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ABOUT THE JOURNAL

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Message from the Patron

It gives me immense pleasure to pen down this foreword for the “Journal of Multidisciplinary Hill Research” an academic initiative from Nar Bahadur Bhandari Government College, Gangtok. This journal stands as a testament to the institution's commitment to fostering intellectual growth, encouraging diverse research, and contributing to the academic discourse on topics relevant to hill regions and beyond.

The “Journal of Multidisciplinary Hill Research” aims to provide a platform for scholars, researchers, and academicians to share insights across various disciplines, ranging from environmental studies and social sciences to humanities, technology, and beyond. Its focus on hill-centric research is particularly significant, as it addresses the unique challenges, opportunities, and perspectives of regions like ours—where geography, culture, and ecology intertwine in fascinating ways.

As the Patron of this journal, I am proud of the efforts made by the editorial board, contributors, and reviewers in upholding the highest standards of academic rigor and originality. Their dedication ensures that this journal not only serves as a repository of knowledge but also inspires meaningful dialogue and actionable solutions to contemporary issues.

I am confident that the “Journal of Multidisciplinary Hill Research” will continue to evolve as a beacon of multidisciplinary research, fostering collaborations and enriching the academic landscape. May this endeavor inspire curiosity, innovation, and a deeper understanding of the world we live in.

Best wishes to the entire team and contributors of this remarkable journal.

Dr. D. Purohit
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Message from the Editor-in Chief

I am delighted to introduce our institution's first ever “*International Journal*” in the name of “*Journal of Multidisciplinary Hill Research*” which is scheduled to be launched in January 2026. We have applied for ISSN number as well as DOI of the journal and all the published articles will be made available initially in the form of hard copy and followed by both in print and online version. The journal will be published twice in a year (January & July). For the first inaugural issue we have waived “Article Processing Fee” (APC).

The aim of our multidisciplinary research journal is to cater and publish high quality innovative research work, case study and mini review articles associated with mountain related research studies and their further applications to mankind. Our aim is also to become an effective medium for inspiring the researchers across the country as well as in the world to bring out their contributions in the form of various unknown aspects of himalayan regions of the world and new findings in the form of research work and also in the fields of pharmacy, medical sciences, social sciences and in literature too. The dissemination would thus help the hill region people, students, researchers, industries, professional organizations to adopt and publish their research findings. The publication would also help in enhancing awareness about the need to become research minded in our hill areas of the country.

After the publication of the inaugural issue of our journal, the next issue will be made available online before it is published in print.

All articles published in the journal will then be freely available to scientific researchers to all over the globe. We will be making sincere efforts to promote our journal across the world in various ways. It is hoped that this journal will act as a common platform for researchers to pursue their objectives.

I wish all the very best and grand success of our inaugural issue of “*Journal of Multidisciplinary Hill Research*” and many congratulations to our dedicated members associated with “*Research & Development Cell, NBBGC*”. Without their wholehearted efforts the publication of our journal would not have been possible. Finally, myself is grateful to our Petron (Dr. Debabrata Purohit, Principal, NBBGC) for giving me the opportunity to act as *Editor-in-Chief* of our journal.

Bhaskar Chakraborty

Prof. Bhaskar Chakraborty
Editor-in-Chief

Journal of Multidisciplinary Hill Research,
Nar Bahadur Bhandari Government College (former Sikkim Government College), Gangtok, Sikkim

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Format of articles

The *Journal of Multidisciplinary Hill Research* invites a) research article b) Mini review or a c) case study. In most cases, we do not impose strict limits on word count or page number. However, we strongly recommend that you write concisely and stick to the following guidelines:

- Articles should ideally be no more than 10 typeset pages
- The Font should be Times New Roman with font size 12 and title font should be 14. The line spacing should be 1.5
- The main text should be no more than 5000 words (not including Abstract, Methods, References and figure legends)
- The title should be no more than 20 words, should describe the main message of the article using a single scientifically accurate sentence, and should not contain puns or idioms
- The abstract should be no more than 200 words

Abstract

Please do not include any references in your Abstract. Make sure it serves both as a general introduction to the topic and as a brief, non-technical summary of the main results and their implications. Abstract should be unstructured, i.e. should not contain sections or subheadings.

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We allow the use of up to 6 keywords/key phrases that can be used for indexing purposes. These should represent the main content of the submission.

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Your manuscript text file should start with a title page that shows author affiliations and contact information, identifying the corresponding author with an asterisk. We recommend that each section includes an introduction of referenced text that expands on the background of the work. Some overlap with the Abstract is acceptable.

