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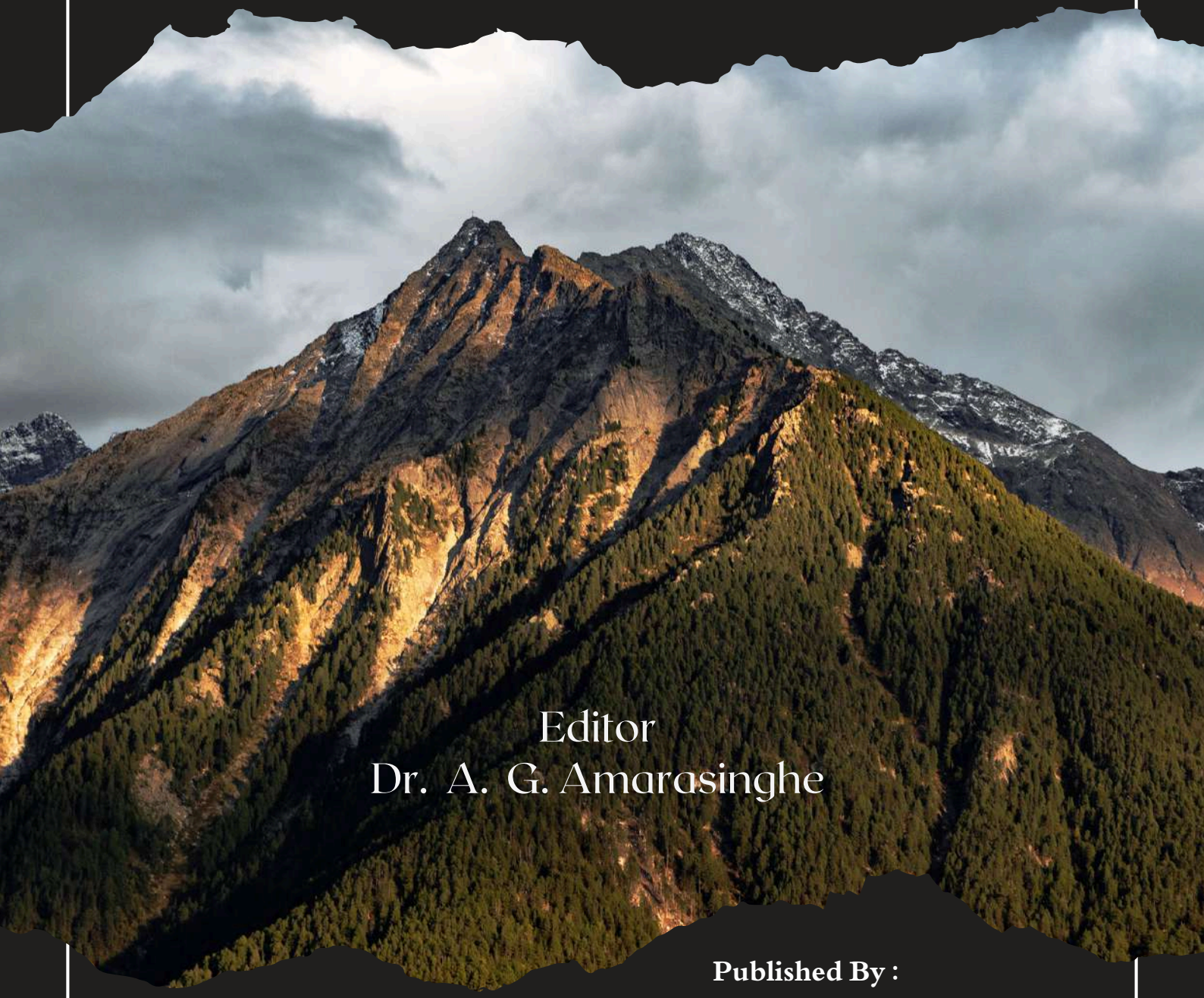

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CHIEF EDITOR

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Professor
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E-mail: principal@sknscoe.ac.in

Dr. Santosh P. Mane
CEO
Royal International Global LLC
16192 Coastal Highway, County of Sussex,
Lewes, Delaware 19958 USA
Email: ceo@royaligllc.us

PUBLISHER

Royal International Global LLC
16192 Coastal Highways, County of Sussex, Lewes, Delaware 19958
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Assistant Professor, Department of Zoology, Government College Chourai, Chhindwara, Madhya Pradesh, India
Email: kumremegha91@gmail.com

Address for correspondence:
Dr. Megha Kumre
Assistant Professor, Department of Zoology, Government College Chourai, Chhindwara, Madhya Pradesh, India
Email: kumremegha91@gmail.com

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Continuous Millet Cultivation as a Driver of Soil Health Changes: Nutrient Depletion, Microbial Shifts and Enzyme Responses

Dr. Megha Kumare

Abstract

Millets are increasingly recognized as climate-resilient cereal crops because of their relatively low water requirements, adaptability to marginal environments and importance for food and nutritional security. However, the expansion of millet cultivation can create soil-management challenges when the same millet crop is repeatedly grown on the same land without adequate nutrient replenishment, organic amendments or crop rotation. Continuous or repetitive millet cultivation may alter soil chemical, physical and biological properties through progressive nutrient removal, changes in soil pH, depletion or redistribution of soil organic matter, modification of rhizosphere microbial communities and changes in soil enzyme activities. The present research paper examines the potential effects of repetitive millet cultivation on soil health, nutrient dynamics, microbial diversity, enzymatic activity, soil structure and crop productivity. Evidence from recent field research indicates that increasing years of continuous millet cultivation can be associated with declining crop yield, reductions in soil nitrogen and phosphorus, changes in soil pH and decreases in important soil enzymes including urease, alkaline phosphatase, sucrase and catalase. In contrast, diversified cropping systems involving legumes and appropriate organic and mineral nutrient management can improve soil biological activity and nutrient availability. Long-term studies of millet systems further indicate that integrated nutrient management, particularly the combination of farmyard manure and balanced mineral fertilizers, can maintain or improve soil nutrient status. The effects of continuous millet cultivation are therefore not inherently determined by the crop alone but emerge from interactions among cropping duration, soil type, residue management, fertilization, tillage, rainfall and microbial processes. Sustainable millet production should consequently move from monocropping toward diversified rotations, residue recycling, integrated nutrient management, conservation agriculture and microbiome-informed soil management. Long-term field experiments combining soil chemistry, microbiology, enzymology and crop productivity measurements are required to establish region-specific thresholds for sustainable millet intensification.

Keywords: *millets, continuous cropping, soil health, soil fertility, soil microorganisms, soil enzymes, nutrient cycling, microbial diversity, crop rotation, sustainable agriculture.*

Introduction

Millets constitute a diverse group of small-seeded cereal crops that include pearl millet (Pennisetum glaucum), finger millet (Eleusine coracana), foxtail millet (Setaria italica), proso millet (Panicum miliaceum), little millet (Panicum sumatrense), kodo millet (Paspalum scrobiculatum) and several related species. These crops have traditionally been cultivated in dryland and semi-arid regions because of their adaptability to water limitation, high temperature and relatively poor soils. Their renewed importance is associated with climate change, increasing pressure on water resources, nutritional security and the need for diversified agricultural systems. Millets are frequently described as crops capable of producing food under comparatively difficult environmental conditions. However, their ecological advantages should not be interpreted as evidence that millet cultivation is independent of soil fertility. Like all crops, millets remove nutrients from the soil through grain and biomass production. When crop residues are removed, nutrient export can become even greater. Repeated cultivation of the same millet species on the same land may therefore progressively modify soil nutrient pools and biological processes if nutrient replacement is insufficient. Continuous cropping refers to the repeated cultivation of the same crop or crop group on the same field over successive seasons or years. Continuous-cropping problems have been documented in several agricultural crops and can involve nutrient depletion, accumulation of crop-specific pathogens, changes in root-derived compounds, altered microbial communities and deterioration of soil biochemical functioning. Recent research specifically investigating continuous millet cultivation demonstrated that increasing continuous-cropping duration was associated with lower millet yields and declining soil enzyme activities.

The distinction between millet cultivation and continuous millet monocropping is therefore important. Millet itself can be an important component of sustainable agriculture, particularly when incorporated into diversified rotations. However, repetitive monocropping without appropriate soil management can create a different ecological situation. A cropping system containing millet, legumes, oilseeds and other crops may maintain greater functional diversity than a system dominated by one crop year after year. Soil health is a multidimensional concept encompassing physical, chemical and biological properties. Important chemical indicators include soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, micronutrients and pH. Physical indicators include bulk density, aggregation, porosity, water-holding capacity and infiltration. Biological indicators include microbial biomass, microbial diversity, respiration and extracellular enzyme activities. These indicators are interconnected: changes in organic carbon influence microbial populations; microorganisms regulate nutrient mineralization; enzymes mediate biochemical transformations; and nutrient availability affects crop growth and root-derived carbon inputs. The rhizosphere is particularly important because millet roots release organic compounds that influence microorganisms, nutrient availability and soil biochemical processes. Continuous cultivation can repeatedly expose the rhizosphere microbial community to similar root-derived substrates. Over time, this may favor certain microbial groups while reducing microbial community balance. Studies of millet rhizospheres have shown that fertilization can substantially modify bacterial community composition and soil enzyme activity, with soil organic matter and available phosphorus being important factors associated with microbial communities.

Recent experimental evidence provides direct support for concerns about long-term continuous millet cultivation. In a four-year field experiment, continuous millet cultivation for two, three and four years resulted in yield reductions of 8.92%, 13.73% and 37.60%, respectively, compared with rotational cultivation. Soil nitrogen and phosphorus declined, soil pH increased, and several enzyme activities showed decreasing trends as the duration of continuous cultivation increased.

Research Objectives

The major objectives of this research are:

- To evaluate the effects of repetitive millet cultivation on soil chemical properties.
- To examine changes in soil nitrogen, phosphorus, potassium and organic carbon under continuous millet production.
- To assess the potential effects of repeated millet cultivation on soil microbial diversity and activity.
- To examine changes in soil enzyme activities associated with nutrient cycling.
- To evaluate relationships between continuous cropping, soil degradation and millet productivity.
- To identify management practices capable of maintaining soil fertility under millet-based production systems.
- To propose sustainable alternatives to continuous millet monocropping.

The objective of this research paper is therefore to critically examine the effects of repetitive millet cultivation on soil health, with emphasis on nutrient dynamics, soil organic matter, microbial diversity, enzyme activity, soil physical properties and crop productivity. The paper also evaluates management strategies that can prevent or reverse continuous-cropping problems and proposes research priorities for sustainable millet-based agricultural systems.

Research Hypothesis

The principal hypothesis is:

Repeated cultivation of millet on the same soil without adequate nutrient replenishment and crop diversification progressively alters soil chemical and biological properties, resulting in reduced soil fertility, changes in microbial functioning, declining enzyme activities and ultimately reduced crop productivity.

A secondary hypothesis is that:

Crop rotation, particularly inclusion of legumes, combined with organic amendments, balanced fertilization, residue recycling and conservation practices can reduce the negative effects associated with continuous millet cultivation.

Materials and Methods

Research approach

The present paper follows a research-synthesis approach based on experimental evidence concerning millet continuous cropping, millet-based rotations, soil microbiology, soil enzyme activity and long-term nutrient management. Particular emphasis is placed on field-based studies rather than solely theoretical assessments. For a future field experiment, a randomized complete block design can be used to quantify the effects of different durations of millet cultivation.

Proposed experimental treatments

A suitable experimental design could include:

T1: Millet cultivated for one year.
T2: Millet continuously cultivated for two years.
T3: Millet continuously cultivated for three years.
T4: Millet continuously cultivated for four or more years.
T5: Millet–legume rotation.
T6: Millet–legume–oilseed rotation.
T7: Millet with organic manure.
T8: Millet with integrated organic and mineral nutrient management.

The exact duration and treatments should be adapted to the target millet species and agroecological region.

Soil sampling

Soil samples should preferably be collected from the rhizosphere and bulk soil at standardized depths, for example 0–15 cm and 15–30 cm. Samples should be collected before sowing and after harvest to identify seasonal nutrient changes.

Soil chemical analysis

The following parameters should be evaluated:

- Soil pH
- Electrical conductivity
- Soil organic carbon
- Soil organic matter
- Total nitrogen
- Available nitrogen
- Available phosphorus
- Available potassium
- Micronutrients
- C:N ratio
- Cation exchange capacity

Soil biological analysis

Microbial biomass carbon and nitrogen, microbial respiration, culturable bacterial and fungal populations, and microbial community composition can be measured.

Modern molecular techniques can include:

- 16S rRNA sequencing for bacteria and archaea
- ITS sequencing for fungi
- Metagenomics
- Metatranscriptomics
- Metabolomics

These approaches would provide greater resolution than conventional culture-based measurements.

Soil enzyme analysis

Important enzymes include:

- Urease
- Alkaline phosphatase
- Acid phosphatase
- Dehydrogenase
- β-glucosidase
- Sucrase
- Catalase
- These enzymes can be used as indicators of microbial activity and soil nutrient cycling.

Crop measurements

Crop measurements should include:

- Germination percentage
- Plant height
- Number of productive tillers
- Panicle length
- Grain number
- Thousand-grain weight
- Grain yield
- Straw yield
- Biological yield
- Harvest index
- Nutrient uptake

Statistical analysis

Data from the experiment should be analyzed using analysis of variance (ANOVA). Correlation and regression analyses can be used to determine relationships between soil properties and crop yield. Principal component analysis and multivariate microbial-community analyses can be used for high-dimensional biological data. A soil-quality index can also be developed using a minimum data set comprising selected physical, chemical and biological indicators.

Effects of Repetitive Millet Cultivation on Soil Chemical Properties

Soil nitrogen

Nitrogen is one of the nutrients most vulnerable to depletion under continuous cereal cultivation. Millet absorbs nitrogen for vegetative growth, grain formation and protein synthesis. When grain and straw are removed from the field, substantial quantities of nitrogen leave the agroecosystem. Repeated cultivation without adequate nitrogen replacement may consequently reduce available nitrogen. Evidence from continuous millet cultivation confirms this concern, with soil nitrogen showing a decreasing tendency as the duration of continuous cultivation increased. The problem can be particularly severe in low-input rainfed agriculture, where fertilizer application may be limited by economic constraints. Nitrogen depletion can reduce leaf development, photosynthetic capacity and grain production, creating a feedback loop in which declining productivity produces less crop residue and therefore fewer organic inputs to the soil. Legumes provide an important biological alternative. Incorporation of legumes into crop rotations can increase nitrogen availability through biological nitrogen fixation and improve the quality of residues returned to soil.

Soil phosphorus

Phosphorus is essential for energy transfer, root development, flowering and grain formation. Continuous cereal production can progressively reduce plant-available phosphorus when removal exceeds replenishment. The continuous millet experiment reported reductions in soil phosphorus with increasing years of monocropping. Phosphorus availability is also closely associated with soil biological processes. Phosphatase-producing microorganisms can release phosphorus from organic compounds, while plant roots and mycorrhizal fungi can increase phosphorus acquisition. Consequently, a decline in microbial activity or phosphatase activity under continuous cultivation may further restrict phosphorus availability.

Potassium dynamics

Potassium plays major roles in osmotic regulation, enzyme activation and drought tolerance. The response of soil potassium to continuous millet cultivation may differ from nitrogen and phosphorus because potassium dynamics depend strongly on soil mineralogy, residue return and fertilization. The available potassium response in the recent continuous-millet experiment was comparatively less pronounced than changes in nitrogen and phosphorus. Nevertheless, sustained nutrient export can eventually create potassium deficits, especially on sandy or low-cation-exchange-capacity soils.

Changes in Soil pH

Soil pH controls nutrient availability, microbial activity and many biochemical reactions. Continuous millet cultivation can modify pH through nutrient uptake, residue decomposition and root exudation. A recent four-year continuous-millet study reported an increase in soil pH, with pH rising from approximately 8.3 to 8.6 after four years under the investigated conditions. 12Although this change may appear relatively small, persistent alkalinization can influence micronutrient availability and microbial community structure. Importantly, pH responses are site-specific. Therefore, the effect of continuous millet cultivation should not be generalized across all soil types.

Effect on Soil Organic Carbon

Soil organic carbon (SOC) is one of the most important indicators of soil health. It supports aggregation, water retention, microbial activity and nutrient cycling. Continuous millet cultivation may affect SOC through several pathways:

- Continuous carbon removal through harvested biomass.
- Limited residue return.
- Repeated soil disturbance.
- Changes in root biomass.
- Altered microbial decomposition.
- Reduced organic matter inputs.

However, millet itself can contribute carbon to soil through root biomass and crop residues. Therefore, the key factor is not simply whether millet is cultivated repeatedly but whether sufficient carbon is returned to the soil. Residue retention, manure, compost and cover crops can increase organic carbon inputs and improve soil biological functioning. Long-term conservation-tillage research involving pearl millet-based systems has demonstrated that reduced tillage can positively influence soil organic carbon, microbial biomass and enzyme activity.

Effects on Soil Microbial Diversity

Soil microorganisms constitute a fundamental component of soil ecosystems. Bacteria, fungi, archaea and other microorganisms participate in decomposition, nitrogen cycling, phosphorus mobilization, carbon transformation and disease suppression. Continuous cropping can modify microbial communities by repeatedly exposing the soil to similar root exudates and crop residues. A five-year continuous monocropping study involving proso millet and other minor crops found significant differences in soil physicochemical properties and enzyme activities among cropping treatments and demonstrated that continuous monocropping can influence bacterial and fungal community composition.

The response of microbial communities may occur through several mechanisms like 1.Root exudation 2.Residue chemistry 3. Nutrient availability

4.Soil pH

5.Soil moisture

Effect on Soil Physical Properties

Continuous cultivation may influence soil physical properties indirectly through changes in organic matter, root biomass, microbial activity and tillage. Potential changes include:

- Increased bulk density
- Reduced aggregate stability
- Reduced porosity
- Lower infiltration
- Reduced water-holding capacity
- Increased susceptibility to erosion

However, these effects are strongly dependent on management. Millet systems that retain residues and minimize soil disturbance may maintain better soil structure than systems in which residues are removed and intensive tillage is repeatedly performed.

Continuous Millet Cultivation and Crop Yield

One of the most important consequences of declining soil quality is reduced crop productivity. The recent continuous-millet experiment provides strong evidence for a duration-dependent yield response. Relative to rotational cultivation, millet yields declined by approximately 8.92%,13.73% and 37.60% under two, three and four years of continuous cultivation, respectively.

This suggests that the negative effects may become progressively stronger with time. A conceptual sequence can be represented as:
Repeated millet cultivation → nutrient removal → altered microbial community → reduced enzyme activity → impaired nutrient cycling → declining soil fertility → reduced plant growth → yield decline

Continuous Cropping and Soil-Borne Pathogens
Continuous cultivation can favor crop-associated pathogens and pests because the same host is repeatedly available. Potential mechanisms include:

- Accumulation of pathogen inoculum
- Persistence of infected residues
- Alteration of beneficial microbial populations
- Changes in root exudates
- Reduced microbial antagonism

However, direct evidence for millet-specific pathogen accumulation remains less extensive than evidence available for major crops such as wheat, maize, soybean and cotton. This represents an important research gap.

Role of Crop Rotation
Crop rotation is among the most effective strategies for reducing continuous-cropping problems.
A millet-based rotation could include:

- Millet → chickpea → millet → oilseed
- Pearl millet → pigeonpea → wheat → millet
- Finger millet → horse gram → finger millet

Legumes are particularly valuable because biological nitrogen fixation can contribute to soil nitrogen inputs. Research on broader Indian cropping systems has demonstrated that inclusion of legumes can improve microbial diversity, enzyme activity, soil organic carbon and overall soil quality. Intercropping millet with legumes can also improve rhizosphere functioning. Research on proso millet–mung bean intercropping found higher rhizosphere nutrient concentrations and enzyme activities under intercropping compared with sole planting, while bacterial diversity responded more strongly than fungal diversity.

Conservation Agriculture and Millet Production
Conservation agriculture can complement millet cultivation through:

- Minimum soil disturbance.
- Permanent or semi-permanent soil cover.
- Crop diversification.

Reduced tillage can improve soil carbon storage and microbial biomass. Long-term Indian research has reported positive effects of zero tillage on soil organic carbon, microbial biomass carbon, microbial biomass nitrogen and dehydrogenase activity in millet-based systems. Therefore, continuous millet production should not automatically be considered harmful if it occurs within a carefully managed conservation system. The distinction between continuous millet monoculture and well-managed millet-based conservation agriculture is critical.

Conceptual Model of Repetitive Millet Farming
The effect of repetitive millet cultivation can be conceptualized as a soil–plant–microbe feedback system.
Continuous millet cultivation
↓
Repeated nutrient uptake and biomass removal
↓
Changes in N, P and other nutrient pools
↓
Altered soil organic matter and carbon inputs
↓
Changes in rhizosphere microbial communities
↓
Changes in enzyme activities
↓
Altered nutrient mineralization and immobilization
↓
Changes in soil fertility
↓
Reduced crop growth and yield under prolonged imbalance
This pathway can be interrupted through crop rotation, organic matter addition, residue retention, balanced fertilization and reduced tillage.

Research Gaps
Despite growing interest in millet sustainability, several important knowledge gaps remain.
Long-term Indian experiments- Most available evidence on continuous millet cultivation is geographically concentrated. Long-term experiments representing Indian agroecological regions are required.

Species-specific responses- Pearl millet, finger millet, foxtail millet, proso millet, little millet and kodo millet have different root architectures and nutrient requirements. Their effects on soil should therefore not be assumed to be identical.
Microbiome mechanisms- More research using metagenomics and metatranscriptomics is needed to identify microbial taxa and functional genes associated with continuous millet cultivation.
Soil carbon- The effect of repeated millet cultivation on stable soil carbon fractions remains insufficiently characterized.
Pathogen dynamics- Long-term studies should determine whether specific soil-borne pathogens progressively accumulate under millet monocropping.
Socio-economic dimensions- Sustainable recommendations must account for farmers' access to manure, fertilizers, irrigation, machinery and markets.

Future Research Directions
Future investigations should integrate conventional soil science with molecular approaches.
- High-throughput sequencing
- 16S rRNA and ITS sequencing can characterize bacterial and fungal communities.
- Metagenomics
- Metagenomic analysis can identify functional genes involved in nitrogen, phosphorus and carbon cycling.
- Metatranscriptomics
- Metatranscriptomics can determine which microbial functions are actively expressed under continuous millet cultivation.
- Metabolomics
- Soil and root metabolomics can identify changes in root-derived compounds and microbial metabolites.
- Soil microbiome engineering
- Beneficial microbial consortia could potentially be developed to improve nutrient cycling, disease suppression and plant growth.
- Artificial intelligence
- Machine-learning models could integrate soil chemistry, microbial data, climate and yield information to predict when continuous millet cultivation begins to compromise soil quality.

Sustainable Management Framework
A sustainable millet production system should combine several practices rather than relying on a single intervention.
- Management practice
- Expected soil benefit
- Crop rotation
- Breaks continuous-cropping cycles
- Legume inclusion
- Biological nitrogen fixation
- Organic manure
- Adds carbon and nutrients
- Residue retention
- Increases carbon return
- Balanced fertilization
- Replaces exported nutrients
- Reduced tillage
- Protects soil structure
- Cover crops
- Protects soil and adds biomass
- Biofertilizers
- Supports nutrient cycling
- Soil testing
- Enables site-specific nutrient management
- Microbial monitoring
- Detects biological degradation

Discussion
The available evidence suggests that repetitive millet cultivation should be evaluated as a cropping-system issue rather than a crop-specific problem. Millets possess several characteristics that make them valuable for sustainable agriculture, including drought adaptation and relatively efficient water use. Nevertheless, resilience of the crop does not mean unlimited resilience of the soil. A crop can survive on nutrient-poor land while simultaneously removing nutrients from that land. The most important finding emerging from recent research is that continuous millet cultivation can progressively affect both soil chemistry and biological functioning. Declines in nitrogen and phosphorus, changes in pH and reductions in soil enzyme activities demonstrate that soil degradation can occur through multiple interacting pathways. The reduction in enzyme activity is particularly significant because soil enzymes provide an early indication of changes in biological functioning. A decline in urease, phosphatase, sucrase and catalase activity suggests that prolonged monocropping may influence nitrogen transformation, phosphorus mineralization, carbon decomposition and microbial oxidative processes. However, these effects should not be interpreted as evidence that millet cultivation is inherently damaging. Evidence from rotation, intercropping and

integrated nutrient-management studies indicates that millet can form part of productive and biologically active agricultural systems. Millet–legume systems, in particular, can enhance nutrient cycling and microbial activity. Therefore, the central management question is not whether farmers should cultivate millet, but how millet should be positioned within a diversified and nutrient-balanced cropping system.

