic challenges in developing contexts.

References

1. Naiman RJ, Décamps H. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics*,1997;28:621–658.
2. Malmqvist B, Rundle S. Threats to the running water ecosystems of the world. *Environmental Conservation*,2002;29(2):134–153.
3. Bunn SE, Arthington AH. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*,2002: 30(4):492–507.
4. The Nature Conservancy. Guide for Restoration of Riparian Zones of Narmada River and Its Tributaries. TNC India, New Delhi, 2022.
5. Madhya Pradesh Water Resources Department. Narmada Basin Management Plan. Government of MP, 2021.
6. Forest Survey of India. India State of Forest Report. MoEFCC, New Delhi, 2021.
7. Gregory SV, Swanson FJ, McKee WA, Cummins KW. An ecosystem perspective of riparian zones. *BioScience*,1991;41(8):540–551.
8. Dwire KA, Kauffman JB. Fire and riparian ecosystems in landscapes of the western USA. *Forest Ecology and Management*,2003:178:61–74.
9. Pham TG, Kappas M, Van Huynh C, Nguyen LHH. Riparian restoration using bioengineering in the Mekong Delta. *Ecological Engineering*,2020:155:10596 3.
10. Strayer DL, Dudgeon D. Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society*,2010;29(1):344–358.
11. Agrawal A, Chhatre A. Explaining success on the commons: Community forest governance in the Indian Himalaya. *World Development*,2006:34(1):149–166.
12. MoEFCC. National River Conservation Plan Guidelines. Government of India, New Delhi, 2019.