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- Introduction
- Methods
- Results (with subheadings)
- Discussion (without subheadings)
- Conclusion

You should then follow the main body of text with:

- References (limited to 60 references, though not strictly enforced). APA referencing style is encouraged to maintain uniformity.
- Acknowledgements (optional)
- Author contributions (optional)
- Additional Information (including a Competing Interests Statement)

Your submission must also include:

- A cover letter
-

- Individual figure files and optional supplementary information files

For first submissions (i.e. not revised manuscripts), you may incorporate the manuscript text and figures into a single file up to 3 MB in size. Whilst Microsoft Word is preferred we also accept LaTeX, or PDF format. Figures can be inserted in the text at the appropriate positions, or grouped at the end.

Cover letter

In your cover letter, you should include:

- The affiliation and contact information of your corresponding author
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The *Journal of Multidisciplinary Hill Research* is broadly classified under five schools. Authors are encouraged to indicate their preferred school while submitting manuscripts, so that the editorial process can be handled appropriately.

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AIMS & OBJECTIVES OF THE JOURNAL

Journal of Multidisciplinary Hill Research is a first of this kind from the Himalayan range higher learning institute of our country Nar Bahadur Bhandari Government College, Tadong). It aims to publish a wide variety of subject area starting from science, humanities and commerce. The journal will also accept environment and soil science related research articles. All the research articles will undergo careful double referee review process if the research articles are found to have less than ten (10%) plagiarism. After the concerned editor's approval, chief editor will take final decision regarding publication of the research article. The following domains are the main core areas where research articles may be sent for publication.

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All the manuscripts should be meticulously check and verified by the authors (self-plagiarism check) and send to the E mail ID attached with *plagiarism check* report and a *declaration* that the manuscript has not send to other journals or any portion of the contents has already been published in any form. All the authors are requested to see and read carefully the directions given for the preparation of their manuscript in the section: *Author's Guidelines*.

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TEMPLATE OF THE JOURNAL**Title of the manuscript in short and concise manner**FIRST AUTHOR^(a), SECOND AUTHOR^(b) and THIRD AUTHOR¹ *Lawrence Berkeley Laboratory, University of California at Berkeley, CA 94720 USA*² *L.Landau Institute for Theoretical Physics, RAN, Moscow, 117334 Russia*

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Abstract – Electronic states in metallic nanoclusters form energy shells and degree of their filling depends on the number of delocalized electrons. In the region close to half-filling the cluster's geometry oscillates between the prolate and oblate configurations (dynamic Jahn-Teller effect). For large clusters ($N > 10^2$; N is the number of delocalized electrons) this effect competes with pair correlation and, as a result, it is perfectly realistic to observe the transition to the superconducting state. For some clusters (e.g., for Al) the value of the critical temperature is rather high ($\sim 140K$).

Keywords: up six keywords may be provided.

First section heading. –

Introduction

Methods and Experimental Outline

Results and Discussion

Conclusion

Acknowledgments to be inserted before references.

Conflicts of Interest (optional)

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The Associate Editor of respective school may decide for each school. However for uniformity APA style is encourage to follow.

INDEX

Volume: 1

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<u>Sl. No.</u>	<u>Title & Author</u>	<u>Page No.</u>
1.	Boosting Crop Health and Inducing Stress Resistance through Beneficial Microorganisms — Bishwanath Chakraborty* and Usha Chakraborty	1 - 15
2.	High altitude, Vitamin D, and Health — Dr. Deb K Barma	16 - 22
3.	Left or Right - Which Way to Go ? The Science of Chiral Separation — Atish Chakraborti	23 - 34
4.	Exploring Higher Secondary School Teachers' Attitudes Toward Life Skills Education : A Study of Personal Variables in Siliguri, West Bengal — Dr. Savita Mishra	35 - 44
5.	Darjeeling Sikkim Hills Calendars : A History of Time Measurement — Umesh Subba and Amitabha Bhattacharyya	45 - 56
6.	Study of drying lakes in Himalayan region : A case study in Uttarey Lake — Keshar Kumar Luitel, Passang Sherpa, Tikendra Hari Sharma Goley Eden Bhutia, Brajesh Gurung and Homnath Luitel	57 - 64
7.	Political Ideas of Mahatma Gandhi : Beyond Non-Violence — Guru Prasad Luitel	65 - 75
8.	Politics and Ethics of Language Endangerment : — a dossier — Samar Sinha	76 - 85
9.	A Study on Cycle-Free Vertex - Connectivity in Graphs — Naongsenti A Chang and Biswajit Deb	86 - 96
10.	Load Invariants, Character Theory, and Spectral Analysis of Automorphism Groups of Recursive Graphs — Prasant Dahal	97 - 105
11.	NEP 2020 Perspective on Integrating Indian Knowledge Systems into Contemporary Indian Education : A Conceptual Understanding — Dr. Punam Chhetri	106 - 112
12.	Estimation of Curie Temperature in Dilute Magnetic Semiconductors : A Theoretical Study — Prabin Pyakurel Sharma' and Homnath Luitel	113 - 122