Conclusion

Repetitive millet cultivation can influence soil health through interconnected changes in nutrient availability, soil pH, organic carbon, microbial communities, enzyme activity and soil physical properties. The available experimental evidence indicates that prolonged continuous millet cultivation may progressively reduce soil nitrogen and phosphorus and decrease important soil enzyme activities. Under specific experimental conditions, increasing years of continuous millet cultivation were associated with substantial yield reductions, demonstrating that continuous monocropping can eventually create measurable productivity constraints. Nevertheless, millet remains an important component of sustainable agriculture. Its ecological value should be maximized through diversified production rather than continuous monocropping. Crop rotation with legumes, residue retention, organic amendments, balanced fertilization, conservation tillage and biological inputs can help maintain soil fertility and microbial functioning.

The future of sustainable millet agriculture therefore depends on moving from a crop-centered approach to a soil–plant–microbe systems approach. Soil health should be monitored using a combination of chemical, physical and biological indicators rather than relying exclusively on crop yield. Microbial diversity, enzyme activity and soil organic carbon should be incorporated into long-term monitoring programs. Overall, repetitive millet farming is not necessarily synonymous with soil degradation; rather, the risk increases when repeated cultivation is combined with nutrient imbalance, residue removal, inadequate organic inputs and insufficient crop diversification. Properly managed millet-based rotations can simultaneously support food production, climate resilience and soil restoration. Future research should establish long-term, region-specific thresholds for continuous millet cultivation and identify management combinations capable of maintaining productivity without compromising soil health.

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Researcher, Department of Geography, Vasantrao Naik Government Institute of Arts and Social Sciences, Nagpur
Email: gaurav.misar@gmail.com

Address for correspondence:
Gaurav Ramhari Misar
Researcher, Department of Geography, Vasantrao Naik Government Institute of Arts and Social Sciences, Nagpur
Email: gaurav.misar@gmail.com

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The Quid Pro Quo Framework in Indian Patent Law: Sufficiency of Disclosure, Best Method, Fair Basis and Biological Deposits under Section 10

Gaurav Ramhari Misar

Abstract

The patent system is founded upon an exchange. The inventor receives a time-limited statutory monopoly, while the public receives access to technical knowledge that would otherwise remain concealed. This exchange is commonly described as the quid pro quo of patent law. In India, one of the principal statutory mechanisms through which this bargain is implemented is Section 10 of the Patents Act, 1970. The provision does more than prescribe the formal contents of a patent specification. It establishes substantive standards governing the quality, completeness and boundaries of the disclosure upon which patent protection is sought. This paper examines the relationship between sufficiency of disclosure, the best method requirement, biological deposits and the requirement that claims be fairly based on the disclosure. It argues that these requirements should not be treated as isolated drafting formalities. Rather, they constitute an interconnected disclosure architecture. Section 10(4)(a) addresses whether the invention and its method of performance have been adequately disclosed; Section 10(4)(b) addresses the applicant's obligation to disclose the best method known to the applicant; the proviso to Section 10(4) addresses situations in which biological material cannot adequately be described in words; and Section 10(5) establishes the boundary between the technical contribution disclosed and the monopoly claimed. The paper further examines the significance of Section 64(1)(h), which provides a revocation ground where the complete specification does not sufficiently and fairly describe the invention or disclose the best method. It considers the relationship between insufficient disclosure and pre-grant and post-grant opposition. Comparative analysis of Biogen Inc v Medeva plc and Amgen Inc v Sanofi demonstrates the continuing international concern with excessive claim breadth unsupported by enabling disclosure. The paper also considers emerging problems created by artificial intelligence and complex biotechnology, where conventional disclosure models encounter black-box systems, large training datasets, biological variability and reproducibility concerns. The paper concludes that Indian patent law should continue to treat disclosure not as a procedural burden imposed upon applicants, but as the constitutional and economic justification for the patent monopoly itself. A modern approach should preserve the quid pro quo while developing clearer examination standards for emerging technologies.

Keywords: *Indian patent law; Section 10; sufficiency of disclosure; enablement; best method; fair basis; biological deposits; Budapest Treaty; patent specification; artificial intelligence; biotechnology.*

Introduction

A patent is often described as a reward for invention. That description, although convenient, is incomplete. The patent system does not grant exclusive rights merely because an applicant has developed something technically new. The legal monopoly is justified by a corresponding disclosure to society. The underlying exchange is straightforward. The State grants the patentee a limited period of exclusivity; in return, the applicant places the technical substance of the invention into the public record. The disclosure must be sufficiently meaningful that a skilled person can understand and work the invention within the legitimate scope of the monopoly. The patent therefore represents not simply a certificate of ownership, but an instrument through which private innovation is converted into public technical knowledge. This principle becomes particularly important when the claimed invention is technologically complex. A simple mechanical invention may often be described through drawings, dimensions and operational instructions. Biotechnology presents a different problem. A microorganism, cell line or other biological material may possess characteristics that cannot be completely reproduced through verbal description. Artificial intelligence creates another difficulty: the system may depend upon data, model architecture, training procedures and parameters whose interaction is difficult to express through conventional patent drafting. The Indian Patents Act, 1970 addresses the disclosure problem primarily through Section 10. The provision establishes requirements concerning the contents of a complete specification and, importantly, links the specification to the scope of the monopoly.

Section 10(4)(a) requires the invention, its operation or use and the method by which it is to be performed to be fully and particularly described. Section 10(4)(b) separately requires disclosure of the best method of performing the invention known to the applicant and for which protection is claimed. Section 10(5) then requires claims to relate to a single invention or a group of inventions forming a single inventive concept and to be clear, succinct and fairly based on the matter disclosed in the specification.

These provisions are mutually reinforcing. Disclosure establishes the technical foundation. Enablement tests whether that disclosure permits the skilled person to perform the invention. The best-method requirement prevents an applicant from retaining the most valuable technical teaching as a private secret while seeking patent protection. The fair-basis requirement prevents the claims from expanding beyond the technical contribution actually disclosed.

The present paper therefore advances a central proposition: **Section 10 should be understood as an integrated disclosure-and-monopoly framework rather than a collection of independent drafting requirements.**

The research proceeds through doctrinal analysis of the Patents Act, the Patents Rules, Indian judicial decisions, relevant international jurisprudence and the special treatment of biological material. It also considers whether existing disclosure principles are sufficiently flexible to address emerging technologies without undermining the public bargain that justifies patent protection.

Research Objectives

The paper has five principal objectives:

1. To examine the statutory architecture of Section 10 of the Patents Act, 1970 in relation to patent disclosure.
2. To distinguish the concepts of sufficiency of disclosure, enablement, best method and fair basis.
3. To analyse the legal treatment of biological material and the role of Budapest Treaty deposits under Section 10(4) and Rule 13.
4. To examine Indian and comparative jurisprudence concerning insufficient disclosure and excessive claim breadth.
5. To identify contemporary challenges arising from artificial intelligence and complex biotechnology and propose reforms for patent examination and drafting practice.

Research Questions

The paper addresses the following questions:

1. what does the quid pro quo principle require from a patent applicant under Indian law?
2. how should sufficiency of disclosure under Section 10(4)(a) be distinguished from the best method obligation under Section 10(4)(b)?
3. how does Section 10(5)'s fair-basis requirement restrict the permissible breadth of patent claims?
4. does the biological-deposit mechanism adequately address the disclosure problem created by biological material?
5. can existing Indian disclosure standards effectively deal with AI systems and other technologies whose operation depends upon complex, data-driven processes?

Methodology

1. The research adopts a doctrinal and comparative legal methodology.
2. The primary sources comprise the Patents Act, 1970, the Patents Rules, 2003, relevant provisions concerning opposition and revocation, and judicial decisions interpreting patentability and disclosure requirements.
3. Secondary and comparative materials are used to understand the broader development of enablement and sufficiency principles, particularly decisions from the United Kingdom and United States.
4. The research is principally qualitative. It examines statutory language, judicial reasoning and the relationship between legal standards and practical patent drafting. The paper does not attempt an empirical assessment of Indian Patent Office examination statistics.

The Patent Bargain and the Disclosure Principle

The concept of quid pro quo provides the normative foundation for understanding Section 10.

The patent monopoly is exceptional because it temporarily restricts the freedom of others to make, use, sell or otherwise exploit the patented invention. That restriction can be justified only if the public receives a corresponding benefit. One component of that benefit is the eventual entry of the invention into the public domain. Another is the immediate publication of technical knowledge contained in the patent specification.

Disclosure therefore serves at least three functions.

First, it informs the public.

Secondly, it defines the technological contribution for which protection is claimed.

Thirdly, it permits courts and patent authorities to determine whether the breadth of the monopoly is justified by the applicant's contribution.

This third function is particularly important. A patent should not allow an applicant to claim an entire technological field merely because the applicant has discovered one workable embodiment. The monopoly must remain connected to the disclosed invention.

The modern relevance of this principle is evident in biotechnology and pharmaceutical patents, where a single inventive concept may potentially encompass an enormous number of compounds, sequences or biological variants. The wider the claim, the greater the burden of demonstrating that the disclosure supports and enables the claimed territory.

Thus, the quid pro quo is not simply:

innovation → patent.

It is better represented as:

technical contribution → enabling disclosure → justified claim scope → limited monopoly.

The integrity of this chain is central to Section 10.

Statutory Architecture of Section 10

1. Section 10 should be read as a structured sequence rather than as disconnected provisions.
2. Section 10(4)(a) requires the complete specification to fully and particularly describe the invention, its operation or use and the method by which it is to be performed.
3. Section 10(4)(b) requires disclosure of the best method of performing the invention known to the applicant and for which protection is claimed.
4. Section 10(4)(c) requires the specification to end with claims defining the scope of protection.
5. Section 10(4)(d) requires an abstract containing technical information about the invention.
6. Section 10(5) subsequently imposes substantive requirements upon the claims themselves: unity or a single inventive concept, clarity, succinctness and fair basis.
7. The procedural framework is supplemented by Rule 13 of the Patents Rules, 2003. Rule 13 requires specifications to be made in Form 2 and establishes detailed requirements concerning the abstract, drawings, inventorship and biological deposits. The current Rule 13(7) provides that the title normally should not exceed fifteen words and that the abstract should not exceed 150 words. Rule 13(8) provides the period for referring to a biological deposit in the specification as three months from the filing date, subject to the specific proviso concerning a request for publication under Rule 24A.

The statutory architecture can therefore be visualised as follows:

Specification → Disclosure → Enablement → Best Method → Claims → Fair Basis → Enforceable Monopoly

A weakness at an earlier stage can affect the legal validity of the later stage.

Sufficiency of Disclosure under Section 10(4)(a)

1. Section 10(4)(a) contains the core disclosure obligation. The applicant must fully and particularly describe the invention, its operation or use and the method by which it is to be performed.
2. The requirement has both descriptive and functional dimensions.
3. A specification may contain considerable technical information and nevertheless be insufficient if the skilled person cannot use that information to perform the invention. Conversely, the law does not necessarily demand that every possible experimental detail be expressly reproduced where the relevant information is part of the common general knowledge of the skilled person.
4. The critical question is therefore not whether the specification contains a large quantity of information, but whether it provides an adequate technical teaching.
5. Section 64(1)(h) reinforces this principle at the revocation stage. It expressly identifies as a ground of revocation a failure of the complete specification to sufficiently and fairly describe the invention and the method by which it is to be performed, including failure to disclose the best method known to the applicant.
6. The distinction between disclosure and enablement is therefore important.
7. Disclosure concerns what the specification teaches.
8. Enablement concerns whether that teaching permits the skilled person to perform the invention.
9. The two questions overlap but are not identical.

The Person Skilled in the Art and the Role of Undue Experimentation

- The sufficiency inquiry is not conducted from the perspective of an ordinary consumer or an inexperienced researcher. Patent law assumes a person possessing the relevant technical skill and common general knowledge.
- This is important because no patent specification can realistically contain every fact required to practise an invention. The skilled person is permitted to use ordinary technical knowledge and undertake routine experimentation.
- The difficulty arises when experimentation becomes excessive, unpredictable or speculative.
- The distinction is particularly significant in biotechnology. A specification may disclose a biological principle but leave the skilled person with a vast experimental programme before identifying which embodiments actually work. At some point the patent stops providing an enabling technical teaching and starts transferring the research burden to the public.
- This concern was central to the United Kingdom's jurisprudence on sufficiency. In *Biogen Inc v Medeva plc*, the House of Lords emphasised the relationship between the width of the monopoly and the extent of enabling disclosure. The principle commonly associated with the case is that the disclosure should enable the invention across the scope of the monopoly claimed.
- The principle is especially relevant to functional or genus claims.
- A claim that covers thousands of possible products cannot necessarily be justified merely because one member of that class has been successfully produced.
- The legal question is not whether one example works.
- The more demanding question is whether the disclosed technical principle genuinely supports the breadth of the monopoly.

The Best Method Requirement under Section 10(4)(b)

- Section 10(4)(b) introduces a separate obligation: the applicant must disclose the best method of performing the invention known to the applicant and for which the applicant is entitled to claim protection.
- The provision reflects a distinctive feature of Indian patent law.
- An applicant may possess several methods of performing an invention. Some may work adequately. Another may produce significantly better results, greater efficiency or improved reliability. If the latter is the best method known to the

applicant at the relevant time, the applicant cannot deliberately withhold it merely because the information has commercial value.

- This produces a tension between patent protection and trade secrecy.
- Trade-secret law rewards secrecy.
- Patent law rewards disclosure in exchange for exclusivity.
- The applicant cannot simultaneously demand the benefits of both systems in respect of the same technical teaching where the best-method requirement applies.
- The distinction between enablement and best method can therefore be expressed in practical terms:
- **Enablement:** Can the skilled person perform the invention from the specification?
- **Best method:** Has the applicant disclosed the best method known to the applicant for performing the invention?
- A specification may theoretically satisfy one inquiry while creating difficulty under the other.
- This is why Section 10(4)(b) should not be treated as merely repetitive of Section 10(4)(a).

Biological Material and the Limits of Written Disclosure

- Biotechnology exposes one of the fundamental limitations of conventional patent drafting: some inventions cannot be adequately reproduced through words alone.
- The proviso to Section 10(4) addresses this problem. Where biological material is mentioned in a specification but cannot adequately be described so as to satisfy the disclosure requirements, and the material is not publicly available, the applicant must use the deposit mechanism under the Budapest Treaty.
- The mechanism is conceptually elegant. Instead of requiring a patent document to contain an impossible textual description, the law supplements written disclosure with physical access to the deposited biological material.
- The statutory framework requires:

1. Deposit of the material no later than the Indian filing date;
2. A reference to the deposit within the prescribed period;
3. Sufficient identifying characteristics in the specification;
4. Identification of the depository institution and relevant deposit details;
5. Appropriate access arrangements; and
6. Disclosure of the source and geographical origin of the biological material where used in the invention.

Rule 13(8) presently specifies a three-month period for making the reference to the deposit in the specification, while also containing a special provision where publication is requested under Rule 24A.

India is a party to the Budapest Treaty, and WIPO presently identifies three Indian International Depositary Authorities: Microbial Type Culture Collection and Gene Bank (MTCC), Microbial Culture Collection (MCC), and National Agriculturally Important Microbial Culture Collection (NAIMCC).

The deposit mechanism should therefore be understood not as an exception to disclosure, but as an alternative technical means of achieving disclosure.

Source and Geographical Origin of Biological Material

- The Indian framework goes beyond merely ensuring reproducibility.
- Section 10(4)(ii)(D) requires disclosure of the source and geographical origin of biological material used in the invention.
- This requirement reflects India's broader biodiversity policy.
- Patent law intersects here with access-and-benefit-sharing principles. The issue is not simply whether a researcher has developed a patentable invention. The legal system also asks where the biological resource came from and whether its use engages the regulatory framework governing biological resources.
- The Patent Office's biotechnology guidance has historically recognised the relationship between disclosure of biological origin and the Biological Diversity Act, 2002.
- The provision is therefore significant from both patent-law and biodiversity-governance perspectives.
- A patent specification concerning biological resources can function simultaneously as:
- a technical disclosure;
- an evidentiary record of the resource used;
- a mechanism of transparency; and
- a point of intersection with access and benefit-sharing regulation.
- This is an example of the Indian patent system performing a regulatory function beyond the traditional patent bargain.

Fair Basis under Section 10(5)

- Section 10(5) provides that claims must relate to a single invention, or a group of inventions linked so as to form a single inventive concept, and must be clear, succinct and fairly based on the matter disclosed in the specification.
- The phrase "fairly based" is particularly important.
- A claim is not simply a legal boundary drawn independently of the specification. The claim represents the legal translation of the technical contribution described in the specification.
- This creates a relationship between two parts of the patent:
- **Specification = technical teaching**
- **Claims = legal boundary**
- The second cannot legitimately become detached from the first.

- An applicant who provides a narrow disclosure but seeks a substantially broader monopoly risks an insufficiency or fair-basis challenge.
- This is particularly relevant to genus and Markush claims in pharmaceutical and biotechnology patents.
- The Indian statute does not expressly use the terms "genus" and "species" in Section 10. Recent Delhi High Court jurisprudence has nevertheless considered the relationship between broad chemical structures, individual molecules and Section 10(5), demonstrating the continuing importance of disclosure and claim architecture in this area.

The Relationship Between Fair Basis and Enablement

- Fair basis and enablement should not be collapsed into one legal test.
- They are related but address different questions.
- Fair basis asks whether the claims are supported by the matter disclosed in the specification.
- Enablement asks whether the disclosure teaches the skilled person how to perform the invention.
- Nevertheless, the two requirements interact strongly.
- Suppose an applicant describes one specific compound and successfully enables its production, but then claims an entire class of thousands of compounds without providing a technical principle that permits the skilled person to practise the invention across that class.
- The problem is not merely that the claim is broad.
- The deeper problem is that the claimed monopoly may exceed the technical contribution disclosed and enabled.
- The fair-basis and sufficiency requirements therefore operate as complementary restraints on excessive claim breadth.

Opposition and Revocation: Disclosure as a Validity Requirement

- The disclosure requirements of Section 10 have practical consequences beyond examination.
- Section 25(1)(g) identifies failure of the complete specification to sufficiently and clearly describe the invention or the method by which it is to be performed as a ground of pre-grant opposition. Section 25(2) provides corresponding statutory grounds in post-grant opposition proceedings.
- At the revocation stage, Section 64(1)(h) addresses insufficiency and failure to disclose the best method. Section 64 also contains a separate ground concerning the scope and fair basis of claims.
- The practical significance is substantial.
- A specification may survive the initial filing stage but later become the subject of a validity challenge.
- Therefore, patent drafting should not be approached merely as an exercise in satisfying the formal requirements necessary to obtain grant.

The relevant question should be:

Would the specification withstand adversarial scrutiny after grant?

That question encourages a substantially higher standard of drafting.

Judicial Perspectives

- Indian patent jurisprudence has repeatedly emphasised the importance of careful claim construction, technical disclosure and statutory compliance.
- In *F Hoffmann-La Roche Ltd v Cipla Ltd*, the Delhi High Court developed a structured framework for analysing inventive step and claim scope. Although the decision is principally associated with inventive-step analysis and claim construction, its broader importance lies in the Court's insistence that patent rights must be assessed by reference to the actual technical and legal boundaries of the patent. The five-step framework has subsequently been reiterated in Indian patent litigation.
- The significance of *Roche v Cipla* for the present discussion should therefore be stated carefully. It should not be inaccurately characterised as a case solely establishing the Section 10(5) fair-basis doctrine. Its relevance is broader: it demonstrates the judicial importance of identifying the inventive concept, understanding the skilled person and objectively analysing the relationship between the patent and the prior art.
- In *Press Metal Corporation Ltd v Noshir Sorabji Pochkhanawalla*, the Bombay High Court considered patentability and ambiguity issues in the context of the statutory concept of manufacture. The case is useful in illustrating the Court's concern with the substantive meaning of patent claims and the technical character of the invention.
- For insufficiency specifically, Section 64(1)(h) remains the more direct statutory anchor. Contemporary Delhi High Court decisions continue to recognise the importance of adequate description, enablement and best-method disclosure.

Comparative Perspective: Biogen and the Problem of Excessive Breadth

- The decision in *Biogen Inc v Medeva plc* remains influential in the development of modern sufficiency doctrine.
- The underlying concern was straightforward: the patent monopoly cannot be significantly broader than the technical teaching that justifies it.
- The principle has particular importance in biotechnology because biological inventions often involve enormous families of possible products.
- A patent specification that discloses a general principle may legitimately support broad claims where the principle is genuinely applicable across the claimed field. But where the applicant's technical contribution is limited to a particular embodiment, an excessively broad claim can place a disproportionate burden upon later researchers.
- This is sometimes described as "Biogen insufficiency": a patent may contain an enabling disclosure for part of the claimed subject matter but fail to enable the full width of the monopoly.
- The lesson for Indian practice is important.

- Claim breadth should correspond to the applicant's demonstrated technical contribution, not merely to the commercial desirability of obtaining the broadest possible monopoly.

Amgen v Sanofi and Functional Claiming

- The United States Supreme Court's 2023 decision in *Amgen Inc v Sanofi* provides another important comparative reference point.
- The dispute concerned broad claims directed to antibodies defined partly by their function. The Supreme Court affirmed the judgment against Amgen, holding that the disclosure did not satisfy the applicable enablement requirement across the full scope of the claims. The Court's decision illustrates the continuing judicial concern that broad functional claims cannot shift an excessive amount of research and experimentation onto the public.
- The decision is not binding upon Indian courts. Its significance is comparative.
- It demonstrates that technologically advanced patent systems continue to confront the same structural problem:
- **How much technical information must an inventor disclose before the State can legitimately grant a monopoly covering a broad technological class?**
- The answer cannot be reduced to the number of pages in a specification. The real issue is whether the specification provides a reproducible technical teaching proportionate to the monopoly claimed.

The AI Black-box Problem

- Artificial intelligence creates a new category of disclosure difficulty.
- Consider a machine-learning invention that claims a system capable of producing a particular technical output. The performance of the system may depend upon:

• training data;
• data preprocessing;
• feature engineering;
• model architecture;
• hyperparameters;
• optimisation procedures;
• loss functions;
• training duration;
• model weights;
• deployment environment; and
• post-training adjustments.

- A patent specification that merely states that a neural network "is trained to perform" a particular task may be legally inadequate where the missing information is essential to reproducing the claimed technical result.
- At the same time, requiring disclosure of every training datum or every model parameter may be commercially and technically unrealistic.
- This creates a genuine policy tension.
- If disclosure requirements are too weak, the patent system may grant monopolies without providing meaningful technical knowledge.
- If requirements are too demanding, applicants may avoid patent protection and rely exclusively on trade secrecy.
- The correct approach should therefore be technology-sensitive but principle-driven.
- For AI inventions, the specification should ordinarily disclose enough information to permit a technically skilled person to understand the architecture and reproduce the claimed technical functionality without undertaking an open-ended research programme.

Depending upon the invention, relevant disclosure may include:

• architecture;
• input and output specifications;
• training methodology;
• relevant preprocessing;
• significant hyperparameters;
• objective or loss function;
• training conditions;
• evaluation criteria;
• representative datasets or their characteristics where necessary;
• model constraints; and
• technical parameters materially responsible for the claimed result.

The law should not automatically require disclosure of commercially irrelevant information. It should require disclosure of information that is technically necessary to practise the claimed invention.

Sequence Listings and Complex Biotechnology

Modern biotechnology creates another form of disclosure challenge.

Patent applications involving nucleotide or amino-acid sequences must comply with the electronic sequence-listing requirements under Rule 9(3). The current rule requires sequence listings to be filed in computer-readable text format and removes the requirement for a printed version of the sequence listing.

This reflects a broader principle: patent disclosure must evolve with technological complexity.

In a modern biotechnology application, disclosure may involve:

- nucleotide sequences;
- amino-acid sequences;
- sequence variants;
- host cells;
- recombinant constructs;
- expression conditions;
- biological deposits;
- functional characteristics; and
- experimental data.

The challenge is not merely volume. It is traceability.

A skilled person should be able to identify which technical features are essential to the claimed invention and how the disclosed biological material relates to those claims.

Section 10 and the Risk of Patent-enabled Trade Secrecy

- One of the most important policy questions concerns the boundary between patent protection and trade secrecy.
- An applicant may possess valuable information concerning manufacturing conditions, purification parameters, concentrations, reaction temperatures or process sequences.
- If the information is material to practising the claimed invention and constitutes the best method known to the applicant, deliberately withholding it creates tension with Section 10(4)(b).
- The problem becomes more serious where the withheld information is the difference between theoretical reproducibility and commercially successful reproduction.
- The patent system should not become a mechanism through which applicants obtain a monopoly while simultaneously withholding the information necessary to realise the technical benefit of the invention.
- This is precisely why the best-method requirement remains conceptually important even in an era in which trade-secret protection is commercially powerful.

The Disclosure-monopoly Balance

- The preceding analysis suggests that Section 10 performs a balancing function.
- On one side is the applicant's interest:
  stronger protection → broader claims → greater commercial value.
- On the other side is the public interest:
  broader monopoly → stronger justification for disclosure.
- The legal system therefore needs proportionality between disclosure and claim scope.
- A narrow technical contribution should ordinarily generate a correspondingly narrow monopoly.
- A genuinely general technical principle may justify broader protection.
- The distinction is not necessarily mathematical. Patent law cannot impose a fixed ratio between pages of disclosure and claim breadth.

Instead, the inquiry must remain technological and functional:

Does the disclosure justify the territory claimed?

That is the central question connecting Section 10(4) and Section 10(5).

Practical Implications for Patent Drafting

The doctrinal analysis has direct consequences for patent practitioners.

First, the complete specification should be drafted with litigation in mind rather than only examination.

Secondly, the specification should clearly identify the technical problem, the technical solution and the essential features responsible for the solution.

Thirdly, working examples should be selected strategically. They should demonstrate the invention rather than merely provide ornamental experimental detail.

Fourthly, the best method known at the filing date should be identified internally before drafting is finalised.

Fifthly, claim scope should be tested against the disclosure. Every important claim limitation should have a clear descriptive foundation.

Sixthly, biological deposits should be completed before the relevant Indian filing deadline and their identifying details should be incorporated within the statutory period.

Seventhly, applicants working with biological material should separately examine source, geographical origin and biodiversity-law implications.

Eighthly, AI patent applications should identify the technical elements necessary to reproduce the claimed result rather than relying upon generic statements that an algorithm or neural network is "trained".

Recommendations

The paper proposes the following reforms and best practices.

1 Develop clearer Indian guidance on enablement

The Patent Office should provide technology-specific guidance explaining how sufficiency should be evaluated in pharmaceuticals, biotechnology, AI and other complex fields.

2 Distinguish insufficiency from mere lack of drafting detail

Patent examination should distinguish between information genuinely necessary to perform the invention and information that represents merely desirable drafting completeness.

3 Adopt an explicit full-scope enablement framework

For broad claims, examiners and courts should expressly ask whether the disclosure enables the claimed invention across its material scope rather than focusing only upon the existence of one successful embodiment.

4 Strengthen AI-specific disclosure guidance

The Patent Office should clarify what categories of model architecture, training information and technical parameters may ordinarily be necessary for reproducibility, while protecting applicants from demands for commercially irrelevant information.

5 Maintain strict biological-deposit discipline

Applicants and patent agents should use an internal filing checklist that separately tracks:

- deposit date;
- Indian filing date;
- depository identity;
- accession number;
- reference deadline;
- publication request;
- source and geographical origin; and
- biodiversity-law requirements.

6 Encourage claim hierarchies

Applicants should develop claims in layers: broad independent claims, technically meaningful intermediate claims and narrow fallback claims. Such architecture can reduce the risk that invalidity of a broad claim destroys the entire commercially valuable subject matter.

7 Treat Section 10 as a substantive validity issue

Patent practitioners should stop treating Section 10 compliance as a purely administrative exercise. Sufficiency, best method and fair basis can directly affect opposition, revocation and enforceability.

Conclusion

- The patent system rests on a bargain.
- The applicant asks society for exclusivity. Society, in return, asks for knowledge.
- Section 10 of the Patents Act, 1970 is one of the principal statutory expressions of that exchange. Its requirements concerning description, enablement, best method and claim drafting ensure that the monopoly is connected to an identifiable technical contribution.
- The significance of the provision becomes particularly clear in technologically complex fields.
- In biotechnology, the written specification may reach the limits of what language can reproduce, requiring a biological deposit. In pharmaceutical patents, broad genus claims may raise questions concerning whether the disclosure genuinely supports the claimed territory. In artificial intelligence, the opacity of machine-learning systems raises new questions about what information is technically necessary to reproduce the claimed result.

Yet these are not entirely new legal problems. At their core, they return to an old question:

Has the applicant given the public enough technical knowledge to justify the monopoly claimed?

Section 10(4)(a) addresses the adequacy of the technical disclosure. Section 10(4)(b) prevents withholding of the best known method. The biological-deposit proviso provides a practical solution where biological material cannot adequately be described. Section 10(5) prevents claims from becoming detached from the disclosure. Section 64(1)(h) demonstrates that these requirements are not merely procedural because insufficiency can become a ground for revocation.

The future challenge is therefore not to weaken the disclosure requirement in response to technological complexity. Nor is it to demand impossible levels of disclosure. The more appropriate approach is to preserve the underlying principle while adapting its application to different technologies.

The guiding rule should remain simple:

The scope of the patent monopoly should correspond to the scope of the technical contribution actually disclosed and enabled.

That is the practical meaning of the quid pro quo.

When the bargain is honoured, patent law performs its intended function: it rewards innovation while enriching the public stock of technological knowledge. When the bargain is weakened, the patent risks becoming an instrument for securing exclusion without providing an equivalent public benefit.

For Indian patent law, therefore, the future of Section 10 should not be understood as a choice between stronger patent protection and stronger disclosure. Properly understood, the two are complementary. A well-disclosed invention produces a stronger and more defensible patent. A carefully limited claim produces a more legitimate monopoly. And a patent that survives scrutiny because its monopoly is proportionate to its disclosure is ultimately more valuable to both the inventor and society.

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Assistant Professor, Dept. of Geography, S. Chandra Mahila Mahavidyalaya, Dist. Gondia (MS)
Email: thakur851982@gmail.com

Address for correspondence:
Lalitkumar G. Thakur
Assistant Professor, Dept. of Geography, S. Chandra Mahila Mahavidyalaya, Dist. Gondia (MS)
Email: thakur851982@gmail.com

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Spatial Patterns of Plastic Lifecycle Emissions and Their Contribution to Global Climate Drivers- A Geographical Study

Dr. Lalitkumar G. Thakur

Abstract
Climate change represents one of the most pressing global challenges of the 21st century, primarily driven by anthropogenic greenhouse gas (GHG) emissions. While fossil fuel extraction, energy generation, deforestation, and agricultural practices are widely recognized as primary drivers, the systemic impact of plastic manufacturing, consumption, and disposal on global climate dynamics has increasingly come under geographic scrutiny. This paper synthesizes the environmental lifecycle of plastics—from fossil fuel-based petrochemical extraction to the atmospheric and oceanic degradation of single-use polymers. Incorporating key empirical metrics, process flow diagrams, carbon budget charts, and comparative statistical figures, we evaluate how plastic production exacerbates GHG emissions, examine ecosystem disruptions caused by ocean microplastics on biological carbon sinks, and critique current policy interventions including Extended Producer Responsibility (EPR) and the circular economy framework.
Keywords: *Plastic Lifecycle, Statistical Data, Atmospheric Impact Diagram, Global Carbon Budget, Microplastics, Circular Economy, Extended Producer Responsibility.*

Introduction and Background:

Climate change is currently garnering unprecedented attention across global media, policy forums, and scientific communities, driven by the increasing frequency and severity of unseasonal and extreme weather events worldwide. With heightened public and scientific scrutiny, researchers are actively analyzing contributing climate factors to formulate effective mitigation pathways. While energy systems, heavy industry, and land-use shifts remain central to climate mitigation dialogues, the pervasive footprint of plastic production, consumption, and disposal has emerged as a critical, yet frequently underestimated, global environmental threat. The modern reliance on plastic products across international markets is undeniable. From food packaging and agricultural films to specialized components in medicine, technology, and automotive engineering, plastic materials possess unmatched versatility, durability, and cost-effectiveness. This widespread industrial adoption began in 1907 with the creation of Bakelite—the world's first fully synthetic commercial plastic. Hailed at the time as a wonder material capable of revolutionizing global manufacturing, its cheap production cost and material flexibility spurred rapid global adoption. However, a little over a century later, the exact physical characteristics that made plastic an indispensable economic asset—its durability and chemical stability—have transformed it into a persistent environmental adversary. Understanding the multi-dimensional geographic and atmospheric impacts of plastic across its lifecycle is imperative for modern climate science.

Understanding Climate Change Mechanics and Drivers:

Climate change refers to significant long-term alterations in global temperatures, precipitation patterns, and atmospheric dynamics. It is primarily driven by human activities that elevate the atmospheric concentration of greenhouse gases (GHGs), inducing a net positive radiative forcing known as global warming. Fossil fuel extraction and combustion (comprising oil, natural gas, and coal) constitute the overwhelming majority of anthropogenic climate impacts. Statistically, approximately 75 percent of global greenhouse gas emissions and nearly 90 percent of all carbon dioxide emissions originate from fossil fuel usage. Power generation remains a central culprit: burning coal, gas, and oil releases immense volumes of carbon dioxide (CO_2) and nitrous oxide (N_2O), which trap solar thermal radiation within the lower atmosphere. To counteract power sector emissions, energy transitions toward zero-carbon renewables—such as wind and solar power—have accelerated. Although nuclear power provides zero-emission electricity generation during operation, it presents distinct environmental hazards, particularly regarding the safe long-term containment of toxic nuclear waste. In the United States alone, approximately 2,000 metric tons of high-level nuclear waste are generated annually, requiring secure geological storage for up to one million years.

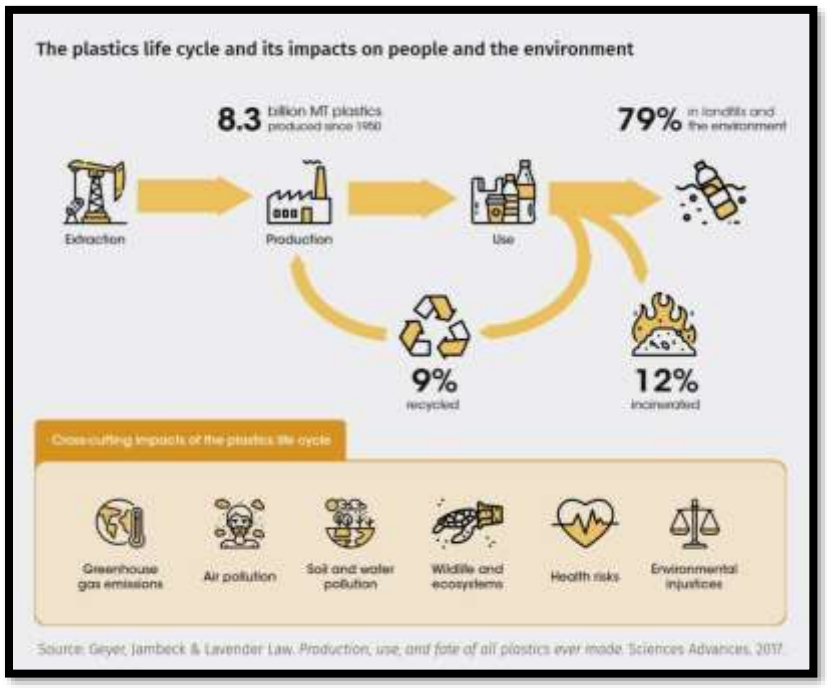
Table 1: Key Contributors to Global Greenhouse Gas Emissions & Environmental Degradation

Sector / Driver	Primary Emissions / Quantitative Impact	Key Environmental Mechanism
Fossil Fuels & Energy	75% of global GHGs, 90% of CO_2	Combustion releases massive CO_2 & N_2O, driving radiative forcing.
Deforestation & Agriculture	1/3 of anthropogenic methane (CH_4)	Removal of carbon sinks; livestock enteric fermentation & feedstock conversion.
Nuclear Power Waste	2,000 metric tons/yr (US standard)	Long-term toxic hazard requiring up to 1,000,000 years of safe containment.
Plastic Lifecycle	Est. 56+ Gigatonnes CO_2e by 2050	Energy-intensive extraction, refining, incineration, and ocean carbon sink disruption.

Quantitative Analysis & Empirical Findings:

To rigorously assess the geographical and atmospheric toll of plastic production, empirical metrics must be evaluated across the entire extraction-to-disposal lifecycle. Statistical modeling indicates that the polymer industry represents one of the fastest-growing industrial sources of greenhouse gases globally.

Figure 1: Atmospheric & Environmental Impact Flow of Plastic Lifecycle



1. **Fossil Fuel Extraction & Extraction Operations:**

a) **Process Input:** Extraction of crude oil, natural gas, and coal.

b) **Atmospheric Impact:** Releases methane (CH4), volatile organic compounds (VOCs), and carbon dioxide (CO2) through drilling, flaring, and pipeline transport leaks.

c) **Environmental Impact:** Habitat destruction, groundwater contamination risk, and land fragmentation.

2. **Refining & Plastic Manufacturing:**

a) **Process Input:** Cracking hydrocarbons to produce monomers (e.g., ethylene, propylene) and polymerizing them into resin pellets.

b) **Atmospheric Impact:** Highly energy-intensive process emitting heavy thermal CO_2, nitrogen oxides (NO_x), and chemical pollutants into the atmosphere.

c) **Environmental Impact:** Toxic chemical releases and localized air quality degradation near industrial petrochemical complexes.

3. **Product Distribution & Transportation:**

a) **Process Input:** Transporting raw resins and finished plastic packaging/goods across international supply chains via shipping, rail, and heavy trucking.

b) **Atmospheric Impact:** Combustion of fossil fuels releasing diesel exhaust emissions CO_2, black carbon, particulate matter ($PM_{2.5}$).

c) **Environmental Impact:** Contributes to ambient urban air pollution and ocean shipping noise/pollution.

4. **End-of-Life (EoL) Waste Management & Degradation:**

a) **Process Input:** Disposal via Incineration, Landfilling, Recycling, or Environmental Leakage.

b) **Atmospheric Impact:** Incineration directly vents fossil-derived CO_2 and toxic dioxins into the atmosphere. Microplastics degrading in open environments continuously release CH_4 and ethylene gas under solar UV radiation.

c) **Environmental Impact:** Soil degradation, leachate contamination of aquatic systems, and persistent ocean microplastic accumulation.

5. **Atmospheric & Ocean Climate Feedback (System Impact):**

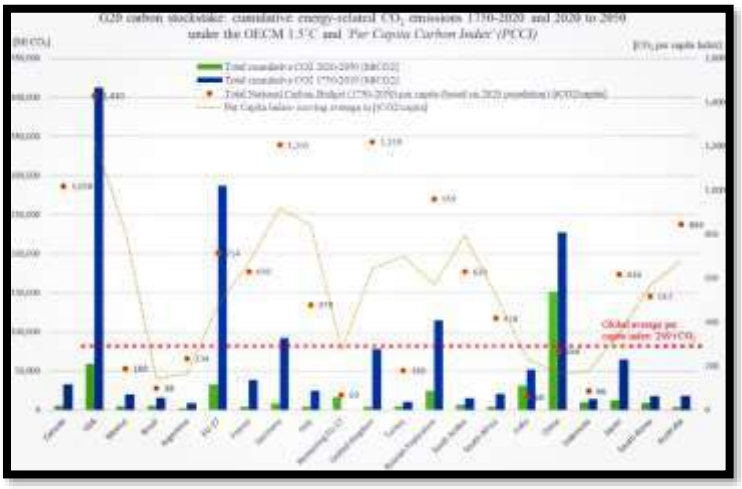
a) **Process Input:** Long-term accumulation of micro- and nano-plastics in atmospheric dust and marine surface layers.

b) **Atmospheric Impact:** Microplastics in marine surface waters disrupt phytoplankton carbon-sequestration capacity, creating a positive climate warming feedback loop.

c) **Environmental Impact:** Biodiversity loss, bioaccumulation of toxins in marine food chains, and alteration of oceanic heat absorption.

1 Global Carbon Budget Projections:

A major concern within atmospheric science is the rapidly increasing share of the global carbon budget allocated to plastic manufacturing and disposal. Under a business-as-usual scenario, the Center for International Environmental Law (CIEL) projects cumulative plastic emissions to reach over 56 gigatonnes of CO_2 equivalent by 2050.



- **Exponential Production Demand:** Global plastic production is on track to nearly triple by 2050–2060 if current market trends persist, turning petrochemicals into a primary growth engine for fossil fuels.
- **Upstream Petrochemical Refining:** Over 90% of plastic life-cycle emissions occur before product use during fossil fuel extraction, cracking, and resin synthesis.
- **End-of-Life Leakage & Incineration:** Incinerating plastic waste rapidly vents fossil carbon directly back to the atmosphere, while uncollected plastic continuing to degrade in open environments steadily emits methane (CH_4) and ethylene gas under solar ultraviolet radiation.

2 Consumption & Waste Metrics of Single-Use Plastics (SUPs):

Single-use plastics represent the largest volumetric component of municipal plastic waste streams. Table 2 provides a comparative statistical summary of daily and annual global turnover rates alongside their primary environmental mechanisms.

Table 2: Statistical Comparison of Global Single-Use Plastic (SUP) Daily Turnover

Metric / Product Category	Global Quantitative Rate	Primary Environmental Impact Mechanism
Plastic Beverage Bottles	1,000,000 units sold / minute	Rapid virgin petrochemical resin consumption; extremely low circular recycling rates.
Plastic Carrier Bags	5,000,000,000,000 units consumed / year	Severe marine entanglement, localized urban drainage blockage, and soil microplastic leaching.
Nuclear Waste Baseline	2,000 metric tons generated / year (US)	Comparative industrial waste standard requiring up to 1,000,000 years of secure storage.

Ecosystem Disruptions and Ocean Carbon Sink Degradation:

An estimated 8 to 10 million metric tons of plastic waste enter the global ocean annually, inflicting severe physical harm on marine ecology. Larger plastic debris leads to entanglement, suffocation, and fatal ingestion among marine vertebrates. Simultaneously, microplastics—tiny polymer fragments resulting from environmental breakdown—pose an insidious biophysical threat.

Emerging oceanic and atmospheric research reveals a catastrophic mechanism by which ocean microplastics accelerate global climate change: Microplastics ingested by marine microalgae and zooplankton alter their physiological processes, reducing microalgae photosynthetic efficiency. Because marine plankton perform a vital role in the biological carbon pump—absorbing surface carbon dioxide and sequestering it in the deep ocean—microplastic pollution directly impairs the ocean's capacity to act as a natural global carbon sink.

Policy Frameworks, Circular Economy, and Mitigation Pathways:

Mitigating the climate footprint of plastic requires a coordinated, multi-scalar global strategy. Because plastic waste crosses political borders via oceanic currents and global supply chains, localized interventions must be complemented by international legislative architecture.

1 Transitioning to a Circular Economy:

A central component of sustainable reform is the adoption of a circular economy framework. Unlike the traditional linear model ('take-make-dispose'), a circular economy preserves the economic value of products and raw materials for as long as possible while eliminating waste streams. This system mandates product redesign for enhanced durability, standardized recyclability, widespread operational reuse, and modern waste recovery infrastructure.

2 Regulatory Interventions and Extended Producer Responsibility (EPR):

National and local governments possess powerful regulatory mechanisms. Legislative bans on specific single-use items—such as plastic carrier bags, plastic cutlery, stirrers, and microbead cosmetics—have been successfully enacted in nations including Bangladesh and Tanzania. Other jurisdictions have implemented targeted carbon levies or plastic packaging taxes. Despite these positive steps, systemic challenges remain. The United Nations estimates that over 5 trillion plastic bags are still consumed globally every year. Furthermore, single-use plastic beverage bottles present a critical environmental challenge: approximately 1 million single-use plastic bottles are sold every minute, the vast majority crafted from virgin petrochemical resins. To address corporate inertia, governments are enacting Extended Producer Responsibility (EPR) laws, which legally mandate that manufacturers fund and manage the entire end-of-life environmental lifecycle of their products.

3 Technological Innovations and Material Alternatives:

Advanced technological solutions offer supplementary pathways for remediation. Chemical recycling techniques, such as pyrolysis (plastic-to-fuel transformation), and high-efficiency Waste-to-Energy (WtE) facilities help recover energy from non-recyclable polymer fractions. Concurrently, bio-based polymers produced from renewable feedstocks like sugarcane or corn starch provide alternatives to fossil-derived plastics.

However, bio-based plastics are not a silver bullet. Bio-polymer cultivation requires substantial land, water, and energy inputs, and improper disposal can still cause localized ecological harm. Consequently, bio-plastics must be combined with absolute reductions in overall single-use packaging consumption and transition to highly recyclable materials like aluminum.

Conclusion and Future Outlook:

The interrelationship between plastic production, environmental pollution, and climate change is undeniable and complex. While synthetic polymers have enabled modern technological and economic conveniences, their long-term environmental toll poses a severe challenge to global climate stability. Addressing this systemic crisis requires synchronized action across three tiers: 1) Enforcing mandatory EPR legislation and single-use bans; 2) Restructuring corporate supply chains to prioritize zero-waste packaging and sustainable bio-materials; and 3) Driving individual consumer behavior toward reusable alternatives and active environmental advocacy. Organizations such as the Plastic Collective demonstrate the efficacy of localized community-based micro-enterprises, combining plastic waste capture, localized recycling machinery, education programs, and plastic credit offsetting schemes to achieve plastic net-zero targets.

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The author expresses sincere gratitude to all researchers, environmental scientists, geographers, policymakers, and institutions whose studies, reports, and publications have contributed significantly to the understanding of plastic pollution, climate change, and sustainable environmental management. Their valuable work provided the theoretical and empirical foundation for this research. Special appreciation is extended to international organizations, including the United Nations Environment Programme (UNEP), the World Bank, the Organisation for Economic Co-operation and Development (OECD), and the Center for International Environmental Law (CIEL), whose reports and data sources greatly assisted in the preparation of this study.

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Dept of Botany, ACS College, Gangakhed.
Email: mmdudhbhate@rediffmail.com

Address for correspondence:
M. M. Dudhbhate
Dept of Botany, ACS College, Gangakhed.
Email: mmdudhbhate@rediffmail.com

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To Study the Effect of Leaf Extract of Some Medicinal Plants on Growth of *Macrophomina Phaseolina* (Tassi Goid) Causing Root Rot Disease of Sarpagandha (Rauwolfia Serpentina).