REVIEW

Boosting Crop Health and Inducing Stress Resistance through Beneficial Microorganisms

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ABSTRACT

Soil is a living, dynamic matrix and soil microorganisms are an integral part of the ecosystem as they are crucial for soil activities that impact plant health and productivity. Microorganisms are crucial for the breakdown of organic matter, the removal of contaminants, the creation of soil structure, and the cycling of carbon, nitrogen, phosphorus, and sulphur. Due to the increasing demand for natural or "organic" products worldwide, biological fertilisers have become more popular in recent years. Agriculturally important microorganisms are therefore used for a variety of purposes, including nutrient delivery, biocontrol, bioremediation, and the restoration of degraded soils by both natural and artificial inoculation. The microorganisms used may be either biological control agents, which indirectly boost plant productivity by controlling plant pathogens, or plant growth promoting microorganisms, which directly promote plant growth. *Trichoderma* sp. continue to be extensively used as biocontrol agents but they are now known to promote plant growth and also mitigate abiotic stress in plants. Arbuscular mycorrhizal fungi are another group of plant growth promoting fungi which act mainly through mobilization of nutrients and are essential components of rhizosphere in almost all plants. Besides fungi, bacteria in the soil improve plant growth through both direct and indirect means. Some of these belong to genera such as *Bacillus*, *Pseudomonas*, *Azotobacter*, *Rhizobium* etc. Besides growth promotion and pathogen suppression, these bacteria also induce tolerance in plants against abiotic stresses. Systemic induced resistance against pathogen attack is a well known mechanism of action by PGPF or BCA, while PGPR use Induced Systemic Tolerance (IST) to help the plants to tolerate abiotic stresses. Increasing crop stress tolerance, yield, and reducing pesticide input in a sustainable and eco-friendly way requires an understanding of root microbiome processes.

Keywords: Plant growth promoting fungi, Biocontrol agent, Plant growth promoting rhizobacteria, Induced resistance, Beneficial microorganisms

INTRODUCTION

A vital part of the terrestrial ecosystem, soil is a living, dynamic matrix that is believed to be a storehouse for microbial activity. Because they participate in several soil activities that impact plant productivity, soil microorganisms are an integral part of the ecosystem. Numerous microorganisms are necessary for a sustainable biosphere, and it is now understood that rhizosphere microbial

communities are crucial for preserving root health, nutrient uptake, and stress tolerance. In both naturally occurring and managed agricultural soils, microorganisms are crucial for the breakdown of organic matter, the removal of contaminants, the creation of soil structure, and the cycling of carbon, nitrogen, phosphorus, and sulphur. Due to the increasing demand for natural or "organic" products worldwide, biological fertilisers have become more popular in recent years. Both organic farming and the natural world rely significantly on a microbial inoculant, which is made up of a variety of naturally occurring helpful bacteria known as "effective microorganisms." Effective microorganisms have a wide range of uses in household environments, agriculture, cattle, gardening, landscaping, composting, bioremediation, septic tank cleaning, and algae management. These cultures' individual positive impacts are significantly amplified in a synergistic way when they are placed in their natural habitat.

Beneficial microorganisms can help create a population structure that is better for healthier and more productive plants by balancing out microbial populations in production systems. Additionally, the maintenance of soil-borne plant illnesses, the promotion of vegetation changes, and plant growth all depend on microbes. Agriculturally important microorganisms (AIMs) are therefore used in a variety of agricultural settings for a variety of purposes, including nutrient delivery, biocontrol, bioremediation, and the restoration of degraded soils by both natural and artificial inoculation (Chakraborty, 2019a). The cycling of organic molecules is aided by soil fungus and bacteria, which are essential elements of many biochemical cycles.

One of the major challenges confronting farmers and scientists today is the need to produce sufficient quantities of high-quality food for the rapidly growing global population, while also meeting the demand for animal feed, biomass for biofuel production, and raw materials for various industrial applications. Soil, being a finite and essentially non-renewable resource, is under increasing pressure—particularly in tropical, arid, and semi-arid regions. A range of abiotic stresses, such as drought and salinity, coupled with intensive human activities, contribute to soil degradation and make cultivation increasingly difficult. Additionally, the prolonged use of pesticides and synthetic fertilizers further disrupts soil ecosystems, exacerbating the problem. Plant stress is generally divided into two main categories: **abiotic** and **biotic** stress (Vocciante *et al.*, 2022). **Abiotic stress** results from the influence of non-living environmental factors such as drought, salinity, or extreme temperatures. In contrast, **biotic stress** occurs through interactions between living organisms, where both partners can detect, produce, and respond to chemical signals, enabling mutual recognition and response (Kalariya *et al.*, 2024). Microbial interactions can help alleviate both types of stress—**directly**, by stimulating the plant's own tolerance or defense mechanisms, or **indirectly**, when microorganisms suppress biotic stressors through the production of toxins or antimicrobial compounds, without the plant's direct involvement (Francis *et al.* 2020; Sharma *et al.* 2025).

DIVERSITY OF BENEFICIAL SOIL MICROORGANISM

Compared to the rhizosphere, the microbial community in bulk soil is far more varied. This is due to the fact that although the bulk soil's unfavourable conditions reduce competitiveness among microbes, the rhizosphere's favourable environment promotes intense competition that suppresses less competitive bacteria. As a result, bacteria that establish themselves in the rhizosphere can multiply more quickly. The roots of many plants release a variety of primary and secondary metabolites, including amino acids, organic acids, and carbohydrates, as well as phenolics, terpenoids, and alkaloids. These rhizo-deposits drive the rich and varied microbial life in the rhizosphere.

The rhizomicrobiome is made up of a wide variety of microorganisms, such as nematodes, bacteria, viruses, fungi, and protozoa. The several groups of organisms inside the rhizobiome can be categorised based on the various functions they perform. Bacterial feeders, shredders, parasites, diseases, root feeders, fungal feeders, and top predators are some of these groupings. Other species include mutualists, grazers, decomposers, predators, and photosynthesizers. The rhizosphere has an extraordinarily complex microbial population that includes pathogens, helpful bacteria, saprophytes, epiphytes, and endophytes. In natural systems, these microbial communities typically coexist harmoniously, with all populations balancing each other out in their battle for resources and available space. In "artificial" systems like agriculture, this natural equilibrium may be upset, which could drastically alter the microbial community, result in the loss of beneficial bacteria, or let plant diseases infiltrate and have a catastrophic effect on plant productivity.

In these circumstances, the microbial community's balance can be tipped in favour of a population structure that supports improved plant health and productivity by introducing beneficial bacteria into production systems. Based on their most well-known positive effects on plants, they are separated into two main categories: (a) biological control agents (BCA), which indirectly boost plant productivity by controlling plant pathogens, and (b) plant growth promoting microorganisms (PGPM), which directly promote plant growth. More specifically, PGPM has proven to have biocontrol effects on illnesses that are spread through the soil. However, BCA has demonstrated traits that directly promote plant development.

From an agronomic standpoint, the number of bacteria in the rhizosphere that fix nitrogen and solubilise phosphate is important. The rhizosphere contains relatively less aerobic microorganisms because to the lower oxygen levels caused by root respiration. They make up about 4–10% of the total root area and are mostly present in the root hair region and occasionally at the root tips. Most of the amino acids and growth factors that bacteria require in the rhizosphere can be readily acquired from the root exudates. Plant roots have little effect on the total quantity of fungi in the rhizosphere, in contrast to how they affect bacteria. Much work was done in the rhizosphere of North Bengal's agricultural fields, forests, and riverine soil to isolate and screen beneficial agriculturally significant microorganisms for their desirable characteristics, choose effective strains, create an inoculum, and

prepare a carrier-based formulation (Fig.1 and Fig.2).