M. M. Dudhbhate

Abstract:

Rauwolfia serpentina (L.) Benth. Ex Kurz is an important medicinal plant recognized from ancient days famously known as Snake root or Sarpagandha. It suffers from various fungal diseases. The fungus Macrophomina phaseolina cause root rots disease to Sarpagandha. The present investigation in vitro was carried out the effect of leaf extract of some medicinal plants' species on growth of Macrophomina phaseolina. The leaf extracts of four medicinal plant species are evaluated against Macrophomina phaseolina. For this, selected four plant species viz. Onion (Allium cepa L.), Ashwagandha (Withania somnifera L.), Ginger (Zingiber officinale) and Tulasi (Oscimum sanctum) are tested. The growth was observed and recorded.

Keywords: *Medicinal plant, Macrophomina phaseolina, root rot, Rauwolfia serpentina etc*

Introduction:

Root rot disease of *Rauwolfia serpentina* caused by *Macrophomina phaseolina* (Tassi) Goid is serious disease. It was found in serious problem in its successful cultivation. Considering this problem, experiment was carried out to find out the suitable control measures for the disease. For this four-leaf extracts medicinal plant species were tested in *vitro* to know their inhibitory effect on the growth of *Macrophomina phaseolina*. The leaf extracts of selected botanicals posses the great potentialities being used as fungicides without any adverse effect on environment for the management of root rot disease. Many researchers have reported the effect of plant extracts of various plant species to inhibit the growth of *Macrophomina phaseolina* in vitro. (D. H. Tandel, Dubey and Dwivedi (1991). Therefore plant leaf extracts are considered as good alternative for the management of plant disease.

Material and Methods:

The effect of plant leaf extracts of different medicinal plant species were tested in vitro by a poisoned food technique to know their inhibitory effect on the growth of *Macrophomina phaseolina*. Fresh healthy leaves were taken, washed thoroughly with fresh water and lastly rinsed with sterile distilled water. Fifty gram of each plant leaf were weighted and cut in to small pieces, grind with the help of grinder make in to powder. Add 50 ml of methanol. Thus, obtained extracts were filtered with double layered muslin cloth in a 150 ml conical flask and tidally plugged with cotton. The filtrate sterilized by autoclave with 15 lbs pressure for 20 minutes or 121 ^{O}C for 15 minutes. The autoclaved extracts were separately poured in sterile petriplates, and then autoclaved and cooled PDA poured in extract containing petriplates. The 5 mm disc of actively growing pure culture of *Macrophomina phaseolina* was placed at the centre. These plates were incubated at room temperature. Repetitions were made for each treatment for three times. Without leaf extracts medium containing plates treated as control. The observations were made after seven days. The colony diameters were recorded and statistically analyzed and percent growth was also worked out. The sclerotia formation was recorded.

Results and Discussion:

The results presented in Table no.1 revealed that all the plant leaf extracts inhibited the growth of fungal pathogen as compared to control. Among these plant extracts, Onion (*Allium cepa* L.) extract was produced maximum inhibition of growth of *Macrophomina phaseolina* followed by extract Ashwagandha (*Withania somnifera L.*), Ginger (*Zingiber officinale*) and Tulasi (*Oscimum sanctum*). The sclerotial formation was also not seen in Onion and Ashwagandha leaf extracts less and medium no of sclerotia are seen in Ginger and Tulasi leaf extracts compared to control. Onion leaf extract was suggested great alternative of hazardous fungicides which requires detail investigation for their active principal and filled efficacy.

Table 1. Effect of different plant leaf extracts on the growth of *Macrophomina phaseolina in vitro*

Sr. No	Name of plant		Average colony diameter of pathogen(mm)	Growth inhibition (%)	Sclerotial formation
	Common name	Scientific name			
1	Onion	*Allium cepa* L.	10.30	98	No
2	Ashwagandha	*Withania somnifera L.*	27.00	80	+
3	Ginger	*Zingiber officinale*	45.10	60	++
4	Tulasi	*Oscimum sanctum* L.	79.60	20	+++
5	Control	-----	90.00	00	More than 30

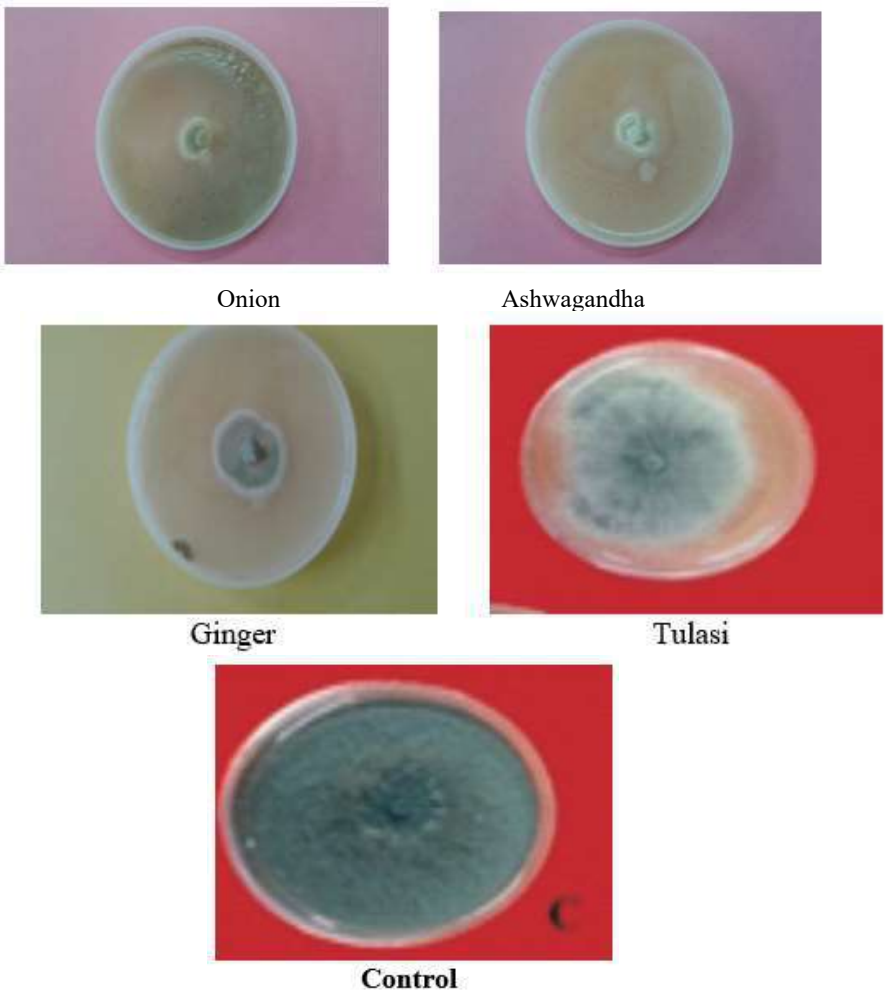

Plate1. Effect of plant extracts on radial growth of *Macrophomina phaseolina* (Sterilized).

Conclusion:

The Medicinal plant leaf extracts were playing an important role in controlling the fungal pathogens. In this experiment leaf extract of four plants were used. Among these plant leaf extracts, Onion leaf extract was inhibited the maximum growth of fungal pathogen *Macrophomina phaseolina* followed by leaf extract of Ashwagandha (*Withania somnifera L.*), Ginger (*Zingiber officinale*) and Tulasi (*Oscimum sanctum*). The sclerotial formation was also not seen in Onion and Ashwagandha leaf extracts Less and medium no of sclerotia are seen in Ginger and more in Tulasi leaf extracts compared to control. Onion leaf extract was more effective hence, suggested great alternative of hazardous fungicides which requires detail investigation for their active principal and filled efficacy.

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Department of Geography, N. M. D. College, Gondia, R. T. M. Nagpur University, Nagpur
Email: jaiswal1988ankit@gmail.com

Address for correspondence:
Ankitkumar Nareshkumar Jaiswal
Department of Geography, N. M. D. College, Gondia, R. T. M. Nagpur University, Nagpur
Email: jaiswal1988ankit@gmail.com

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Occupational Structure and Spatial-Temporal Transformation in Gondia District, Maharashtra: A Geographical Analysis (1981–2011)

Dr. Ankitkumar Nareshkumar Jaiswal

Abstract:

Occupational structure is an important indicator of the economic and socio-spatial development of a region. The distribution of population among different categories of workers reflects the economic base, employment opportunities, level of diversification and degree of dependence on primary activities. The present study examines the occupational structure of Gondia District of Maharashtra during 1981–2011, with particular emphasis on the spatial and temporal variation in main workers, marginal workers, total workers and non-workers at the tahsil level. The study is based primarily on Census data and examines Gondia, Tirora, Amgaon, Goregaon, Salekasa, Sadak Arjuni, Arjuni Morgaon and Deori tahsils for the periods for which comparable data are available. The analysis reveals considerable spatial variation in workforce participation. At the district level, total workers constituted 50.43 percent in 1981, 50.13 percent in 1991, 48.30 percent in 2001 and 53.28 percent in 2011. A major structural change occurred between 1991 and 2001, when the proportion of main workers declined substantially while marginal workers increased. Between 2001 and 2011, total worker participation increased and the proportion of non-workers declined. The findings indicate that Gondia District experienced a complex occupational transformation rather than a uniform shift in its employment structure. The growth of marginal work, together with spatial differences among tahsils, indicates variations in employment stability and the economic base of different parts of the district. The study concludes that occupational transformation in Gondia needs to be understood through the interaction of demographic characteristics, availability of employment, agricultural dependence, skills and regional economic conditions.

Keywords: *Occupational Structure, Main Workers, Marginal Workers, Non-workers, Gondia District, Spatial Variation, Temporal Change.*

Introduction:

Occupational structure refers to the distribution of the economically active population among different economic activities. It is an important component of regional geography because the occupational composition of a population reflects the economic character and developmental condition of a region. The working population constitutes an important productive resource. The size and nature of the workforce are influenced by demographic and socio-economic factors such as age composition, availability of employment, family structure, income, education and other regional characteristics. The uploaded study material emphasizes that the economically active population is directly associated with the production of goods and services and therefore constitutes an important agency of regional economic development. Gondia District has historically had a considerable dependence on agriculture and allied activities. Its occupational structure therefore provides an important basis for understanding regional economic change. However, the changing proportion of main and marginal workers suggests that the employment structure has not remained static.

The present research examines occupational structure in Gondia District over a thirty-year period from 1981 to 2011. The study focuses on the spatial differences among tahsils and the temporal changes occurring between successive Census periods.

Statement of the Problem:

The occupational structure of a region is not uniform. Differences in physical environment, agricultural conditions, population characteristics, infrastructure, urbanization, economic opportunities and accessibility may create substantial spatial variations in employment. In Gondia District, the workforce has undergone significant changes during the period 1981–2011. In particular, the decline in main workers during 1991–2001 and the simultaneous increase in marginal workers raise important questions regarding the stability and nature of employment. The major problem addressed by this research is therefore:

How and to what extent did the occupational structure of Gondia District change spatially and temporally between 1981 and 2011, and what does this transformation indicate about the regional economic structure?

Objectives of the Study:

The major objectives of the study are:

1. To examine the occupational structure of Gondia District during 1981–2011.
2. To analyse the proportion of main workers, marginal workers, total workers and non-workers.
3. To examine tahsil-wise variations in occupational structure.
4. To analyse spatial and temporal changes in workforce participation.
5. To identify major changes between 1981–1991, 1991–2001 and 2001–2011.
6. To compare the occupational structure of different tahsils.

Hypothesis:

The study is based on the following broad hypothesis:

H_1: The occupational structure of Gondia District underwent significant spatial and temporal transformation during 1981–2011, characterized particularly by changes in the relative proportions of main and marginal workers.

A subsidiary hypothesis is:

H_2: Occupational structure varied considerably among the tahsils of Gondia District because of differences in their economic and demographic characteristics.

Study Area:

Gondia District is located in the eastern part of Maharashtra. The study covers the tahsils represented in the Census-based occupational data used in the source material: Gondia, Tirora, Amgaon, Goregaon, Salekasa, Sadak Arjuni, Arjuni Morgaon and Deori. The study region has traditionally been associated with agriculture, forest-related activities and other primary-sector occupations. These characteristics provide an important geographical context for examining workforce participation and occupational transformation.The economic structure of the region has historically been influenced by forest areas and traditional agricultural practices.

Data Sources and Methodology: -

Data Sources: -

The study is primarily based on secondary data obtained from Census-related sources.

Census Handbook, Gondia District, 2001–2011 and Bhandara District, 1981–1991.

The principal variables examined are:

- Main Workers
- Marginal Workers
- Total Workers
- Non-workers

Main workers as persons engaged in economically productive work for six months or more, while marginal workers are those working for less than six months. Total workers comprise both main and marginal workers.

Analytical Method: -

The study employs:

- Percentage analysis
- Tahsil-wise comparison
- Decadal comparison
- Spatial analysis
- Temporal analysis
- Comparative interpretation of worker and non-worker proportions

The analysis is based on the percentages reported in the source tables.

Concept of Occupational Structure: -

The Census classification identifies several broad industrial categories, including:

1. Cultivators
2. Agricultural labourers
3. Livestock, forestry, fishing, hunting, plantation and allied activities
4. Mining and quarrying
5. Manufacturing, processing, servicing and repairs
6. Construction
7. Trade and commerce
8. Transport, storage and communication
9. Other services.

However, because of changes in Census classification over time, the source study analyses occupational structure principally through the categories of main workers, marginal workers, total workers and non-workers.

This approach enables comparison across the study period.

Tahsil-wise Occupational Structure: -

Significant differences existed among the tahsils.

In 1991, Goregaon recorded the highest total worker proportion at 55.45 percent, followed by Salekasa at 54.86 percent. Gondia had the lowest total worker proportion at 44.47 percent.

In 2001, Sadak Arjuni recorded the highest total worker proportion at 52.38 percent, followed by Arjuni Morgaon at 52.01 percent. Salekasa recorded the lowest at 48.62 percent.

By 2011, Salekasa recorded the highest total worker proportion at 57.01 percent, while Gondia recorded the lowest at 49.65 percent.

These variations demonstrate that occupational participation was spatially differentiated rather than uniform across the district (Table 1 and Fig. 3.21).

Sr. No.	Tahsil	1981				1991				2001				2011			
		Main	Marginal	Total	Non	Main	Marginal	Total	Non	Main	Marginal	Total	Non	Main	Marginal	Total	Non
1	Gondia	46.14	4.29	50.43	49.43	41.57	2.90	44.47	55.53	24.53	6.47	48.97	64.27	20.59	10.58	49.65	35.17
2	Tirora	N.A.	N.A.	N.A.	N.A.	47.24	4.67	51.91	48.09	30.24	17.27	51.07	47.61	30.52	14.38	52.39	40.81
3	Amgaon	N.A.	N.A.	N.A.	N.A.	48.33	4.13	52.46	47.54	28.90	9.59	48.76	56.36	31.94	16.09	54.27	48.01
4	Goregaon	N.A.	N.A.	N.A.	N.A.	48.38	7.07	55.45	44.55	34.06	18.00	51.33	50.34	35.24	16.66	51.90	48.10
5	Salekasa	N.A.	N.A.	N.A.	N.A.	50.83	4.03	54.86	45.14	27.35	18.92	48.62	50.12	31.72	22.55	57.01	43.99
6	Sadak Arjuni	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	39.78	12.66	52.38	46.14	33.83	22.03	55.86	44.13
7	Arjuni Morgaon	N.A.	N.A.	N.A.	N.A.	48.27	5.35	53.62	46.38	31.03	20.98	52.01	46.49	31.64	23.15	54.79	45.21
8	Deori	N.A.	N.A.	N.A.	N.A.	47.17	6.13	53.30	46.70	27.90	20.90	51.85	48.86	23.21	27.31	56.15	46.55
District Average		**46.14**	**4.29**	**50.43**	**49.43**	**45.79**	**4.34**	**50.13**	**49.87**	**32.6**	**15.6**	**48.3**	**51.7**	**33.53**	**19.75**	**53.28**	**46.72**

Table: 1: Tahsil wise Occupational Structure in Gondia district (1981-2011)

(Figures in percentage)

Source: Census Handbook Gondia District 2001-2011 and Bhandara District 1981-1991.

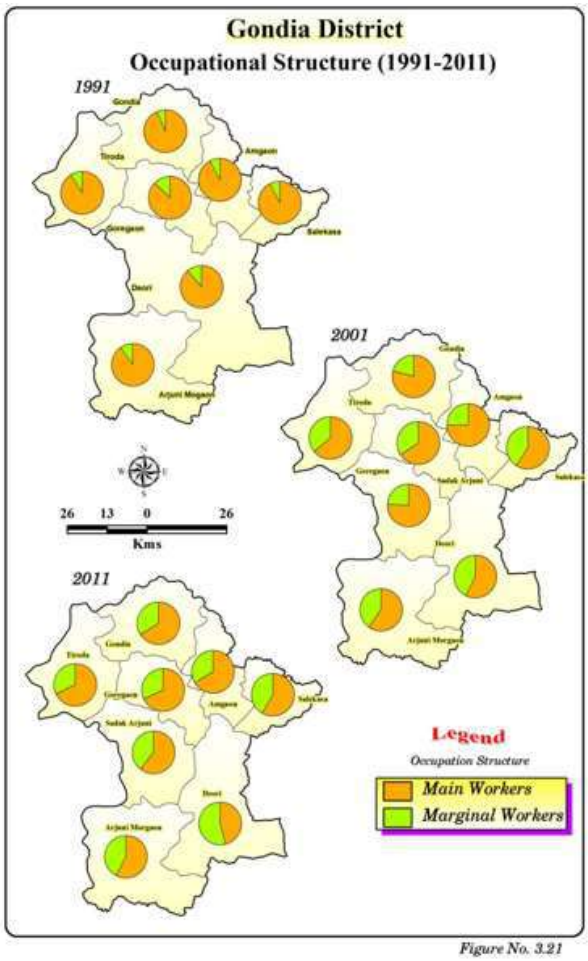

Figure No. 3.21

Spatial-Temporal Changes:

The period 1981–2011 can be divided into three major phases.

1 Change during 1981–1991:-

At the district level, the change in main workers was -0.35 percentage points, while marginal workers increased by 0.05 percentage points. Total workers declined by 0.30 percentage points and non-workers increased by 0.44 percentage points. The change during this decade was therefore relatively limited.

2 Change during 1991–2001:-

The period 1991–2001 witnessed the most substantial transformation. Main workers declined by 13.19 percentage points, whereas marginal workers increased by 11.26 percentage points. Total workers declined by 1.83 percentage points and non-workers increased by 1.83 percentage points. This suggests a shift away from relatively stable main employment toward greater dependence on marginal work.

3 Change during 2001–2011;-

During 2001–2011, main workers increased by 0.93 percentage points and marginal workers increased by 4.15 percentage points. Total workers increased by 4.98 percentage points, while non-workers declined by 4.98 percentage points. This decade therefore represents a period of increasing workforce participation (Table 2).

Table: 2: Spatio-Temporal Changes in Occupational Structure in Gondia District (1981-2011)

(Figures in percentage)

Sr. No.	Tahsil	1981-1991				1991-2001				2001-2011			
		Main	**Marginal**	**Total**	**Non**	**Main**	**Marginal**	**Total**	**Non**	**Main**	**Marginal**	**Total**	**Non**
1	Gondia	-4.57	-1.39	-5.96	6.1	-17.04	3.57	4.5	8.74	-3.94	4.33	0.68	-2.91
2	Tirora	47.24	4.67	51.91	48.09	-17.00	12.6	-0.84	-0.46	0.28	-2.89	1.32	-6.80
3	Amgaon	48.33	4.13	52.46	47.54	-19.43	5.46	-3.7	8.82	3.04	6.50	5.51	-8.35
4	Goregaon	48.38	7.07	55.45	44.55	-14.32	10.93	-4.12	5.71	1.18	-1.34	0.57	-2.24
5	Salekasa	50.83	4.03	54.86	45.14	-23.48	14.89	-6.24	4.98	4.37	3.63	8.39	-6.13
6	Sadak Arjuni	N.A.	N.A.	N.A.	N.A.	N.A.	12.66	52.38	46.14	-5.95	9.37	3.48	-2.10
7	Arjuni Morgaon	48.27	5.35	53.62	46.38	-17.24	15.63	-1.61	0.11	0.61	2.17	2.78	-1.28
8	Deori	47.17	6.13	53.30	46.70	-19.27	14.77	-1.45	2.16	-4.69	6.41	4.35	-2.31
Total		**-0.35**	**0.05**	**-0.3**	**0.44**	**-13.19**	**11.26**	**-1.83**	**1.83**	**0.93**	**4.15**	**4.98**	**-4.98**

Source: Census Handbook Gondia District 2001-2011 and Bhandara District 1981-1991.

Tahsil-Wise Decadal Variation in the Occupational Structure in Gondia district during 1981-2011:-

As far as the decadal variation in occupational structure in Gondia district is concerned, change in occupational structure of the Main workers was -12.61 percent during 1981-2011. Greatest change in percentage of Main workers was reported for Goregaon tahsil, while lowest for the Deori tahsil. Change in the Marginal workers for the district was 15.46 percent. Maximal change in percentage of Marginal workers was recorded for Deori tahsil, while minimal for the Gondia tahsil. The average percentage change of total workers for the district was 2.85 percent. Salekasa tahsil had uppermost value of 57.01 percent of Total working population while Gondia tahsil had lowermost value among all the tahsil, it has -0.78 percent total population. Change in the percentage of Non workers for the district was -2.71 percent. Maximum percentage of Non workers was found in Goregaon tahsil, while least value was found for the Gondia tahsil (Table 3 and Fig. 3.22).

Table: 3: Tahsil wise Decadal Variation in the Occupational Structure in Gondia District (1981-2011)
(Figures in percentage)

Sr. No.	Tahsil	1981-2011			
		Main Worker	Marginal Worker	Total Worker	Non Worker
1	Gondia	25.55	6.29	-0.78	-14.26
2	Tirora	30.52	14.38	52.39	40.81
3	Amgaon	31.94	16.09	54.27	48.01
4	Goregaon	35.24	16.66	51.90	48.10
5	Salekasa	31.72	22.55	57.01	43.99
6	Sadak Arjuni	33.83	22.03	55.86	44.13
7	Arjuni Morgaon	31.64	23.15	54.79	45.21
8	Deori	23.21	27.31	56.15	46.55
District Total		**-12.61**	**15.46**	**2.85**	**-2.71**

Source: Census Handbook Gondia District 2001-2011 and Bhandara District 1981-1991.