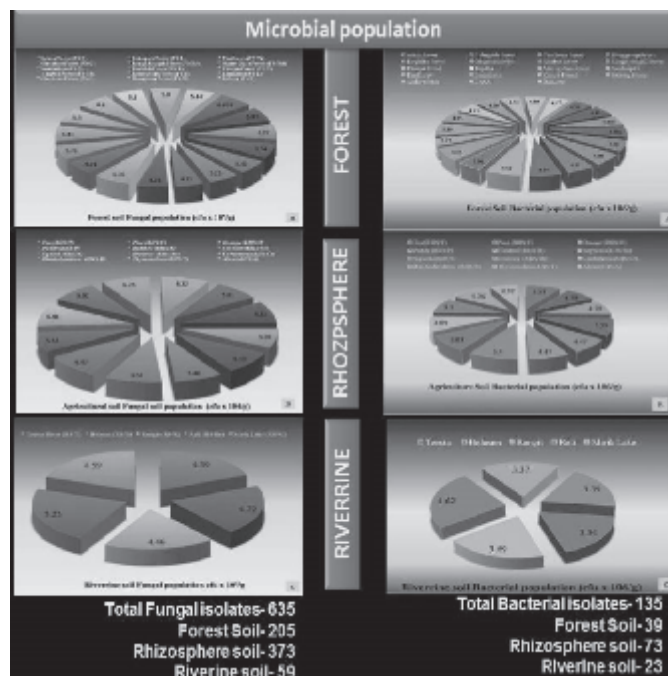


Fig.1. Microbial populations (Fungal and Bacterial isolates) of rhizosphere of agricultural fields, forests and riverine soil of North Bengal

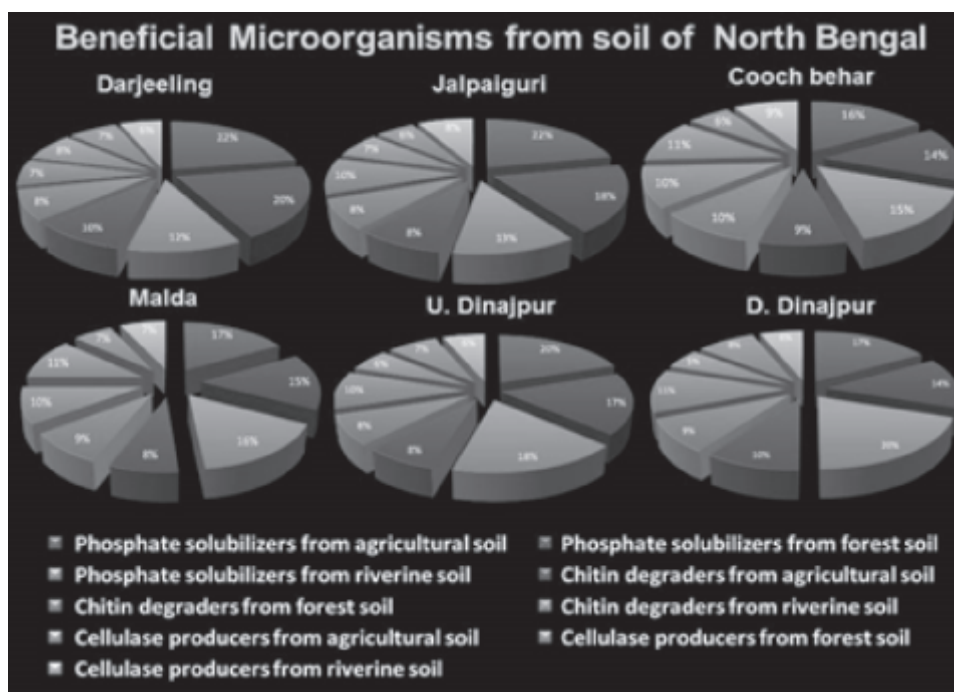


Fig.2. Phosphate solubilizers, chitin degraders and cellulase producers (%) from agricultural soil, riverine soil and forest soil of North Bengal

BENEFICIARY RHIZOMICROBIOME.

Plant Growth Promoting Fungi (PGPF)

Rhizosphere fungi known as "plant growth promoting fungi" (PGPF) have the capacity to promote plant growth following root colonisation. It has been demonstrated that these saprophytes, which are non-pathogenic soil inhabitants, protect many crop plants from illness and promote their growth. A few isolates from this PGPF group are especially effective at developing systemic plant resistance to phytopathogens. It has been discovered that the growth and yields of plants boosted by the fungus *Trichoderma* are correlated with a decrease in plant diseases. *Talaromyces flavus*, another fungus, shown far greater capacity for phosphate solubilisation and fungal pathogen inhibition. In addition, it has been documented that a number of *Aspergillus* species affect the growth and development of plants by releasing phosphate from the soil.

Arbuscular mycorrhizal fungi (AMF), another type of fungal symbiont, are becoming more well-known because of their expanding range of uses in ecosystem management and sustainable agriculture. Nearly 80% of the major vascular plant groups form mutualistic interactions with them. A variety of edaphic factors influence the dynamic process of AMF root colonisation. As a link between plants and the soil, mycorrhizae are an essential part of the soil's structure. By boosting the intake of immobile minerals, especially phosphorus, which the fungus mobilises, they also directly increase soil fertility and quality. Because of a number of intricate relationships between the fungus and the plant, AMF is necessary for the robust growth of host plants even in adverse environmental conditions (Chakraborty, 2019b).