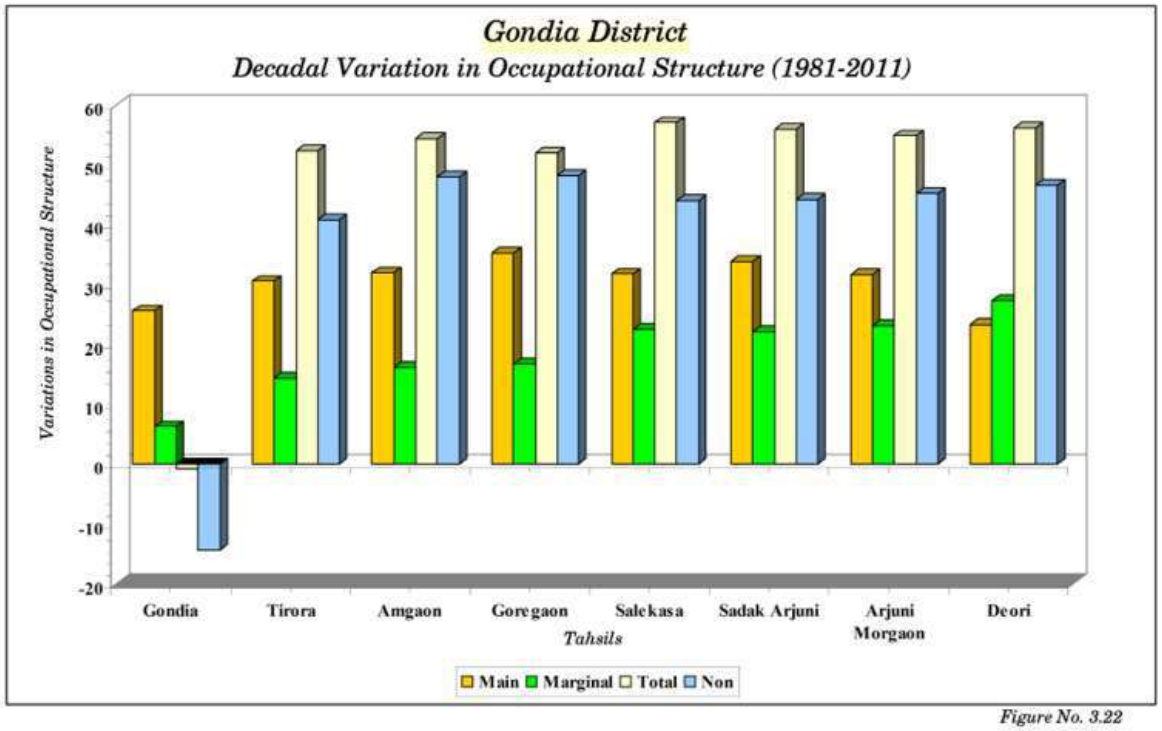

Figure No. 3.22

Major Findings: -

The major findings of the study are as follows:

1. Occupational structure in Gondia District changed considerably between 1981 and 2011.
2. Total worker participation increased from 50.43 percent in 1981 to 53.28 percent in 2011.
3. Main-worker participation declined considerably, particularly during 1991–2001.
4. Marginal workers increased substantially from 4.29 percent in 1981 to 19.75 percent in 2011.
5. Salekasa recorded the highest total worker proportion in 2011 at 57.01 percent.
6. Gondia recorded the lowest total worker proportion in 2011 at 49.65 percent.

Discussion: -

The occupational transformation of Gondia District reflects a complex interaction between workforce participation and employment structure. The most important feature is not simply the increase or decrease in total workers but the changing composition of workers.The decline in main workers between 1991 and 2001 accompanied by a substantial rise in marginal workers indicates that employment became increasingly characterized by shorter-duration work. This transformation is important from the perspective of regional development because a higher proportion of marginal workers may indicate greater dependence on seasonal or irregular employment. The subsequent increase in total workers between 2001 and 2011 suggests an improvement in overall participation. However, the continued increase in marginal workers indicates that higher participation did not necessarily correspond to a comparable expansion of stable main employment. The spatial variation among tahsils further demonstrates that regional occupational change cannot be understood solely at the district level. Different tahsils exhibited different combinations of main, marginal and total workers. Such spatial differentiation is an important geographical characteristic of the district.

Implications for Regional Development:

The findings have several implications for regional planning.

1. Employment Diversification:

The district requires greater diversification of employment opportunities beyond traditional activities. Expansion of secondary and tertiary employment can reduce excessive dependence on seasonal employment.

2. Skill Development:

The increasing importance of marginal work highlights the need for skill-development programmes that can improve the employability of the rural workforce.

3. Rural Employment:

Employment programmes should be designed according to the specific characteristics of individual tahsils rather than applying a uniform district-level strategy.

4. Agricultural Modernization:

Since agriculture has traditionally formed an important component of the regional economic base, improving agricultural productivity, irrigation, processing and allied activities can generate more stable employment.

5. Tahsil-Level Planning;

The strong spatial differences observed in the data suggest that planning should be decentralized and tahsil-specific.

Conclusion:

The study of occupational structure in Gondia District during 1981–2011 reveals substantial spatial and temporal transformation. The district experienced a relatively stable workforce participation level during the initial period, followed by a marked structural change during 1991–2001 and increased workforce participation during 2001–2011. The most important finding is the substantial rise in marginal workers. Main-worker participation declined from 46.14 percent in 1981 to 33.53 percent in 2011, whereas marginal-worker participation increased from 4.29 percent to 19.75 percent. At the same time, total workers increased from 50.43 percent to 53.28 percent, while non-workers declined from 49.43 percent to 46.72 percent. The spatial variation among tahsils demonstrates that occupational transformation was uneven. Salekasa, Sadak Arjuni, Arjuni Morgaon and Deori displayed comparatively high levels of marginal work in the tabulated data, while Gondia consistently showed a relatively low total-worker proportion. Thus, occupational transformation in Gondia District should be interpreted not merely as an increase in workforce participation but as a restructuring of the nature of employment. The increasing significance of marginal employment presents an important challenge for sustainable regional development. Future planning should therefore emphasize stable employment generation, skill development, economic diversification and tahsil-specific development strategies.

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Associate Professor, Balasaheb Desai College, Patan
Email:
santoshpatilanjani@gamail.com

Address for correspondence:
Santosh Prakash Patil,
Associate Professor, Balasaheb Desai College, Patan
Email:
santoshpatilanjani@gamail.com

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The Role of Pilgrimage Tourism in Promoting Sustainable Tourism Development

Dr. Santosh Prakash Patil

Abstract
Pilgrimage Tourism is one of the main factors that contribute to the development of sustainable tourism development due to its attraction towards tourists and economic growth of the local economy. In this research work, the role played by Pilgrimage Tourism was examined with respect to the opinions of 45 respondents. The primary data were gathered using a questionnaire which was analyzed using percentages, means, and standard deviations. The study concludes that improved infrastructure and sustainable tourism management are essential for the long-term development of pilgrimage destinations.

Keywords: *Pilgrimage Tourism, Sustainable Tourism Development, Tourism Development, Socio-Economic Development, Agro-Tourism.*

Introduction

India is fortunate to have many locations that welcome pilgrims from different religions, such as Buddhism, Sikhism, Islam, Christianity, Hinduism, and Jainism. In addition to being places of worship, these locations receive millions of visitors each year, which significantly contributes to the socioeconomic advancement of the local populace. Sustainable tourism development has gained significant importance in recent times. In order to provide long-term benefits to present and future generations, sustainable tourism entails finding a balance between three factors: economic development, environmental protection, and sociocultural preservation. Hence, pilgrimage tourism can contribute effectively towards achieving sustainable tourism by creating job opportunities, developing local businesses, conserving cultural heritage and improving infrastructure. However, a number of issues, including overcrowding, environmental pollution, waste management challenges, and infrastructure strain, have been brought up by the increased number of pilgrim tourists. As a result, management and planning become crucial. Through an analysis of its numerous economic, social, cultural, and environmental effects, this study aims to investigate how pilgrimage tourism contributes to the sustainable growth of tourism. This research could offer valuable inputs to policy makers and tourism administrators regarding the sustainable management of pilgrimage tourism destinations.

Romila Chawla (2006) in through her book 'Agro Tourism' the author has explained agro tourism trends in different countries. Various cases have been quoted as examples to comprehend concepts of agro tourism and development of its market and products. The author explains the traits of agro tourism market and the strategies for developing agro tourism products. In depth explanation is made about marketing of agro tourism products. **Savita and Dr. Anilkumar Wavare (2019)** in their book titled 'Agro-Tourism in Maharashtra' they have described all about agro tourism in Maharashtra. In order to analyze the agro tourism business situation in Maharashtra, the authors have selected agro tourism centers located in hilly region, drought-prone region, and plauto region as samples and have done an analysis of those. They use separate questionnaires for owners, employees, and visitors for collecting information and problems are analyzed. Some suggestions have been made in order to improve the performance of agro tourism centers. **Ratandeep Singh** In his book named "Infrastructure of Tourism in India", he has given information regarding the infrastructure of tourism in India, the pioneering role played by ITDC, the role of national committees in tourism, tourism marketing strategies, pricing of products. Information has been provided by him regarding resources of hospitality and facilitation, classification of tourists and visitors, identification of the market, and problems in travel trade, etc. Information has been provided by him about starting agro tourism and rural tourism.

Statement of the Problems

In the recent past, pilgrimage tourism has been playing an increasingly significant part in the development of regional tourism and economic development in local areas. Although pilgrimage tourism has been contributing towards job creation, revenue generation, and preservation of culture, the consistent increase in the numbers of pilgrims has resulted in degradation of the environment, overcrowding, traffic problems, and poor waste management at most of the pilgrimage sites. This is likely to affect the quality of experiences for visitors as well as the sustainability of such destinations in the long run. It is therefore imperative to understand the role of pilgrimage tourism in sustainable tourism development.

Objectives of the Study

1. To examine the role of pilgrimage tourism in promoting sustainable tourism development.
2. To analyze the economic, social, cultural, and environmental impacts of pilgrimage tourism on sustainable tourism development.

Hypothesis

H_0 (Null Hypothesis): Pilgrimage tourism has no significant role in promoting sustainable tourism development.

H_1 (Alternative Hypothesis): Pilgrimage tourism has a significant role in promoting sustainable tourism development.

Analysis for Role of Pilgrimage Tourism

Travel that completely or significantly inspires travelers to adopt religious beliefs and behaviors is known as pilgrimage tourism. It can be divided into various forms and is one of the earliest ways to visit the sites. It was a worldwide experience during the earlier periods of spiritual development. The views on pilgrimage tourism's role in agrotourism are explained in the table.

Table: 1

Table Showing Role of Pilgrimage tourism

Sr. No	Variables	Stat.	SD	D	N	A	SA	Total	Mean	SD
1	Pilgrimage tourism plays a significant role in attracting tourists?	Fr.	5	6	3	8	23	45	3.83	1.44
		Per.	11.11	13.33	6.67	17.78	51.11	100		
2	Pilgrimage tourism plays significant role for development of the tourism in Kolhapur district?	Fr.	2	6	4	21	12	45	3.77	1.10
		Per.	4.44	13.33	8.89	46.67	26.67	100		
3	Pilgrimage tourism is increasing tourism business in study area	Fr.	2	8	7	11	17	45	3.74	1.23
		Per.	4.44	17.78	15.56	24.44	37.78	100		
4	Pilgrimage tourism is increasing tourist population in study area	Fr.	3	7	5	20	10	45	3.59	1.20
		Per.	6.67	15.56	11.11	44.44	22.22	100		
5	Do you agree that pilgrimage tourism is playing a major role in socio-economic development?	Fr.	3	5	6	14	17	45	3.87	1.20
		Per.	6.67	11.11	13.33	31.11	37.78	100		
6	Pilgrimage tourism helps to promote and attract tourist for agro tourism?	Fr.	1	2	5	21	16	45	4.1	0.97
		Per.	2.22	4.44	11.11	46.67	35.56	100		

Source: Primary data

The above table indicates the role of pilgrimage tourism. Six variables are taken in the above data to access the role of pilgrimage tourism.

Table shows that the majority of respondents have a positive opinion about the role of pilgrimage tourism. 51.11% of the respondents strongly agreed and 17.78% agreed that pilgrimage tourism plays a significant role in attracting tourists. Regarding the development of tourism in Kolhapur district, 46.67% agreed and 26.67% strongly agreed. Similarly, 37.78% strongly agreed and 24.44% agreed that pilgrimage tourism is increasing tourism business in the study area. About 44.44% agreed and 22.22% strongly agreed that pilgrimage tourism is increasing the tourist population. Further, 37.78% strongly agreed and 31.11% agreed that pilgrimage tourism plays a major role in socio-economic development. The highest level of agreement was observed for the statement that pilgrimage tourism helps to promote and attract tourists for agro-tourism, where 46.67% agreed and 35.56% strongly agreed. Overall, the findings indicate that the majority of respondents agreed or strongly agreed that pilgrimage tourism plays a significant role in tourism development, business growth, socio-economic development, and the promotion of sustainable tourism in the study area.

The response mean value is 3.87 and the standard deviation is 1.20. It is seen that the maximum farmers have favorable opinion towards the important role of pilgrimage tourism in socio-economic development. The sixth variable is whether pilgrimage tourism helps to promote and attract tourists for agro-tourism. Out of the total farmers, 3 percent of farmers strongly disagree, 4.62 percent of farmers disagree and 12 percent of farmers have given neutral opinion. On the other hand, 46.8 percent farmers agree and 33.56 percent of farmers strongly agree. The response mean value is 4.1 and the standard deviation is 0.97. It is seen that maximum farmers have given positive opinion that pilgrimage tourism helps to promote and attract tourist for agro tourism.

Testing of Hypothesis

H_0 (Null Hypothesis): Pilgrimage tourism has no significant role in promoting sustainable tourism development.

H_1 (Alternative Hypothesis): Pilgrimage tourism has a significant role in promoting sustainable tourism development.

Table: 2.

One-Sample Statistics for role of Pilgrimage tourism				
	N	Mean	Std. Deviation	Std. Error Mean
Role of pilgrimage tourism for attracting tourists	45	3.8103	.65664	.03159

Source: Primary data

The sample statistics for the role of pilgrimage tourism in drawing visitors for the agri-tourism industry are displayed in the above table. According to the data, the response mean value for pilgrimage tourism's ability to draw tourists is 3.81, with an SD of 0.65. It suggested that pilgrimage tourism plays a significant role in drawing travelers for the agri-tourism industry.

Table: 3.

Table showing one sample statistics for Pilgrimage tourism for attracting tourists

One-Sample Test						
	Test Value = 4					
Variables	t	df	Sig. (2-tailed)	Mean Diff.	95% Confidence Interval of the Difference	
					Lower	Upper
Role of pilgrimage tourism for attracting tourists	-6.0	45	.000	-.1897	-.2518	-.1276

Source: Primary data

The table data shows a single sample of statistics regarding the contribution of pilgrimage tourism to tourist attraction. The null hypothesis is rejected after it is determined that the P value (Sig Value.000) is less than 0.05: Ho: Pilgrimage tourism does not play a major role in drawing visitors to the Kolhapur district.

Major Findings

1. The large majority of the respondents (68.89%) felt that pilgrimage tourism plays a major role in attracting tourists, indicating that religious sites play a significant role in increasing tourist visits. 2.
2. The respondents (73.34%) felt that pilgrimage tourism helps in the development of tourism in Kolhapur district, and 68.89% of the respondents felt that pilgrimage tourism plays an important role in socio-economic development by providing employment and generating income.
3. High agreement (82.23%) was achieved from the statement "Pilgrimage tourism is used to promote and attract tourists for the destination of agro-tourism," which implies that pilgrimage tourism facilitates sustainable tourism development through the promotion of rural/agricultural attractions.

Suggestions

1. To improve the visitor experience while preserving the environment, the government and tourism authorities should upgrade basic infrastructure at pilgrimage sites, including roads, parking lots, sanitation, waste management, drinking water, and lodging.
2. Tourism departments ought to create integrated travel packages that incorporate pilgrimage sites with neighboring cultural, heritage, and agrotourism destinations. This will extend visitors' stays, boost local economies, and encourage the growth of sustainable tourism.

Conclusions

It concludes that pilgrimage tourism plays an important role in promoting sustainable tourism development. It aids in drawing a sizable number of visitors and supports the expansion of the regional tourism sector. By generating jobs and raising local communities' incomes, pilgrimage tourism also promotes socioeconomic development. It promotes the growth of associated industries like local businesses, transportation, hospitality, and agro-tourism. The results show that respondents view pilgrimage tourism's advantages favorably. Therefore, to guarantee the long-term growth and sustainability of pilgrimage tourism destinations, efficient planning, enhanced infrastructure, and sustainable management techniques are required.

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Head Department of Geography,
Shivneri College Shirur Anantpal
Dist. Latur
Email: jomprakash57@gmail.com

Address for correspondence:
Omprakash Wamanrao Jadhav
Head Department of Geography,
Shivneri College Shirur Anantpal
Dist. Latur
Email: jomprakash57@gmail.com

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Climate Change in Maharashtra

Dr. Omprakash Wamanrao Jadhav

Abstract
Climate change is one of the major environmental challenges affecting Maharashtra. Changes in temperature, rainfall patterns, drought frequency, floods, and extreme weather events are increasingly influencing the state's agriculture, water resources, biodiversity, and human life. Maharashtra experiences considerable regional variation, with some areas facing water scarcity and drought while others are affected by heavy rainfall and flooding. Changes in monsoon patterns have a direct impact on agricultural production and the availability of water for domestic and industrial use. Rising temperatures also increase pressure on natural resources and may affect public health and ecosystems. Rapid urbanization, deforestation, industrial development, and increasing energy consumption further contribute to environmental changes. The study of climate change in Maharashtra is therefore important for understanding its regional impacts and developing suitable adaptation and mitigation measures. Sustainable water management, climate-resilient agriculture, afforestation, renewable energy, and public awareness can help reduce the effects of climate change and support sustainable development in Maharashtra.

Keyword: *Climate Change Global Warming Temperature Rise Rainfall Variability Drought Floods Water Scarcity Sustainable Development.*

Introduction

Climate change is one of the major environmental challenges affecting Maharashtra. It has caused changes in temperature, rainfall, and seasonal weather patterns across the state. Maharashtra experiences droughts, floods, heat waves, and irregular rainfall in different regions. Changes in the monsoon have a significant impact on agriculture and water resources. Rising temperatures also increase water scarcity and affect human health and natural ecosystems. Climate change has an impact on forests, biodiversity, soil, and agricultural production. Rapid urbanization, deforestation, industrialization, and increasing pollution further increase environmental pressure. Farmers are especially affected by changing rainfall patterns and extreme weather conditions. Therefore, proper water management, afforestation, sustainable agriculture, and renewable energy are important to reduce the effects of climate change. The study of climate change in Maharashtra is essential for sustainable development and effective environmental planning.

Objectives

Following are the main objectives of the study

1. To study Climate Change in Maharashtra
2. To Study Present condition of Climate Change in Maharashtra

Database And Methodology

The present study based on only secondary data. Reference books, Internet, Many other books.

History of Climate Change in Maharashtra

The history of climate change in Maharashtra can be understood through long-term changes in temperature, rainfall, monsoon patterns, and extreme weather events. Maharashtra has always experienced natural variations in climate, but in recent decades these changes have become more noticeable. Rising temperatures, irregular monsoon rainfall, frequent droughts, floods, and heat waves have affected different parts of the state. Agriculture, water resources, forests, and biodiversity have been particularly influenced by these changes. Rapid urbanization, industrialization, deforestation, and increasing energy consumption have also contributed to environmental pressure. During the 20th and 21st centuries, changes in rainfall distribution and increasing temperatures have become important concerns for Maharashtra. Major droughts and extreme rainfall events have highlighted the vulnerability of the state to climate-related risks. Coastal areas such as Mumbai and Konkan are also vulnerable to heavy rainfall, flooding, and sea-level-related impacts. In response, the government and various organizations have promoted water conservation, afforestation, renewable energy, sustainable agriculture, and climate adaptation measures. Thus, the history of climate change in Maharashtra reflects both natural climatic variability and increasing human influence on the environment.

Importance of Climate Change in Maharashtraa

- **Impact on Agriculture:** Climate change affects rainfall, temperature, crop growth, and agricultural production in Maharashtra.
- **Water Resources:** Changes in rainfall and increasing temperatures can lead to water scarcity and affect rivers, dams, and groundwater.
- **Drought Management:** Understanding climate change helps in planning measures to reduce the effects of frequent droughts in drought-prone areas.
- **Flood Control:** Changes in rainfall patterns can increase the risk of heavy rainfall and floods, especially in urban and coastal regions.
- **Human Health:** Rising temperatures and extreme weather conditions can increase health risks and affect the well-being of people.
- **Biodiversity Conservation:** Climate change affects forests, wildlife, and natural ecosystems, making conservation and protection important.
- **Sustainable Development:** Studying climate change helps in developing sustainable practices for agriculture, industries, cities, and natural resources.
- **Future Planning:** Knowledge of climate change supports effective environmental planning and helps Maharashtra prepare for future climatic risks.

Present condition of Climate Change in Maharashtra

1.Rising Temperature

Maharashtra is experiencing a gradual rise in temperature in many regions.Higher temperatures are especially noticeable during the summer season.Heat-wave conditions are becoming an important climate-related concern.Rising temperatures increase water requirements for people and agriculture.They also place additional pressure on human health and natural ecosystems.

2. Changes in Monsoon Rainfall

The monsoon pattern in Maharashtra has become more variable.Rainfall is not always evenly distributed across different regions and seasons.Some areas may receive heavy rainfall within a short period, while others experience rainfall shortages.Such changes create difficulties for agriculture and water management.Therefore, reliable monsoon forecasting and planning are increasingly important.

3. Increasing Drought Conditions

Several parts of Maharashtra are naturally drought-prone and face water shortages. Irregular rainfall and high temperatures can increase drought-related pressure. Drought affects drinking water supplies, agriculture, livestock, and rural livelihoods.
Farmers may experience crop losses when rainfall is insufficient.Water conservation and drought-resistant agricultural practices are therefore important.

4. Heavy Rainfall and Floods

Climate variability can contribute to periods of intense rainfall in Maharashtra.Heavy rainfall may cause flooding in urban, rural, and river-basin areas.Floods can damage crops, roads, houses, and other infrastructure.Urban areas are particularly vulnerable when drainage systems cannot handle large amounts of rainwater.Better drainage, flood forecasting, and disaster preparedness are needed.

5. Impact on Agriculture

Agriculture is highly dependent on suitable temperature and rainfall conditions. Changes in rainfall timing and intensity can affect crop growth and productivity. Extreme heat and water shortages can increase stress on crops. Farmers may need to adjust crop selection, sowing periods, and water-use practices. Climate-resilient agriculture can help reduce these risks.

6. Water Scarcity

Climate change is increasing pressure on Maharashtra's water resources.Higher temperatures can increase evaporation and water demand.Irregular rainfall also affects the recharge of groundwater and storage in reservoirs.Water scarcity is a major concern for both rural and urban populations.Rainwater harvesting and efficient water management are important solutions.

7. Impact on Forests and Biodiversity

Changes in temperature and rainfall can affect forests and wildlife habitats.Some plants and animals may face difficulties when climatic conditions change rapidly.Drought, forest fires, and human pressure can further affect forest ecosystems.Loss of biodiversity can disturb ecological balance and ecosystem services.Forest conservation and restoration are important for climate resilience.

8. Increasing Heat-Wave Risk

Heat waves are an important climate-related risk, particularly during summer.Urban areas can experience greater heat because of concrete structures and limited vegetation. High temperatures can affect outdoor workers, elderly people, and other vulnerable groups.
Heat also increases demand for water and electricity.Green spaces, tree plantation, and heat-action planning can help reduce the impact.

9. Coastal Climate Risks

Maharashtra has a long coastline along the Arabian Sea, including the Konkan region. Coastal areas are vulnerable to heavy rainfall, flooding, coastal erosion, and sea-level rise. These risks can affect settlements, agriculture, fisheries, and infrastructure. Coastal ecosystems such as mangroves provide important natural protection.Protecting mangroves and planning coastal development carefully are therefore essential.

10. Impact of Urbanization

Rapid urbanization is increasing environmental pressure in Maharashtra's cities.Large cities generate more heat, traffic pollution, waste, and demand for water and energy.The reduction of open spaces and vegetation can increase local temperatures.Heavy rainfall can also cause urban flooding when natural drainage is reduced.Sustainable urban planning and increased green spaces can improve climate resilience.

11. Impact on Human Health

Climate change can indirectly and directly affect human health.Extreme heat can increase the risk of heat-related illness and dehydration.Floods and changing environmental conditions can also create conditions favourable for some diseases.Poor air quality combined with high temperatures can further increase health concerns.Public awareness, early warnings, and effective health services are important for adaptation.

12. Need for Climate Adaptation

The present climate situation shows the need for stronger adaptation measures in Maharashtra. Water conservation, sustainable agriculture, afforestation, and renewable energy can reduce climate-related pressure.Early-warning systems can help communities prepare for floods, heat waves, and other extreme events.Government agencies, local communities, farmers, and industries all have important roles to play.Long-term climate planning is necessary to achieve sustainable and resilient development in Maharashtra.

Role of Public for Climate Sustainable Conservation in Maharashtra

1. Planting and Protecting Trees

People can actively participate in tree plantation and protect existing forests.Trees absorb carbon dioxide and help maintain environmental balance.Public participation in local plantation programmes can improve green cover.