These interactions promote improved water absorption, increased gas exchange, and higher rates of photosynthesis, all of which contribute to the general health of the plants. Serological formats have been created for the identification of two prominent AMF (*Glomus* sp. and *Gigaspora* sp.) from soil and plant roots, and the diversity of AMF association with roots of *Citrus* spp. (Allay et.al., 2021), Tea, Arecanut, Coffee, and Rubber (Fig. 3) has been investigated. One strategy to improve the nutritional status of both partners is the successful creation of a mutualistic connection between plants and AMF. In agriculture, the host crop's reliance on mycorrhizal colonisation, the tillage system, fertiliser input, and the potential of the mycorrhizal fungus inoculum can all have an impact on plant response and benefits from mycorrhizae.

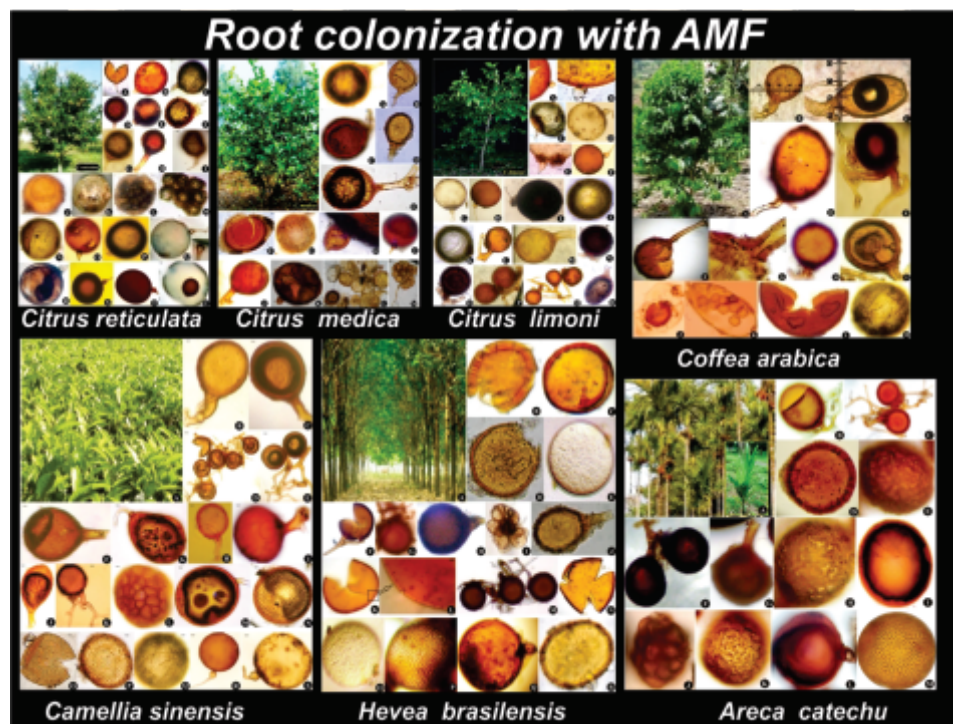


Fig.3 . Root colonization of plantation crops with arbuscular mycorrhizal fungi (AMF)

Biocontrol Agents (BCA)

Trichoderma spp., a filamentous ascomycetous fungus that has been thoroughly studied as a biocontrol agent against significant phytopathogens (Sharma and Sharma, 2020). *T. virens*, *T. harzianum*, *T. asperellum*, *T. viride*, *T. atroviride*, *T. erinacium*, and *T. reesei* are some of the commercially important species among them. They are a common mycoflora that has taken over several soils in all agroclimatic zones and habitats. These species are widely known for their ability to colonise cellulosic materials and for creating systemic resistance in the rhizosphere of plants against plant diseases. These fungi are identified by their quick growth, bright green conidia, and usually branching conidiophores.

Because of their potent antagonistic and mycoparasitic properties, some strains of *Trichoderma* have the ability to inhibit plant pathogens, mainly those located in the soil or on plant roots, hence reducing the severity of plant diseases. By creating either localised or induced systemic resistance in bacteria, fungi, oomycetes, and even viral illnesses, they do control a wide range of plant pathogens. They have antagonistic qualities against soilborne and foliar fungal plant diseases, such as basidiomycetes, deuteromycetes, and ascomycetes.