2. Water Conservation

People can save water in homes, farms, and public places.Rainwater harvesting and reuse of water can help reduce water scarcity.Community participation is important for protecting local water resources.

3. Waste Management

The public should reduce waste, reuse useful materials, and separate dry and wet waste. Proper waste management reduces pollution and pressure on natural resources.People can also avoid unnecessary use of plastic products.

4. Use of Public Transport

Using buses, trains, bicycles, and walking can reduce the use of private vehicles.This helps reduce fuel consumption and greenhouse gas emissions.Public transport also helps control air pollution in cities.

5. Saving Energy

People can reduce electricity consumption by switching off unnecessary lights and appliances. Using energy-efficient equipment can further reduce energy use. Public awareness about renewable energy can support climate-friendly development.

6. Sustainable Agricultural Practices

Farmers can adopt water-saving irrigation and soil conservation practices.Using suitable crops and sustainable farming methods can reduce environmental pressure.Public awareness can encourage climate-resilient agriculture.

7. Protection of Biodiversity

People should protect forests, wildlife, wetlands, rivers, and other natural habitats.Avoiding activities that damage ecosystems help conserve biodiversity.Community participation can strengthen local conservation efforts.

8. Environmental Awareness

The public can spread awareness about climate change through schools, colleges, social groups, and community programme.People should understand the importance of sustainable use of natural resources.Awareness encourages individuals to adopt environmentally responsible habits.

9. Participation in Government Programmes

Citizens can participate in government programme related to tree plantation, water conservation, cleanliness, and renewable energy.Public cooperation makes environmental programme more effective.People can also support and monitor local conservation activities.

10. Responsible Lifestyle

People can adopt simple and environmentally friendly lifestyles in their daily lives. Reducing unnecessary consumption helps conserve natural resources. Responsible public behaviour is essential for achieving long-term climate sustainability in Maharashtra.

Conclusion:

Climate change is a major environmental challenge for Maharashtra, affecting agriculture, water resources, forests, biodiversity, and human life. Rising temperatures, irregular rainfall,droughts, floods, and heat waves are creating increasing pressure on the state's natural resources. Agriculture is particularly vulnerable because it depends heavily on rainfall and suitable climatic conditions. Urbanization, industrialization, deforestation, and pollution further increase climate-related problems. Therefore, effective climate adaptation and mitigation measures are necessary for the future development of Maharashtra. Water conservation, afforestation, sustainable agriculture, renewable energy, and proper waste management can help reduce environmental pressure. Public participation and environmental awareness are equally important for successful climate action. Government agencies and local communities should work together to protect natural resources and reduce climate risks. Sustainable planning and responsible use of resources can help Maharashtra become more climate-resilient. Thus, collective efforts are essential for building a safe, sustainable, and environmentally balanced future for Maharashtra.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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[1]Research Student, Deshbhakta Sambhajirao Garad Mahavidyalaya, Mohol, Dist- Solapur
Email: waghmareuday4@gmail.com

[2]Principal, Deshbhakta Sambhajirao Garad Mahavidyalaya, Mohol, Dist- Solapur

Address for correspondence:
Uday Balasaheb Waghmare
Research Student, Deshbhakta Sambhajirao Garad Mahavidyalaya, Mohol, Dist- Solapur
Email: waghmareuday4@gmail.com

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Impact of Population Pressure on Agricultural Landuse in Solapur District: A Geographical Analysis

Uday Balasaheb Waghmare[1], Dr. Nandkumar Jaganath Patil[2]

Abstract
Climate change is one of the major environmental challenges affecting Maharashtra. Changes in temperature, rainfall patterns, drought frequency, floods, and extreme weather events are increasingly influencing the state's agriculture, water resources, biodiversity, and human life. Maharashtra experiences considerable regional variation, with some areas facing water scarcity and drought while others are affected by heavy rainfall and flooding. Changes in monsoon patterns have a direct impact on agricultural production and the availability of water for domestic and industrial use. Rising temperatures also increase pressure on natural resources and may affect public health and ecosystems. Rapid urbanization, deforestation, industrial development, and increasing energy consumption further contribute to environmental changes. The study of climate change in Maharashtra is therefore important for understanding its regional impacts and developing suitable adaptation and mitigation measures. Sustainable water management, climate-resilient agriculture, afforestation, renewable energy, and public awareness can help reduce the effects of climate change and support sustainable development in Maharashtra.

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Introduction

Climate change is one of the major environmental challenges affecting Maharashtra. It has caused changes in temperature, rainfall, and seasonal weather patterns across the state. Maharashtra experiences droughts, floods, heat waves, and irregular rainfall in different regions. Changes in the monsoon have a significant impact on agriculture and water resources. Rising temperatures also increase water scarcity and affect human health and natural ecosystems. Climate change has an impact on forests, biodiversity, soil, and agricultural production. Rapid urbanization, deforestation, industrialization, and increasing pollution further increase environmental pressure. Farmers are especially affected by changing rainfall patterns and extreme weather conditions. Therefore, proper water management, afforestation, sustainable agriculture, and renewable energy are important to reduce the effects of climate change. The study of climate change in Maharashtra is essential for sustainable development and effective environmental planning.

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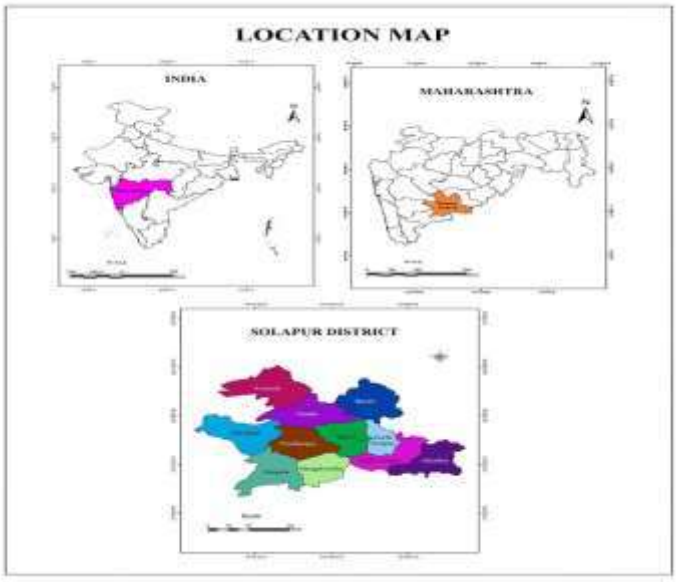
Study Area

Solapur district is located in the south-eastern part of Maharashtra and forms part of the Deccan Plateau, extending approximately between 17°10′ to 18°32′ North latitudes and 74°42′ to 76°25′ East longitudes. The district covers about 14,895 sq. km and consists of 11 tahsils—Karmala, Madha, Barshi, North Solapur, Mohol, Pandharpur, Malshiras, Sangola, Mangalvedha, South Solapur and Akkalkot. The district has a mainly semi-arid climate, with low and uneven rainfall and varying water availability, which influences agricultural activities. According to Census 2011, the district had a population of 4,317,756, including 2,918,665 rural and 1,399,091 urban population. It had 607,657 main cultivators and 508,141 main agricultural labourers, showing the importance of agriculture as a source of livelihood. In 2024-25, the district had 1,078.86 thousand hectares of Agricultural landuse area, 1,144.88 thousand hectares of total cropped area, 223.81 thousand hectares of net irrigated area and 317.45 thousand hectares of total irrigated area. The large population, extensive agricultural land, agricultural dependence, semi-arid climate and growing urbanization make Solapur district suitable for studying the impact of population pressure on agricultural landuse.



Objectives

The major objectives of the study are:

1. To examine the growth and distribution of population in Solapur district.
2. To analyse the agricultural landuse the district.
3. To analyse the relationship between population pressure and agricultural intensification.

Data Source and Methodology

The present study is based mainly on secondary data collected from the Census of India, 2011 and Solapur District Statistical Information, 2024–25. Census data were used for total population, male and female population, households, rural and urban population, total workers, main workers, marginal workers, cultivators and agricultural labourers for all 11 tahsils of Solapur district. Agricultural data were used for Agricultural landuse area, total cropped area, irrigated area and other agricultural landuse information. The study uses descriptive, comparative and statistical methods to study population and agricultural landuse. The Z-score method was used to compare the population and Agricultural landuse area of each sub-district with the average of the 11 tahsils. The Z-score was calculated by using $Z = (X - \bar{X}) / SD$, where X is the value of a sub-district, $\bar{X}$ is the mean and SD is the standard deviation. The values were classified into High, Moderate and Low categories. Population pressure was calculated by using Population Pressure = Agricultural landuse Area (ha) ÷ Total Population, and the result was expressed in hectares per person. A higher value shows more Agricultural landuse area available per person, while a lower value shows less agricultural land available per person and comparatively greater pressure on agricultural land. The population, Agricultural landuse area and population pressure of the 11 tahsils were compared to understand the spatial differences and their relationship with agricultural landuse in Solapur district.

Data Analysis

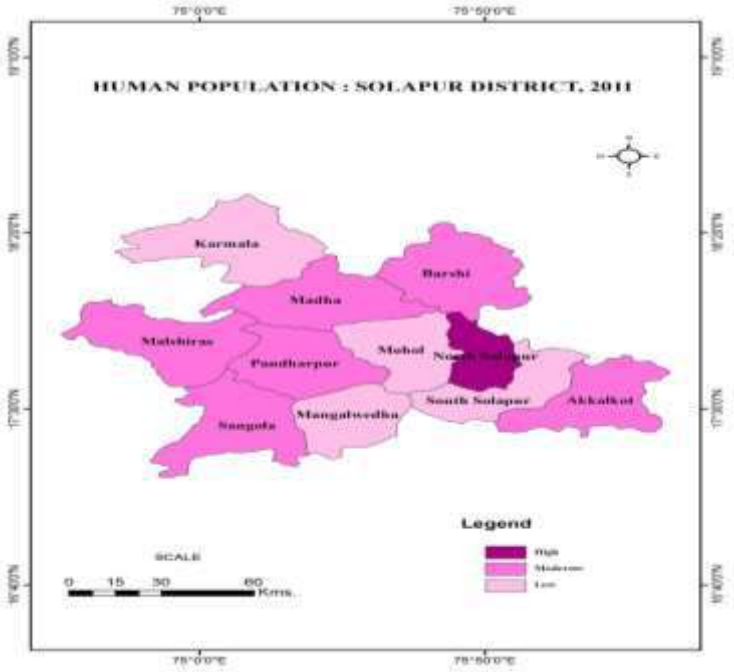
Human Population

Human population is an important part of the study Impact of Population Pressure on Agricultural Landuse. More population means greater demand for food, employment, houses, water and land. In rural areas, population is closely related to agriculture because many people depend on cultivation and agricultural labour. In urban areas, increasing population creates demand for houses, roads, markets, industries and other facilities. These activities can also affect agricultural land. Therefore, the population of all 11 tahsils has been compared with the average population by using the Z-score method.

Table 1
Human Population: Solapur District, 2011

Sr. No.	Sub-district	Population	Z-Score	Classification
1	Karmala	254,489	−0.615	Low
2	Madha	324,027	−0.305	Moderate
3	Barshi	372,711	−0.088	Moderate
4	North Solapur	1,057,352	+2.963	High
5	Mohol	276,920	−0.515	Low
6	Pandharpur	442,368	+0.222	Moderate
7	Malshiras	485,645	+0.415	Moderate
8	Sangola	322,845	−0.311	Moderate
9	Mangalvedha	205,932	−0.832	Low
10	South Solapur	260,897	−0.587	Low
11	Akkalkot	314,570	−0.347	Moderate
Total	Solapur District	4,317,756	—	—

Source: Census of India, 2011.



The total population of Solapur district was 4,317,756 persons in 2011, and the average population of the 11 tahsils was about 392,523 persons. The table shows a clear difference in population among the tahsils. North Solapur tahsil has the highest population, with 1,057,352 persons, and its Z-score is +2.963. It is placed in the High category. The population of North Solapur is much higher than the average population of the district. The concentration of population around Solapur city has increased the need for houses, roads, markets, industries, transport and other facilities, which can also create pressure on agricultural land. Malshiras tahsil has the second-highest population with 485,645 persons, followed by Pandharpur with 442,368 persons. Their Z-scores are +0.415 and +0.222, respectively, and both are in the Moderate category. These tahsils have a large population along with an important agricultural base. Therefore, population in these areas is closely related to the demand for agricultural production, employment and agricultural land. Madha, Barshi, Sangola and Akkalkot tahsils have Z-scores of −0.305, −0.088, −0.311 and −0.347, respectively. They are classified as Moderate because their Z-scores are between −0.50 and +0.50. Their population is close to the average when compared with the other tahsils. Karmala, Mohol, South Solapur and Mangalvedha tahsils have Z-scores of −0.615, −0.515, −0.587 and −0.832. Under the revised classification, these four tahsils are placed in the Low category. Mangalvedha has the lowest population of 205,932 persons, followed by Karmala tahsil , South Solapur tahsil and Mohol tahsil. Generally, the population classification gives 1 High, 6 Moderate and 4 Low tahsils. The population is strongly concentrated in North Solapur, while the remaining tahsils have lower and moderate population levels. This difference is important for the present study because population creates demand for land and resources. The population figures alone, however, do not show the actual pressure on agricultural land. For this reason, population needs to be compared with Agricultural landuse area, which shows how much agricultural land is available in relation to the population in each sub-district.

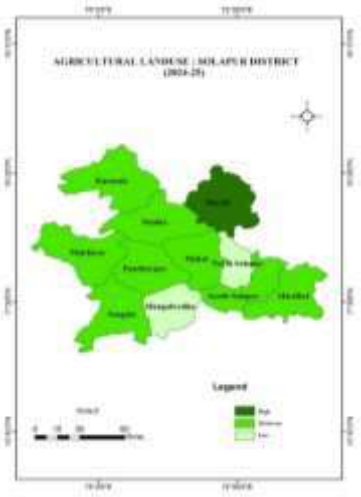
Agricultural Landuse

Agricultural landuse has a close relationship with population pressure. It represents the area used for cultivation during the agricultural year. The amount of agricultural landuse area varies considerably among the 11 tahsils of Solapur district. This variation is important because the population is also unevenly distributed across the district. A sub-district with a larger agricultural landuse area has a comparatively larger land base available for agricultural activities, whereas a sub-district with a smaller agricultural landuse area has comparatively less land available for cultivation. In this study, the Z-score method

is used to compare the agricultural landuse area of each sub-district with the overall distribution of the 11 tahsils. Based on the Z-score values, the tahsils are classified into High, Moderate and Low categories.

Table 2
Agricultural Landuse Area: Solapur District

Sr. No.	Sub-district	Agricultural Landuse Area (ha)	Z-Score	Classification
1	Karmala	124,106.33	+0.838	Moderate
2	Madha	114,622.00	+0.422	Moderate
3	Barshi	136,668.99	+1.389	High
4	North Solapur	54,908.01	−2.197	Low
5	Mohol	122,015.00	+0.747	Moderate
6	Pandharpur	103,482.99	−0.066	Moderate
7	Malshiras	100,308.58	−0.205	Moderate
8	Sangola	96,970.79	−0.352	Moderate
9	Mangalvedha	71,598.00	−1.465	Low
10	South Solapur	110,226.59	+0.230	Moderate
11	Akkalkot	120,016.97	+0.659	Moderate
Total	Solapur District	1,144,882.49	—	—



Source: Agricultural Department Report,2024-25

Table No. 2 shows considerable variation in the distribution of agricultural landuse area among the 11 tahsils of Solapur district. The total agricultural landuse area of the district is 1,144,882.49 hectares. Barshi tahsil has the largest agricultural landuse area, with 136,668.99 hectares, and records a Z-score of +1.389. It is the only sub-district placed in the High category. The high agricultural landuse area indicates the comparatively greater importance and extent of agricultural land in Barshi. Karmala tahsil has 124,106.33 hectares, Mohol tahsil has 122,015 hectares, and Akkalkot tahsil has 120,016.97 hectares of agricultural landuse area. Their Z-scores are +0.838, +0.747 and +0.659, respectively. All three tahsils are classified as Moderate. Their positive Z-scores indicate a comparatively higher position within the distribution of agricultural landuse area, although their values do not reach the High category. Madha tahsil has 114,622 hectares and South Solapur tahsil has 110,226.59 hectares of agricultural landuse area, with Z-scores of +0.422 and +0.230, respectively. Both are classified as Moderate. Pandharpur tahsil, with 103,482.99 hectares, has a Z-score of −0.066, while Malshiras tahsil, with 100,308.58 hectares, records a Z-score of −0.205. Sangola tahsil, with 96,970.79 hectares, has a Z-score of −0.352. All three are also placed in the Moderate category. Mangalvedha tahsil has 71,598 hectares of agricultural landuse area and a Z-score of −1.465, placing it in the Low category. North Solapur tahsil has the smallest agricultural landuse area, with only 54,908.01 hectares, and records the lowest Z-score of −2.197. Therefore, North Solapur tahsil is also classified in the Low category. The classification shows 1 High, 8 Moderate and 2 Low tahsils. Barshi is the only sub-district in the High category, while North Solapur and Mangalvedha fall in the Low category. The remaining eight tahsils including Karmala, Madha, Barshi, Mohol, Pandharpur, Malshiras, Sangola, South Solapur etc. are distributed mainly within the Moderate category, with Barshi being the exception as the sole High category. The spatial distribution of agricultural landuse area becomes particularly important when it is compared with the human population distribution. North Solapur tahsil has the highest human population but the lowest agricultural landuse area, whereas Barshi has the highest agricultural landuse area but a considerably smaller population than North Solapur. This contrasting pattern indicates that the availability and distribution of agricultural landuse area are not uniform in relation to population distribution. Therefore, the comparison of agricultural landuse area and human population is important for understanding the spatial pattern of population pressure on agricultural land in Solapur district.

Population Pressure

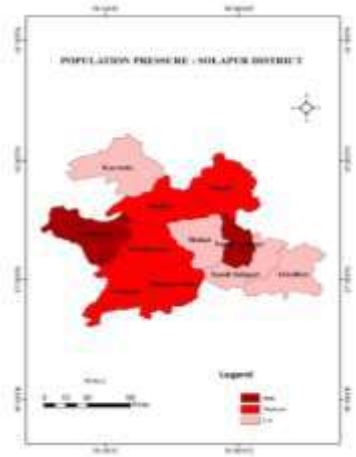
Population pressure is an important part of the study “Impact of Population Pressure on Agricultural Landuse in Solapur District: A Geographical Analysis.” The pressure on agricultural land depends not only on the number of people but also on the amount of agricultural land available for them. In this study, population pressure is measured by comparing total population with Agricultural landuse area of each sub-district. The result gives the Agricultural landuse area available per person. A higher value shows more agricultural land available per person, while a lower value shows less agricultural land

available per person and comparatively greater pressure on agricultural land. The 11 tahsils of Solapur district show considerable differences in both population and Agricultural landuse area. Therefore, this calculation helps to understand the spatial variation of population pressure on agricultural land.

Table 3
Population Pressure: Solapur District

Sr. No.	Sub-district	Total Population	Agricultural landuse Area (ha)	Population Pressure (ha/person)	Classification
1	Karmala	254,489	124,106.33	0.4877	Low
2	Madha	324,027	114,622.00	0.3537	Moderate
3	Barshi	372,711	136,668.99	0.3667	Moderate
4	North Solapur	1,057,352	54,908.01	0.0519	High
5	Mohol	276,920	122,015.00	0.4406	Low
6	Pandharpur	442,368	103,482.99	0.2339	Moderate
7	Malshiras	485,645	100,308.58	0.2065	High
8	Sangola	322,845	96,970.79	0.3004	Moderate
9	Mangalvedha	205,932	71,598.00	0.3477	Moderate
10	South Solapur	260,897	110,226.59	0.4225	Low
11	Akkalkot	314,570	120,016.97	0.3815	Moderate
Total	Solapur District	4,317,756	1,144,882.49	0.2652	—

Source: Compiled by researcher, 2026.



The table no.3 shows a clear difference in the amount of Agricultural landuse area available in relation to population among the 11 tahsils of Solapur district. The district has 1,144,882.49 hectares of Agricultural landuse area and a total population of 4,317,756 persons. The average availability of Agricultural landuse area is 0.2652 ha/person. Karmala tahsil has the highest value of 0.4877 ha/person. It has 254,489 persons and 124,106.33 hectares of Agricultural landuse area. This shows that agricultural land availability is comparatively high in relation to its population. Mohol tahsil follows with 0.4406 ha/person, while South Solapur has 0.4225 ha/person. These three tahsils have comparatively more agricultural land available per person. Akkalkot tahsil has 0.3815 ha/person, Barshi tahsil 0.3667 ha/person, Madha tahsil 0.3537 ha/person, and Mangalvedha tahsil 0.3477 ha/person. All these values are higher than the district average of 0.2652 ha/person. This indicates comparatively better availability of agricultural land in relation to population. Sangola tahsil has 0.3004 ha/person, with 322,845 persons and 96,970.79 hectares of Agricultural landuse area. Its value is slightly higher than the district average, showing a moderate level of land availability in relation to population. The situation is different in Pandharpur tahsil and Malshiras tahsil. Pandharpur tahsil has 442,368 persons and 103,482.99 hectares of Agricultural landuse area, giving 0.2339 ha/person. Malshiras tahsil has 485,645 persons and 100,308.58 hectares, giving 0.2065 ha/person. Both values are below the district average. Therefore, comparatively less Agricultural landuse area is available per person in these two tahsils. North Solapur tahsil has the lowest value of only 0.0519 ha/person. It has the highest population, 1,057,352 persons, but only 54,908.01 hectares of Agricultural landuse area. This gives the largest difference between population and available agricultural land among the 11 tahsils. The low value indicates high pressure on agricultural land. The urban character of North Solapur tahsil also increases demand for land for residential, commercial, industrial, transport and other non-agricultural activities. The comparison shows that population and Agricultural landuse area are not equally distributed in Solapur district. Karmala tahsil has the highest agricultural land availability per person, whereas North Solapur has the lowest. Malshiras tahsil and Pandharpur tahsil also have relatively low values because their populations are large in relation to their Agricultural landuse areas. The district average of 0.2652 ha/person provides a useful basis for comparison. North Solapur, Malshiras and Pandharpur tahsil have values below the district average and therefore show comparatively greater pressure on available agricultural land. Karmala, Mohol and South Solapur tahsil have higher values and comparatively lower pressure.

Impact of Population Pressure on Agricultural Landuse

1) North Solapur tahsil has the highest population, 1,057,352 persons, but its Agricultural landuse area is only 54,908.01 hectares. The agricultural land available per person is only 0.0519 ha/person. This shows the highest pressure on agricultural land among the 11 tahsils.
2) Malshiras tahsil has a population of 485,645 persons and 100,308.58 hectares of Agricultural landuse area. The land available per person is 0.2065 ha/person, which is below the district average of 0.2652 ha/person. This shows comparatively high pressure on agricultural land.
3) Pandharpur tahsil has 442,368 persons and 103,482.99 hectares of Agricultural landuse area. Its value is 0.2339 ha/person, which is also below the district average. The available agricultural land is therefore comparatively less in relation to its population.
4) Barshi tahsil has the largest Agricultural landuse area of 136,668.99 hectares. Its population is 372,711 persons, giving 0.3667 ha/person. The larger agricultural land area reduces the pressure on land in comparison with North Solapur, Malshiras and Pandharpur.
5) Karmala tahsil has 124,106.33 hectares of Agricultural landuse area and a population of 254,489 persons. Its value is 0.4877 ha/person, the highest among all the tahsils. This indicates comparatively more agricultural land available per person.
6) Mohol tahsil has 122,015 hectares of Agricultural landuse area and 276,920 persons. Its value of 0.4406 ha/person is considerably higher than the district average. The pressure on agricultural land is therefore comparatively lower.
7) South Solapur has 110,226.59 hectares of Agricultural landuse area and 260,897 persons. The value of 0.4225 ha/person shows that agricultural land availability per person is relatively high.
8) Akkalkot, Barshi, Madha and Mangalvedha tahsils have values of 0.3815, 0.3667, 0.3537 and 0.3477 ha/person, respectively. All four have more agricultural land available per person than the district average of 0.2652 ha/person.
9) Sangola tahsil has 96,970.79 hectares of Agricultural landuse area and 322,845 persons. Its value is 0.3004 ha/person, which is slightly higher than the district average. The pressure on agricultural land is therefore moderate compared with the tahsils having lower values.