They are widely acknowledged as effective biocontrol agents due to their high rate of reproduction, ability to withstand extremely harsh conditions, efficiency in utilising nutrients, ability to modify the rhizosphere, robust aggressiveness against plant pathogens, and effectiveness in promoting plant

growth. *Trichoderma* flourishes in the rhizosphere and fosters the growth of positive interactions with plants because fungal prey and nutrients from roots are readily available. Furthermore, it has been shown that some rhizosphere-competent *Trichoderma* strains directly impact plants, increasing their ability to grow and absorb nutrients, as well as their fertiliser utilisation efficiency, the percentage and rate of seed germination, and the activation of their defence mechanisms against biotic and abiotic stresses.

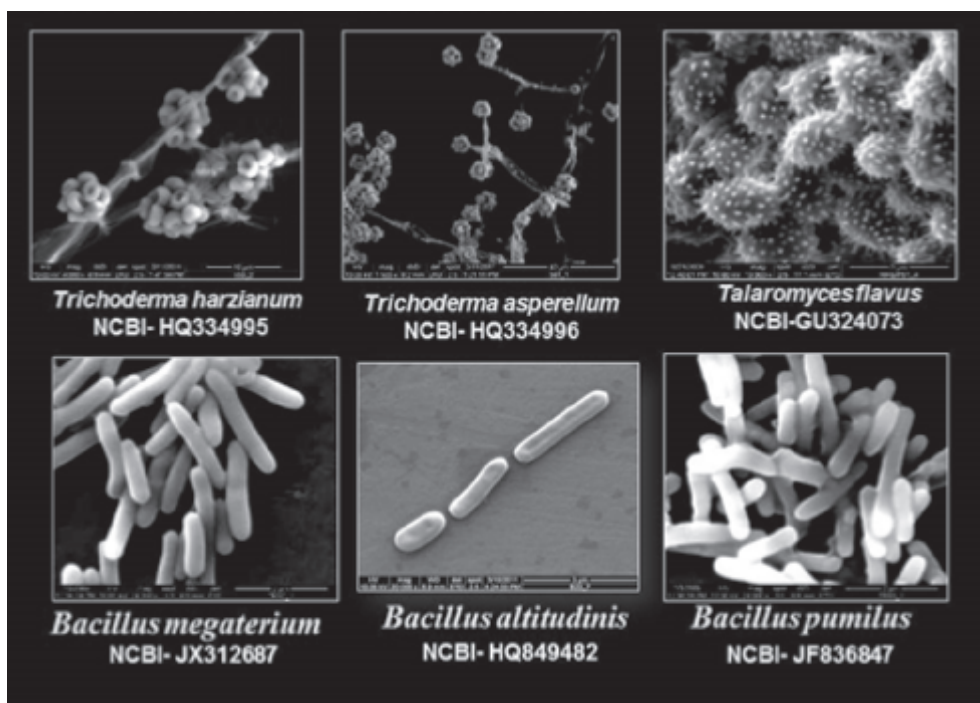


Fig.4. Potential PGPF and PGPR from microbial resources of North Bengal selected for biocontrol of root diseases

Plant Growth-Promoting Rhizobacteria (PGPR)

Numerous helpful, free-living bacteria that support the development of plant roots can be found in the rhizospheric zone. Rhizobacteria that promote plant growth include *Pseudomonas*, *Rhizobium*, *Bacillus*, and *Acinetobacter*. These bacteria are vital because they generate growth regulators and phosphorus solubilizers that increase an organism's resistance to biotic and abiotic stress. PGPR not only functions as a bio-control agent but also encourages rhizoremediation, boosts fertiliser effectiveness, and effectively controls phytopathogens (Chakraborty *et.al.*, 2014a). Researchers have discovered that PGPRs can shield seedlings from bacterial inoculation, especially from diseases spread through the soil. PGPR has been re evaluated as biofertilizers that require little to no extra inputs because to the growing popularity of organic farming practices (Chakraborty *et.al.*, 2014b). Biofertilizers such *Allorhizobium* species, *Pseudomonas fluorescens*, and *Rhizobium* are

advantageous to the growth and development of plants. Numerous studies conducted in both historical and contemporary contexts have provided ample evidence of the positive impacts of PGPRs on different plant systems (Table 1).