Conclusion

The study shows that population and agricultural land are not equally distributed in Solapur district. Solapur district had a population of 4,317,756 persons, while the Agricultural landuse area was 1,144,882.49 hectares. The comparison of population with Agricultural landuse area shows different levels of pressure in different tahsils. North Solapur tahsil has the highest population of 1,057,352 persons and the lowest agricultural land available per person, only 0.0519 ha/person. This indicates the highest pressure on agricultural land. Malshiras tahsil (0.2065 ha/person) and Pandharpur tahsil (0.2339 ha/person) also have comparatively less agricultural land available in relation to their population. On the other hand, Karmala tahsil (0.4877 ha/person), Mohol tahsil (0.4406 ha/person) and South Solapur tahsil (0.4225 ha/person) have more agricultural land available per person and comparatively lower pressure. The study also shows that population pressure is not related to population size alone. The amount of agricultural land available in each sub-district is equally important. In areas with a large population and limited agricultural land, pressure on land is greater. In urban areas such as North Solapur tahsil, increasing demand for houses, roads, commercial activities, industries and other facilities can further reduce agricultural land. In rural areas, increasing population can increase dependence on existing agricultural land and agricultural production. Therefore, protection of productive agricultural land, proper landuse planning and careful control of unnecessary conversion of agricultural land are important for the future agricultural development of Solapur district.

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Associate Professor, Department of Geography, Rajarshi Shahu Arts and Commerce College, Rukadi, Hatkanangale, Kolhapur,
Email: patilashok824@gmail.com

Address for correspondence:
Ashok Shamrao Patil
Associate Professor, Department of Geography, Rajarshi Shahu Arts and Commerce College, Rukadi, Hatkanangale, Kolhapur,
Email: patilashok824@gmail.com

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Effect of Drip Irrigation on Agriculture Development and Crop Growth

Dr. Ashok Shamrao Patil

Abstract

Drip irrigation delivers water and nutrients directly to plant roots through a network of tubes and emitters, providing high efficiency compared to traditional watering methods. Clogged emitters, incorrect water pressure, and physical line damage are the most frequent problems with drip irrigation systems. Irrigation supplies controlled amounts of water to crops, ensuring reliable growth. It boosts food production, protects against droughts, and enables year-round farming, maximizing land use and farm income. Drip irrigation is an efficient and hassle-free solution to watering your garden. But to ensure you're getting the most out of your drip irrigation system, regular maintenance is crucial. This includes checking for leaks, flushing tubes and filters, and replacing damaged parts.

Key words: Drip Irrigation, Crop System, Production, Farm, Growth Rate, Water Management, Agricultural Development etc.

Introduction:

Drip irrigation is an easy and hassle-free solution for anyone who wants to spend less time and effort watering their gardens. A drip system releases water from drippers placed along tubes by your plants. This method provides more precision in watering, ensuring that each plant gets the appropriate amount of water it needs. Each dripper has a specific flow rate that drips water over the roots of nearby plants. The flow rate is measured in gallons per hour and is timed depending on climate. Drip systems can save up to 70% of the water used in traditional irrigation and sprinklers. Traditional watering methods like hand watering, overhead sprinklers, and soaker hoses have been used by gardeners for decades. While these methods can be effective, they also have significant drawbacks, such as water wastage, uneven watering, and the potential to promote plant disease growth. With rising concerns over water conservation and efficiency, a drip irrigation system offers several advantages.

Problems of the Study:

Irrigation is the process of applying water to the crops artificially to fulfil their water requirements. Nutrients may also be provided to the crops through irrigation. The various sources of water for irrigation are wells, ponds, lakes, canals, tube-wells and even dams. Irrigation offers moisture required for growth and development, germination and other related functions. The frequency, rate, amount and time of irrigation are different for different crops and also vary according to the types of soil and seasons.

Objectives of the Study:

The primary objective of this research is to study modern agricultural production methods, drip irrigation, and crop growth; the researcher has outlined specific objectives as follows. Modern agricultural practices and drip irrigation are helping to bring about economic changes in people's lives and improve their living conditions.

1. To Study the impact of drip irrigation on agricultural development.
2. To Study the economic and social impact of drip irrigation and modern agricultural production methods on human life.
3. To Study the factors affecting modern agricultural production methods.

Significance of the Study:

A drip irrigation system delivers water and nutrients drop by drop directly to the plant roots, resulting in high water efficiency, healthier crops, and significantly lower resource waste. Crop growth is a permanent increase in size or weight, while development is the phase-wise progress of a plant through its life cycle. Agriculture development and crop growth are closely linked processes that drive national food security and economic stability.

Scope of the Study:

Irrigation is the process of supplying water to the land at regular intervals by means of canals and other artificial methods, to enhance agricultural growth and maintain the landscape during the periods of less average rainfall. Micro-irrigation is the application of small quantities of water frequently directly above and below the surface of the soil, in the form of discrete drops, continuous drops through water emitters. In basin irrigation, the land is divided into basins. It has a simpler design than the furrow and border design.

Limitation of the Study:

Crops require water at regular intervals of time for proper growth and development. This supply of water to the crops at regular intervals is known as irrigation. There are two methods of irrigation, namely, traditional and modern. Growth in the agriculture sector plays a pivotal role in the economic development of the Indian economy, as agriculture offers numerous inputs to the industrial service sectors. The increase in agricultural production increase in the per-capita income of the rural population, along with industrialization urbanization, will lead to an increase in demand the Mechan products

Period of the Study:

Researchers have completed their study by reviewing data from 2025–26 to examine modern agricultural production methods and drip irrigation. A key aspect of this research is to study modern agricultural production methods, the sustainable role of drip irrigation in agricultural development, and its impact on socio-economic conditions. The researchers employed a descriptive analysis method to conduct and complete the study.

Research Methodology:

The researcher has utilized various forms of secondary research to study the economic and social impacts of crop production methods on human life. This involved the extensive use of research papers, articles, journals, newspapers, annual reports, books, and other such sources.

Research Method:

A key aspect of this research is to study modern agricultural production methods, the sustainable role of drip irrigation in agricultural development, and its impact on socio-economic conditions. The researchers employed a descriptive analysis method to conduct and complete the study.

Results and Discussion:

Agriculture is the necessary resource of food supply for all countries of the nation, either underdeveloped, developing or slightly developing. Due to a high population anxiety in underdeveloped & developing countries and rapid increase in demand for food, the demand for food is rising rapidly. If agriculture satisfies the growing stipulate for food goods, the growth rate of the economy would be adversely affected. The increase in food supply by the agricultural sector is therefore of major importance for the country's economic growth.

Sprinkler Irrigation

Sprinkler irrigation is done in areas with less water and uneven ground level. The main pipeline is laid in the field. They are joined to perpendicular pipelines with rotating nozzles. Water from the tube wells is allowed to pass through these pipelines under pressure, which escapes from the rotating nozzles and gets sprinkled on the crops. It is an easy and simple method of irrigation nowadays. Water is provided to the fields by spraying water droplets, like rain, through pipes. Any loss of water is avoided in the sprinkler system. The problem of waterlogging is not present in this system. The balance of groundwater is also maintained. Sprinkler irrigation is done in areas with less water and uneven ground level. The main pipeline is laid in the field. They are joined to perpendicular pipelines with rotating nozzles. Water from the tube wells is allowed to pass through these pipelines under pressure, which escapes from the rotating nozzles and gets sprinkled on the crops.

Drip Irrigation:

This method of irrigation is gaining popularity in areas with a scarcity of water. Narrow pipes with small holes are laid on the fields. When water flows through the pipes, it drips at the place of the roots of the plants. The roots absorb the water and supply it to the plants. Furthermore, no water is wasted in this method.

Advantages of Drip Irrigation:

1. Water reaches directly to the roots of the plants. 2. It saves a lot of water, which can be utilized for irrigating more areas. 3. Weeds do not grow because the water reaches directly to the plants and does not spread anywhere on the field. 4. Crop yield is increased in this method. 5. The area near the plants is dry so bacterial growth is limited. 6. It reduces the use of water in agriculture.

Disadvantages of the Drip Irrigation:

1. High initial investment requirements 2. Regular capital requirement for replacement of drip irrigation equipment 3. Drip irrigation emitters are vulnerable to clogging and dysfunction
4. High skills are required for irrigation and water management 5. Soil salinity hazard.

Modern Agriculture Production:

Modern agriculture production uses advanced technology, data, and mechanization to grow more food while using fewer resources like water and labour. Drip irrigation is a modern watering method that delivers water and nutrients drop by drop directly to plant roots, saving 30% to 50% more water than traditional flooding. Modern agriculture uses science, tech, and data to grow more food with fewer resources. It helps feed a growing world, fight climate changes, and save water. Key tools include smart machines, GPS tracking, and gene science.

Creation of Infrastructure:

The growth of agriculture includes highways, market yards, factories, rail transport, postal facilities and several others for infrastructure generating demand for agricultural goods and for the creation of the commercial sector.

Relief from Shortage of Capital:

The development of the agricultural sector has reduced the burden on several developed countries which were facing a scarcity of foreign capital. When international money is accessible with the 'lines' tied to it, another big challenge will emerge. The agricultural sector needs less capital for its production. This minimizes the development issue of international resources.

Create Effective Demand:

The development of the agricultural sector would help improve the purchasing power of farmers, contributing to the growth of the non-agricultural sector of the country. The market field would have improved. It is well understood in underdeveloped nations that even many citizens depend on agriculture, and they also must be able to afford the food they generate. It would also help to promote the growth of the non-agricultural sector. Comparably, an improvement in cash crop productivity paves the way for the development of a consumer economy capable of supporting the growth of the non-agricultural industry

Conclusion:

The purchase of agricultural goods, including chemicals, farm equipment, and so forth., also contributes to global degradation. Helpful in Phasing out Economic Recession: after a downturn, the production of a factory may be stopped or decreased, but agricultural output continues to satisfy the needs of life. Also in adverse economic conditions, strong demand continues to be produced. Most developed countries in the world are primary goods exporters. Such products represent approximately 60-70 % of their overall total exports. The ability to import capital goods and equipment for economic development is therefore consequently dependent on the export earnings of products may not rise at a reasonably fast rate; these countries are forced to endure a large deficit in the balance of payments resulting in a severe foreign exchange issue. In fact, primary goods are met with dropping prices on the world market and there are modest hopes of a rise in export earnings. As a result, major developing countries such as India aim to diversify their manufacturing base and promote exports of manufactured goods, even though this entails the implementation of security measures in the initial planning process.

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[1]*Research scholar, Department of Geography, Bangalore University, Bengaluru, India*
Email: anilkumarv@bub.ernet.in
[2]*Assistant Professor, Department of Geography, The Rural College, Kanakapura, Karnataka, India*
Email: drshivakumarrajendra@gmil.com
[3]*Assistant Professor, Department of Geography, Bangalore University, Bengaluru, India*
Email: suredrabub@gmail.com
[4]*Student, Department of Geography, Bangalore University, Bengaluru, India*
Email: Nightingalepegu.13@gmail.com

Address for correspondence:
Anilkumar V, Research scholar, Department of Geography, Bangalore University, Bengaluru, India
Email: anilkumarv@bub.ernet.in

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Geospatial Assessment of Tourism Resources across Karnataka Administrative Divisions Using GIS and Descriptive Spatial Statistics

Anilkumar V[1], Dr. Shiva Kumar R[2], Dr. Surendra P[3], Jaryum Pegu[4]

Abstract

Tourism resources are unevenly distributed across geographical space, and systematic assessment of their distribution is important for regional tourism planning. This study examines the district- and division-level distribution of 347 selected tourist places across Karnataka's 31 districts and four administrative divisions using a GIS-supported descriptive statistical framework. The tourism database was organised in Microsoft Excel, linked to district and divisional administrative boundaries, and analysed using totals, percentage shares, district-level means, standard deviations, coefficients of variation, rankings, and a district tourism-place index. Separate GIS maps were prepared for Belagavi, Kalaburagi, Bengaluru, and Mysuru divisions. Mysuru Division records the highest number of selected tourist places (108, 31.12%), followed by Bengaluru (85, 24.50%), Belagavi (80, 23.05%), and Kalaburagi (74, 21.33%). Mysuru also has the highest average of 12.00 destinations per district, whereas Kalaburagi has the lowest average (10.57). Belagavi shows the greatest within-division variation (CV = 19.47%), largely because Uttara Kannada contains 16 destinations while several districts contain 10. At district level, Uttara Kannada, Bengaluru Urban, and Mysuru have the highest counts, with 16, 15, and 14 selected destinations, respectively. The findings demonstrate the value of district- and division-level GIS assessment for destination promotion, infrastructure planning, and inter-district tourism circuits. Because the database contains selected destinations rather than an independently verified census of every tourism asset, the results are interpreted as a spatial assessment of the selected inventory rather than a complete measure of tourism potential.

Keywords: *Tourism resources, Karnataka, GIS; administrative divisions, regional disparity, tourism planning.*

Introduction

Tourism is a complex social, cultural, economic, and geographical activity that involves traveling outside of one's normal surroundings for personal, recreational, cultural, religious, or commercial purposes (World Tourism Organization, 2021). The connection between tourist destinations, transit options, accommodations, villages, tourist markets, and auxiliary infrastructure give its geographical character. Infrastructure can be improved, employment can be created, small businesses can benefit, cultural interchange can be promoted, and legacy can be preserved. However, these benefits are not always evident everyplace. This is due to the fact that certain locations may be tourist hotspots while others may be rather secluded due to factors such as the quantity of resources available, the ease of access to them, the amount of money invested, the popularity of the location, the quality of the roads and buildings, and the efficiency of the administration.

For the purpose of regional tourism planning, the geographical distribution of tourist destinations is crucial. Destination competitiveness, visitor flow, infrastructure requirements, and the creation of tourism circuits are all impacted by the quantity and concentration of attractions. Destination type, timing, cost, accessibility, past knowledge, and individual preferences all influence tourist movements (Debbage, 1991; Becken et al., 2007; Lew & McKercher, 2006). According to Buhalis and Law (2008), Caldeira and Kastenholz (2018), and Vansteenwegen et al. (2011), modern visitors rely more and more on digital information and aim to visit multiple sites in a short amount of time and money. As a result, visitor experiences and the growth of regional tourism are influenced by the location, proximity, distribution, and connection of tourist destinations.

An efficient framework for recording and evaluating tourism resources is offered by geographic information systems. Administrative boundaries, transportation networks, communities, lodging, protected areas, land use, and demographic data can all be integrated with geocoded attractions using GIS. Tourism inventory, destination mapping, route planning, infrastructure assessment, appropriateness evaluation, and sustainable tourism management have all used it (Bahaire & Elliott-White, 1999; Jovanović & Njeguš, 2008; Vuković, 2022). Planners can also determine regions with relatively high or low concentrations of tourism resources using GIS-based tourism inventory.

The value of GIS and spatial techniques in tourism planning has been shown in earlier research. Terrain, animals, roads, settlements, cultural resources, and amenities have all been used to determine ecotourism appropriateness using GIS and multicriteria techniques (Bunruamkaew & Murayama, 2011; Çetinkaya et al., 2018). In India, the potential for tourism has been linked to infrastructure and environmental conditions through the use of remote sensing and GIS (Acharya et al., 2022). To find resource-rich regions, undeveloped locations, and chances for regional collaboration, other research has used resource mapping, gap analysis, network analysis, and spatial-association techniques (Van der Merwe & Van Niekerk, 2013; Ruda, 2016; Kang et al., 2018; Liu et al., 2017).

Administrative-scale analysis is particularly relevant because tourism policies, infrastructure investments, destination promotion, and development programmes are commonly implemented through districts and regional administrative units. Divisional totals can conceal internal variation; therefore, total destinations should be considered together with the number of districts, district-level means, variability, and rankings.

Karnataka's unique heritage, religious, cultural, ecological, wildlife, coastal, hill, rural, adventure, wellness, business, and urban tourist resources make it a suitable environment. According to the Government of Karnataka (2020), the Karnataka Tourism Policy encourages the development of tourist destinations, tourism circuits, infrastructure enhancement, community involvement, digital projects, and data-driven tourism planning. Evidence on the allocation of tourism resources among districts and administrative divisions must be geographically organized in order to implement these initiatives.

Although there is a wealth of information available about Karnataka tourism, it is frequently presented as tourist data, policy documents, destination lists, and promotional categories. A statewide selected-destination inventory and GIS analysis at the district and division levels have been combined in relatively few studies. In order to close this gap, this study compiles 347 carefully chosen tourist destinations and compares how they are distributed throughout the 31 districts and four administrative divisions of Karnataka. The goals are to map the chosen tourism resources, compare totals and percentage shares at the district and division levels, use descriptive statistics to analyze internal variance, and identify districts with comparatively higher and lower counts for regional tourism planning.

Study Area

The current study was carried out in Karnataka, a state in the southwest of the Indian peninsula that spans a total geographical area of roughly 1,91,791 km², between latitudes 11°30′N and 18°45′N and longitudes 74°05′E and 78°40′E. The state is bordered to the north and northwest by Maharashtra and Goa, to the west by the Arabian Sea, to the south by Kerala and Tamil Nadu, and to the east by Andhra Pradesh and Telangana. From sea level along the narrow coastal belt (Karavali) to 1,930 meters at Mullayanagiri, the state's highest peak, which is located in the Western Ghats (Malnad) region of Chikmagaluru district, Karnataka's topography shows significant variety in elevation. The four administrative divisions of Karnataka—Bengaluru, Mysuru, Belagavi, and Kalaburagi—together include 31 districts and constitute the administrative framework for this research. The capital area falls under the Bengaluru division, located in the southeastern part of the state, noted for its rapid urbanization on the Deccan plateau. Parts of the Western Ghats and the coastal Karavali area, which are characterized by heavy rainfall and deep forest cover, are included in the Mysuru division, which is located in the southern and southwestern regions. The Kalaburagi division, situated in the northeastern part of the state, represents the driest and most drought-prone tract, dominated by black cotton soils and the Krishna River basin, while the Belagavi division, in the northwest, transitions from the Western Ghats into the semi-arid interior plateau.

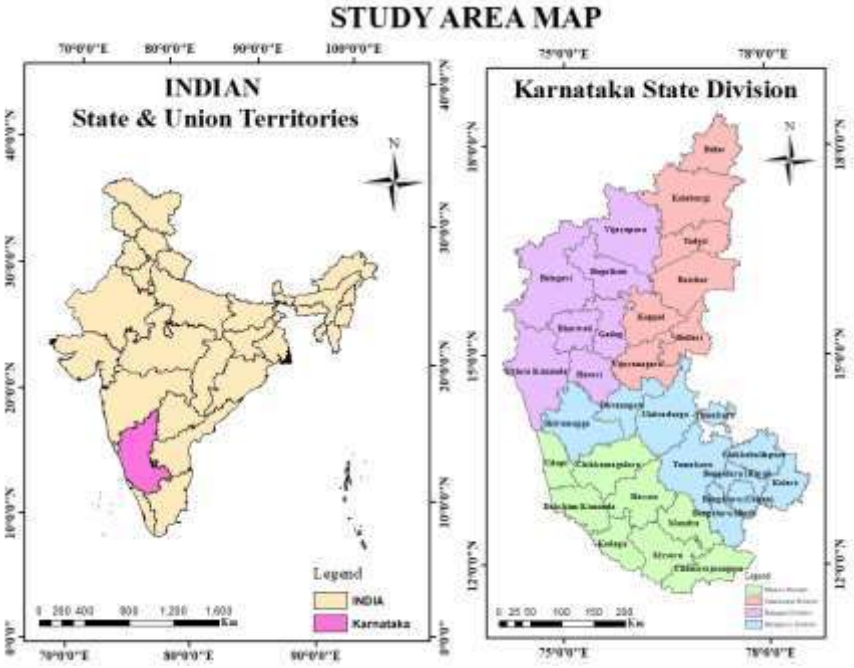

Fig 1: Study Area

The study considers Karnataka's 31 districts grouped into four administrative divisions: Belagavi, Kalaburagi, Bengaluru, and Mysuru. The selected tourism inventory contains 347 destinations assigned to their respective districts and divisions. The

divisions contain seven districts each in Belagavi and Kalaburagi, eight in Bengaluru, and nine in Mysuru; consequently, district-level averages are used alongside total counts for comparison.

Data and Methodology

The analytical dataset consists of 347 selected tourist places organised in Microsoft Excel. Each destination was assigned to one of the 31 districts and one of the four administrative divisions. The present analysis focuses on the number of selected tourist places rather than visitor arrivals, tourism revenue, or accommodation capacity. District and divisional administrative boundaries were used as the spatial framework. Tourist-place records were associated with their corresponding administrative units, after which district totals were aggregated to divisional totals. Four regional maps were prepared for Belagavi, Kalaburagi, Bengaluru, and Mysuru divisions to show district boundaries and tourist-place counts. Divisional share was calculated as the number of selected tourist places in a division divided by the Karnataka total and multiplied by 100. Because divisions contain different numbers of districts, the mean number of destinations per district was calculated. Standard deviation and coefficient of variation (CV) were used to assess within-division variability.

A district tourism-place index was calculated relative to the Karnataka district mean of 11.19.

Divisional share (%) = (Tourist places in division / 347) × 100

Mean per district = Tourist places in division / Number of districts

Tourism-place index = (District count / 11.19) × 100

CV (%) = (Standard deviation / Mean) × 100

Results and Discussion

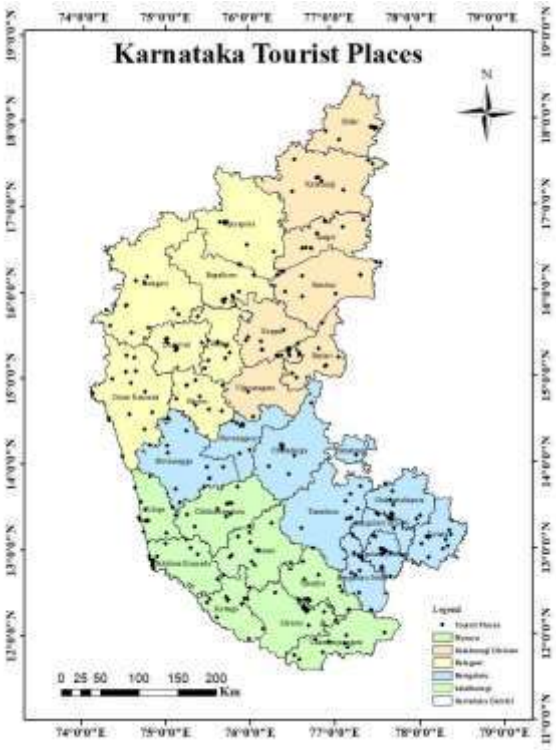

Fig 2: Karnataka Tourism places

Division-wise distribution

Division	Districts	Total	Share (%)	Mean	SD	CV (%)
Mysuru	9	108	31.12	12.00	0.94	7.86
Bengaluru	8	85	24.50	10.62	1.65	15.56
Belagavi	7	80	23.05	11.43	2.06	18.03
Kalaburagi	7	74	21.33	10.57	0.90	8.55
Karnataka	31	347	100.00	11.19	1.57	14.07

Table 1: Division-wise distribution

Mysuru Division contains the largest share of the selected tourism inventory, with 108 destinations (31.12%), followed by Bengaluru with 85 (24.50%), Belagavi with 80 (23.05%), and Kalaburagi with 74 (21.33%). The difference between the highest and lowest divisional totals is 34 destinations. Mysuru also contains the largest number of districts, so its mean of 12.00 destinations per district provides an important standardised comparison. Kalaburagi records the lowest mean at 10.57.

Belagavi Division

There are 80 well-chosen tourism destinations spread throughout seven districts in the Belagavi Division. With 16, Uttara Kannada has the most, followed by Belagavi and Vijayapura, each with 12. There are ten in each of Bagalkote, Dharwad, Gadag, and Haveri. As a result, the division combines a clearly higher-count district in Uttara Kannada with a baseline that is generally balanced across other districts. The largest internal variation in the chosen inventory is indicated by its CV of 19.47%, which is the highest of the four divisions.

Kalaburagi Division

Kalaburagi Division records 74 selected tourist places across seven districts, the lowest divisional total. Kalaburagi and Vijayanagara each contain 12 destinations, while Bidar, Raichur, Yadgir, Ballari, and Koppal each contain 10. Its CV of 9.23% indicates a comparatively uniform numerical distribution across districts.

Bengaluru Division

There are eight districts and 85 well-chosen tourist destinations in Bengaluru Division. Ten are found in each of the other seven districts, with Bengaluru Urban having the maximum number (15). The division's CV is 16.64% and its mean is 10.63. As a result, the pattern demonstrates Bengaluru Urban's notable numerical prominence in an otherwise extremely consistent district-level inventory.

Mysuru Division

31.12% of the Karnataka inventory, or 108 chosen tourist destinations spread over nine districts, are included in the Mysuru Division. There are fourteen destinations from Mysuru, twelve from Mandya, Hassan, Kodagu, Shivamogga, Chikkamagaluru, Udupi, and Dakshina Kannada, and ten from Chamarajanagar. The division's distribution is relatively even among its districts, as evidenced by its highest mean (12.00) and low CV (8.33%).

District ranking and index

At the state level, Uttara Kannada ranks first with 16 selected tourist places, followed by Bengaluru Urban (15) and Mysuru (14). The Karnataka district mean is 11.19. The corresponding tourism-place indices are 143.0 for 16 destinations, 134.0 for 15, 125.1 for 14, 107.2 for 12, and 89.3 for 10. Thus, districts containing 12 or more selected destinations are above the statewide district mean, whereas districts containing 10 are below it.

Implications for Tourism Planning

The results indicate that division-level totals should not be interpreted independently of district structure. Mysuru has the largest total partly because it contains nine districts, while Belagavi and Kalaburagi contain seven. Standardised district averages therefore provide a more defensible comparison. The higher-count districts can serve as anchor nodes for inter-district tourism circuits, while lower-count districts can be examined for destination promotion and connectivity to neighbouring tourism centres.

The four divisional GIS maps can support spatially targeted planning by showing where selected tourism resources are concentrated within administrative regions. However, resource quantity alone should not determine investment priorities. Future planning should integrate accessibility, visitor demand, accommodation, infrastructure capacity, environmental sensitivity, heritage condition, and community participation.

A critical limitation is the structure of the present database. Many districts contain exactly 10 or 12 selected destinations. This indicates that the dataset should be treated as a selected tourism inventory unless the authors can demonstrate that it represents an exhaustive official inventory. Accordingly, the present findings describe the spatial distribution of the selected destinations and should not be interpreted as a complete measure of each district's total tourism potential.

Conclusion

This study offers a GIS-supported evaluation of 347 chosen tourism destinations at the district and division levels throughout the 31 districts and four administrative divisions of Karnataka. The greatest selected inventory is found in Mysuru Division (108), followed by Bengaluru (85), Belagavi (80), and Kalaburagi (74). While Belagavi exhibits the largest within-division variability, Mysuru likewise has the highest district-level mean. Mysuru, Bengaluru Urban, and Uttara Kannada hold the top spots at the district level. The analysis shows that descriptive statistics, administrative aggregation, district-level standardization, and GIS visualization offer a helpful foundation for evidence-based tourist planning. To create a more thorough tourism-resource assessment, future research should incorporate tourist categories, exact coordinates, transportation accessibility, visitor demand, lodging, environmental sensitivity, and spatial autocorrelation techniques.

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Associate Professor, C.H.C. Arts, S.G.P. Commerce and B.B.J.P. Science College, Taloda, Dist. Nandurbar (Maharashtra)
Email: mr.yashod@gmail.com

Address for correspondence:
Raju Z. Yashod
Associate Professor, C.H.C. Arts, S.G.P. Commerce and B.B.J.P. Science College, Taloda, Dist. Nandurbar (Maharashtra)
Email: mr.yashod@gmail.com

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An Analytical Study of Geospatial Data Framework with Special Reference to Indian Cyber Security

Dr. Raju Z. Yashod

Abstract

This paper investigates the conceptual framework of geospatial data collection, monitoring, valuation, geospatial digital data protection, and cybersecurity in the cyber world. The researcher focuses on an analytical study of the geospatial data framework with special reference to Indian cybersecurity. The present era is powered by IoT (Internet of Things) automation worldwide, ultra-high-speed 5G networks, and upcoming future-generation communication networks. The paper examines how geospatial data enables the assessment of spatial location, spatial accuracy, and ultimately spatial efficiency, while also identifying lacunae in geographical data security in the Indian peninsula. The study analyses cybersecurity on electronic devices and work sites, noting that users often provide authenticated information quickly and without sufficient awareness, thereby increasing vulnerability to cybercrimes and attacks. The researcher concentrates on the conceptual and analytical study of the geospatial data framework, particularly with reference to Indian cybersecurity.

Keywords: *Geospatial, Geographical, Data security, Cybercrime, Cybersecurity, India*

Introduction

Presently, the concept of the world appears to be a very small global village. It is easy to access and manipulate each and every point in the world through different electronic gadgets of the modern era. In the present era, geography is related to the basic science streams in the world.

Geographically, geospatial data, which includes geographical maps, aerial photographs, and satellite images, is associated with location information represented by longitude and latitude in the Geographic Coordinate System (GCS). Geospatial data means geographical data related to information associated with the Geographic Coordinate System (GCS), Global Positioning System (GPS), and System-generated location data are used globally and around the world.

Criminals can easily gather geographical and geospatial data in and out of cyberspace and cyber-attacks are given time, space, period, and choice for the particular system-generated location site for cybercrime in India and all over the world. This research paper focuses on the present scenario of geospatial data security management in India. The researcher has focused on the security requirements for a data protection framework that ensures data security in cloud-native environments for geospatial data security in India.

Objectives

A. To study the conceptual framework of geospatial data security present in India.
B. To study the geographic data collection, data monitoring, control, and manipulation systems of electronic devices.
C. To study cybercrime in the field of geospatial data security.
D. To study the remedies for cybercrimes in India.

Conceptual Framework of Geospatial Data Security

Geospatial data security refers to the protection of location-based information throughout its life cycle, including collection, processing, storage, transmission, publication, and deletion. Unlike ordinary datasets, geospatial information may reveal the location of critical infrastructure, defence installations, transportation networks, individuals, vehicles, or essential services. Consequently, its protection requires attention to confidentiality, integrity, availability, authenticity, privacy, and positional accuracy.

A useful analytical model consists of five connected layers:

A. Data layer: Raster images, vector features, digital elevation models, coordinate, metadata, sensor data, and personal location records.
B. Application layer: GIS software, web mapping platforms, mobile navigation applications, cloud services, and spatial databases.
C. Network layer: Internet, mobile networks, satellite communication, sensor networks, and APIs through which geospatial data is transferred.
D. User and organizational layer: Government agencies, private companies, researchers, citizens, defence organisations, and third-party service providers**.**
E. Regulatory layer: Data-protection law, national geospatial policy, cybersecurity standards, sectoral rules, and institutional procedures.

Security weaknesses at any layer may affect the entire system. For example, accurate satellite imagery may be protected in storage but exposed through an insecure application programming interface. Similarly, a mobile application may collect a user's location lawfully but retain it longer than necessary or share it without adequate transparency.

India's National Geospatial Policy, 2022 seeks to promote the availability and use of geospatial data and provides for a National Geospatial Data Registry containing catalogues of datasets and services. The policy therefore creates an important framework for accessibility, innovation, and economic development, but these objectives must be balanced with national security, privacy, and cybersecurity requirements.

Major Threats to Geospatial Data

A. Unauthorized access: Attackers may obtain restricted maps, location histories, infrastructure databases, or administrative records through stolen credentials or weak access controls.

B. Data manipulation: Altered coordinates, boundaries, road networks, elevation values, or imagery can produce incorrect analysis and may affect emergency response, land administration, navigation, and defence planning.

C. Ransomware and availability attacks: A geospatial database or online mapping service may be encrypted or disabled, preventing public authorities and emergency agencies from accessing essential information.

D. Location privacy violations: Continuous GPS records can reveal a person's home, workplace, religious activity, medical visits, travel patterns, or social relationships.

E. Metadata exposure: File names, timestamps, sensor information, coordinate reference systems, and embedded location tags can disclose sensitive information even when the main image appears harmless.

F. Supply-chain vulnerabilities: GIS software, cloud platforms, satellite-data providers, plugins, sensors, and external APIs may introduce vulnerabilities into an otherwise secure system.

G. Spoofing and jamming: False positioning signals can mislead navigation systems, while interference with satellite signals can reduce the reliability of positioning, navigation, and timing services.

H. Insider threats: Employees, contractors, or partners with legitimate access may intentionally or accidentally disclose sensitive data.

I. Re-identification: Even when names are removed, a combination of coordinates, time, movement patterns, and external datasets may identify individuals or households.

Indian Legal and Policy Context

Geospatial security in India is governed by a combination of geospatial policy, information-technology law, data-protection law, sectoral regulations, and national cybersecurity institutions. The National Geospatial Policy, 2022 encourages wider access to geospatial datasets while recognising the need to regulate sensitive information and protect national interests.

The Digital Personal Data Protection Act, 2023 is relevant where geospatial information is linked or reasonably linkable to an identifiable person. Examples include live location, travel history, household coordinates, vehicle movement, and employee tracking information. The Act establishes obligations concerning the processing of digital personal data and recognises the interest of individuals in protecting their personal data.

However, geospatial datasets are not always personal data. A general geological map, publicly available administrative boundary, or anonymised satellite image may not identify an individual. The legal assessment should therefore consider the nature of the dataset, the possibility of re-identification, the purpose of processing, the sensitivity of the location, and the identity of the data controller or processor.

The Information Technology Act, 2000, the Information Technology Rules, sector-specific security directions, and the work of the Indian Computer Emergency Response Team also form part of the wider cybersecurity environment. Institutions handling geospatial information should maintain documented security policies, incident-response procedures, access logs, vulnerability-management processes, and reporting mechanisms.

Security Framework for Geospatial Systems

The NIST Cybersecurity Framework 2.0 provides a useful structure for protecting geospatial systems. It organises cybersecurity activities around the functions Govern, Identify, Protect, Detect, Respond, and Recover. Applied to geospatial data, the framework may be implemented as follows:

a) Govern: Establish ownership, risk tolerance, data-classification rules, privacy responsibilities, and third-party requirements.

b) Identify: Prepare an inventory of datasets, sensors, servers, cloud services, applications, APIs, users, and critical dependencies.

c) Protect: Use encryption, multifactor authentication, role-based access, secure backups, network segmentation, patch management, and staff training.

d) Detect: Monitor abnormal downloads, unusual coordinate queries, failed logins, unauthorised API use, and changes to spatial layers.

e) Respond: Isolate affected systems, preserve logs, assess the scale of exposure, notify relevant authorities, and correct manipulated datasets.

f) Recover: Restore verified backups, validate spatial accuracy, review lessons learned, and improve controls after an incident.

A geospatial organization should also introduce data classification. For example, datasets may be categorised as public, internal, restricted, sensitive, or critical. Classification should consider the potential consequences of disclosure, manipulation, or unavailability rather than only the technical format of the file.

Recommended Safeguards

- Apply data minimisation by collecting only the location information required for a clearly defined purpose.
- Remove or reduce unnecessary precision when exact coordinates are not required.
- Encrypt data during storage and transmission.
- Use multifactor authentication and role-based access control.
- Separate production, testing, public, and classified geospatial environments.
- Maintain immutable backups and regularly test restoration procedures.
- Digitally sign datasets and retain version histories to detect unauthorised modification.
- Record provenance, date of collection, sensor details, processing steps, accuracy, and licensing conditions in metadata.
- Conduct privacy-impact and security-impact assessments before launching location-based services.
- Review third-party GIS applications, cloud providers, plugins, APIs, and data suppliers.
- Train employees to identify phishing, insecure file sharing, malicious attachments, and accidental disclosure.
- Establish an incident-response plan involving technical, legal, administrative, and communications teams.
- Validate spatial accuracy using independent control data before important decisions are based on a dataset.
- Use anonymisation, aggregation, masking, or geofencing when publishing information about people or sensitive sites.
- Periodically audit access rights and immediately remove accounts that are no longer required.

Conclusion

Geospatial data supports navigation, urban planning, agriculture, disaster management, environmental monitoring, public health, logistics, defence, and economic development. At the same time, the increasing use of mobile devices, cloud platforms, remote sensing, IoT sensors, and open data services has expanded the attack surface of geospatial systems.

The central finding of this study is that geospatial security cannot be achieved through authentication alone. It requires an integrated approach combining data quality, privacy protection, cybersecurity governance, secure system design, legal compliance, user awareness, and continuous monitoring. Indian organisations should implement risk-based controls that distinguish between ordinary public datasets, personal location data, and strategically sensitive geospatial information.

A practical security model should include data classification, least-privilege access, multifactor authentication, encryption, secure APIs, audit trails, verified backups, incident response, and independent quality assessment. The National Geospatial Policy, 2022 and the Digital Personal Data Protection Act, 2023 provide important policy and legal foundations, while the NIST Cybersecurity Framework 2.0 and ISO 19157-1:2023 offer useful operational and quality-management guidance.

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Dept. of Botany, Shripatrao Chougule Arts and Science College malwadi kotoli
Email:
sanchitkamalakar98@gmail.com

Address for correspondence:
Sanchit Uttam kamalakar
Dept. of Botany, Shripatrao Chougule Arts and Science College malwadi kotoli
Email: sanchitkamalakar98@gmail.com

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Systematics, Digital Taxonomy, and the Evolution of Herbaria: Transforming Botanical Collections into Machine-Readable Biodiversity Engines

Sanchit Uttam kamalakar

Abstract

Plant systematics is undergoing its most radical transformation since the introduction of Linnaean binomial nomenclature. For centuries, physical herbaria have served as the foundational bedrock of botanical taxonomy, preserving voucher specimens that anchor our understanding of global phytodiversity. However, physical collections face inherent geographical, logistical, and material constraints. This paper examines the multi-tiered evolution of traditional herbaria into interconnected, digital taxonomic platforms. We analyze the technical pipelines driving high-throughput imaging and semantic metadata extraction using the Darwin Core standard. Furthermore, we explore the integration of computer vision, deep convolutional neural networks (CNNs), and extended specimen networks (ESNs) that bridge the gap between gross morphology, molecular genomics, and spatial ecology. Finally, we address critical systemic challenges, including digital data silos, geographical resource disparities, and the "dark data" bottleneck. We conclude that digital taxonomy does not replace physical collections but rather supercharges their utility, turning static regional archives into dynamic, machine-readable engines capable of accelerating biodiversity discovery during an era of unprecedented anthropogenic extinction.

Introduction

The discipline of plant systematics is tasked with the monumental challenge of discovering, naming, classifying, and resolving the evolutionary relationships of the world's flora. Historically, the primary infrastructure supporting this enterprise has been the physical herbarium—a distributed global network of repositories holding an estimated 390 million pressed, dried, and mounted botanical specimens spanning over three centuries of field exploration. These voucher specimens represent the ultimate truth-standard in botany; they anchor scientific names through nomenclatural types and serve as permanent, physical verifications of a species' existence at a specific point in space and time.

Despite their undeniable utility, physical herbaria operate under severe operational limitations. They are geographically static, requiring researchers to travel across continents or rely on slow, high-risk physical loans to inspect diagnostic characters. They are vulnerable to catastrophic loss from fire, pests, and political instability, and they scale poorly when subjected to high-throughput macroecological modeling or rapid evolutionary analysis. Furthermore, traditional taxonomic workflows are notoriously time-consuming, resulting in a "taxonomic impediment" where new species remain undescribed on herbarium shelves for an average of 30 to 40 years post-collection.

In the contemporary era, the intersection of biodiversity informatics, high-resolution digitization, molecular genetics, and artificial intelligence has catalyzed the emergence of **digital taxonomy**. This paradigm shift goes far beyond the creation of simple digital image galleries. It represents a fundamental evolutionary leap: the conversion of analog physical vouchers into multi-dimensional, machine-readable data nodes. By unlocking the data trapped on herbarium sheets and linking it directly to global computational networks, digital taxonomy is democratizing botanical knowledge, accelerating the discovery of cryptic species, and providing the baseline data needed to model ecosystem responses to the climate crisis. This paper provides a comprehensive synthesis of this evolution, mapping the technical, analytical, and conceptual frameworks that define the modern digital herbarium.

The Historical and Structural Evolution of Herbaria

To understand the digital revolution in systematics, one must first trace the structural lineage of the herbarium itself. Pioneered by Luca Ghini in the 16th century, the core methodology of pressing plants between sheets of paper and housing them mounted to heavy cardstock has remained virtually unchanged for nearly 500 years. This structural conservatism is a strength, ensuring the long-term preservation of morphological traits, but it has historically isolated these data points within individual institutional silos.

Throughout the 19th and 20th centuries, herbaria evolved from private collections into massive institutional repositories (e.g., the Royal Botanic Gardens, Kew; the Muséum National d'Histoire Naturelle, Paris; and the New York Botanical Garden).

As these collections swelled into the millions of specimens, managing them required strict, linear categorization systems organized by evolutionary arrangements (e.g., the Engler or Bentham & Hooker systems).

The late 20th century marked the dawn of the "informatics era" in botany, characterized by the deployment of localized relational databases to log specimen catalogs. However, these early databases were isolated, plagued by non-standardized text fields, and devoid of visual data. The true evolutionary leap occurred in the early 2000s with the birth of global biodiversity aggregators. The realization that biodiversity data must be open, interconnected, and globally accessible forced herbaria to transition from passive museums into active, open-access nodes within a decentralized global network.

Methodological Frameworks in Digital Taxonomy

The transformation of a physical herbarium specimen into a high-fidelity digital asset requires a standardized, multi-tiered curation pipeline. This pipeline must ensure that no scientific value is lost during translation and that the resulting data is entirely interoperable across different software platforms and international databases.

High-Throughput Digital Curation and Imaging

Modern digitization projects have abandoned manual, flatbed scanning methods in favor of automated, industrial high-throughput workflows. Facilities utilize specialized conveyor systems or custom inverted camera rigs equipped with medium-format, high-resolution digital sensors (typically capturing at a minimum of 600 to 1200 DPI). Lighting is strictly controlled using synchronized strobe arrays to eliminate shadows and ensure perfect color calibration via standardized color targets (e.g., X-Rite ColorChecker). This extreme visual fidelity is required because researchers must be able to zoom in to examine microscopic diagnostic characters—such as trichome density, stomatal patterns, and fine floral venation—directly on their screens without needing to handle the delicate physical specimen.

Semantic Data Harmonization and the Darwin Core Standard

An image of a herbarium sheet is scientifically useless without its accompanying contextual data. Every sheet contains a label denoting the taxon name, collector, collection number, date, geographic location, and habitat descriptions. Modern pipelines employ advanced Optical Character Recognition (OCR) combined with Natural Language Processing (NLP) models to automatically extract text from these labels. To make this data machine-readable, it is parsed and mapped directly to the **Darwin Core (DwC)** metadata standard. Key fields are strictly harmonized:

- **scientificName:** Standardized against authoritative taxonomic backbones (e.g., the International Plant Names Index).
- **Recorded By and record Number:** Standardizing the collector identity to track collection histories.
- **Decimal Latitude and decimal Longitude:** Converting descriptive text descriptions into precise, georeferenced coordinate data using automated geocoding tools.

Distributed Global Repositories

Once standardized, the rich datasets are exported via automated API networks to international biodiversity clearinghouses, primarily the **Global Biodiversity Information Facility (GBIF)** and **iDigBio** (Integrated Digitized Biocollections). This architecture breaks down geographical barriers. A researcher in a developing nation can instantly query millions of global records, cross-referencing collections from major world herbaria simultaneously to perform macroecological studies without incurring prohibitive travel costs or shipping risks.

The Integration of Artificial Intelligence and Molecular Systematics

Digital taxonomy is no longer a passive archiving system; it has become an active analytical engine. By combining massive digital image libraries with computational intelligence and genomic data, systematics is expanding into new frontiers.

Computer Vision and Deep Learning in Phenotypic Automated Discovery

The transformation of digitized herbarium collections into automated diagnostic environments relies heavily on deep learning architectures, specifically Deep Convolutional Neural Networks (CNNs) and Vision Transformers (ViTs). Rather than relying on human-selected diagnostic markers, these models treat the entire ultra-high-resolution herbarium sheet as an unsegmented, high-dimensional tensor input. Standard baseline architectures utilized in botanical classification include ResNet-50, EfficientNet-B7, and ConvNeXt. These models apply residual connections to mitigate vanishing gradient problems during deep backpropagation. For a network optimized across millions of global herbarium records, the classification objective is mathematically defined by minimizing a cross-entropy loss function over target plant classes using Softmax activation layers.

Beyond multi-class species identification, digital herbaria leverage regional object detection models such as YOLO (You Only Look Once) and Mask R-CNN to automate high-throughput phenotyping. Models are deployed for instance segmentation to count leaves, flowers, or fruits across historical sheets, compiling vast datasets that allow macroecologists to model phenological shifts induced by climate change over centuries. Furthermore, clustering algorithms applied to latent space representations help taxonomists flag outliers, mixed mounts, or completely new cryptic species.

Bridging the Digital Voucher with the Extended Specimen Network (ESN)

The modern frontier of digital taxonomy revolves around the concept of the **Extended Specimen Network (ESN)**. A physical herbarium sheet is no longer viewed as an isolated object, but rather as the core physical anchor of a massive web of digital data extensions. Through unique, persistent identifiers (such as DOIs or HTTP URIs), a single digital specimen record seamlessly links outwards to: (1) genomic databases including NCBI GenBank or the Sequence Read Archive; (2) ecological and spatial databases such as WorldClim or SoilGrids; and (3) living field observational data integrating real-time community science platforms like iNaturalist.

Systemic Challenges and Future Outlook

Despite the remarkable progress made in digital taxonomy, significant technical, structural, and philosophical hurdles remain to be solved.

While major international herbaria have digitized millions of sheets, a vast percentage of global collections remains trapped as **"dark data"**—specimens stored in smaller, regional herbaria or institutions in biodiverse developing nations that lack the funding, infrastructure, or technical training to initiate high-throughput workflows. This creates a severe geographic bias in global biodiversity aggregators.

To overcome the limitations of flat imaging, pioneering institutions are experimenting with 3D micro-Computed Tomography (micro-CT) scanning and photogrammetry. These techniques allow researchers to digitally dissect delicate, century-old flowers in virtual 3D space without damaging the underlying type specimen. Furthermore, the integration of "herbariomics"—extracting and sequencing highly degraded ancient DNA directly from historical herbarium specimens—will merge seamlessly with digital informatics.

Conclusion

The rapid evolution of herbaria from dusty, localized physical cabinets into dynamic, cloud-based digital ecosystems represents a monumental leap forward for comparative biology. Digital taxonomy does not replace or minimize the value of traditional physical collections; rather, it liberates the irreplaceable data trapped within them. By standardizing specimen metadata via the Darwin Core framework, deploying machine learning algorithms to automate phenotypic extraction, and constructing deep Extended Specimen Networks, the botanical community is creating a resilient, scalable infrastructure for the future. As the planet faces an accelerating biodiversity crisis, these machine-readable engines provide the critical, high-velocity data pipelines required to document, understand, and ultimately preserve global plant life before it disappears.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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