Table 1. Beneficial PGPR used in growth improvement of various crops

Crop	PGPR
Rice	<i>Bacillus megaterium</i> , <i>Aeromonas veronii</i> , <i>Enereobater cloacae</i> , <i>Rhizobium leguminosarum</i> , <i>Pseudomonas</i> sp., <i>Burkholderia</i> sp., <i>Herbaspirillum</i> sp., <i>Azospirillum</i> sp., <i>Bacillus</i> sp., <i>Paenibacillus</i> sp., <i>Brevundimonas</i> sp.
Wheat	<i>Azotobacter</i> sp., <i>Azospirillum brasilense</i> , <i>Pseudomonas fluorescens</i> , <i>Bacillus circulans</i> , <i>Cladosporium herbarum</i>
Barley	<i>Bacillus licheniformis</i> , <i>Pseudomonas putida</i> , <i>Paenibacillus polymyxa</i> , <i>Rhodobacter capsulatus</i>
Maize	<i>Bacillus megaterium</i> , <i>Azospirillum lipoferum</i> , <i>Burkholderia cepacia</i> , <i>Azospirillum brasilense</i> , <i>Azotobacter</i> sp., <i>Herbaspirillum seropedicae</i> , <i>Pseudomonas aurantiaca</i> , <i>Bacillus amyloliquefaciens</i> , <i>Microbacterium oleovorans</i>
Sorghum	<i>Bacillus cereus</i> , <i>Serratia marcescens</i>
Soybean	<i>Bradyrhizobium japonicum</i> , <i>Azotobacter chroococcum</i> , <i>Bacillus subtilis</i> , <i>Bacillus thuringiensis</i> , <i>Azospirillum brasilense</i> , <i>Pseudomonas aureofaciens</i> , <i>Serratia liquefaciens</i> , <i>Serratia proteamaculans</i>
Groundnut	<i>Pseudomonas fluorescens</i>
Chilli	<i>Bacillus simplex</i> , <i>Bacillus cereus</i>
Lettuce	<i>Agrobacterium</i> sp., <i>Alcaligenes piechaudii</i> , <i>Bacillus megaterium</i> , <i>Pseudomonas fluorescens</i>

PLANTATION CROP

There was a notable 33% increase in the promotion of *Arabidopsis* growth. In a controlled pot experiment, the introduction of *Bacillus* spp., *Pantoea agglomerans*, and *Pseudomonas taiwanensis* enhanced plant health measures and raised the production of siderophores and IAA (indole-3-acetic

acid). The number of beneficial bacteria in the soil, plant health indices, and maize crop production could all be raised by using *Bacillus* species as a bioinoculant. PGPRs release signal molecules during infection that are crucial for encouraging plant growth. Beneficial microorganisms are drawn to these signal molecules, promoting plant growth.

The rhizosphere had higher concentrations of malic acid, which served as a signal to attract helpful *Bacillus subtilis* and promote the development of biofilms on *Arabidopsis* roots. PGPRs have the ability to initiate a broad-spectrum resistance response against pathogenic microorganisms. Two examples of antibiotic metabolites that are known to be produced by a range of bacterial species are iturin A and surfactin. These compounds function as antiseptics for plant roots, successfully warding off dangerous germs and fungi. PGPR has been demonstrated to affect soil security, enhance crop growth, development, yield, and quality by directly synthesising hormones, antibiotics, and other secondary metabolites; increase nutrient availability by solubilising phosphate and potassium; and induce tolerance to biotic and abiotic stresses by controlling plant-related gene expressions.

INDUCTION OF IMMUNITY AGAINST BIOTIC STRESSES IN THE HOST

The resistance mechanism that plants have that can be activated and used to treat diseases is known as induced resistance. The identification of microbial compounds by plants is the first stage in the establishment of immunity in plants. These molecules are then transduced through a number of channels that result in reactions, which in turn activate defence mechanisms that suppress the bacteria. Chemical or biological elicitors can help plants establish this immunity, which keeps them prepared to withstand pest and disease attacks in the future. This primed state is characterised by heightened defence reactions when a disease strikes. A plant will usually react defensively to an elicitor, also called a pathogen-associated molecular pattern (PAMP), such as lipopolysaccharides, peptidoglycan, β -glucans, chitin, or flagellin, by strengthening its cell walls, increasing the quantity of PR proteins it accumulates, and biosynthesising phytoalexin. Resistance proteins and pathogen recognition receptors (PRRs), which are involved in pathogen detection, are two more receptors present in plants.

As NB-LRR (nucleotide binding leucine rich repeat) proteins, most R proteins interact with pathogen effector proteins. Higher levels of induced immunity against a greater variety of diseases are found in plant sections that show induced systemic resistance (ISR). The type of interaction and proteins involved often dictate which particular defence pathway needs to be activated. By regulating an intricate network of interconnected signalling channels, plant hormones produce induced resistance. It is believed that phytohormones like SA and JA play a significant role in regulating signalling during plant defence. Systemic acquired resistance (SAR) has drawn a lot of attention in research employing all available cutting-edge approaches because of SA's enormous potential. For SAR to be used in crop protection, it must be able to be activated by spraying SA or its synthetic functional counterparts, such as 1,2,3-benzothiadiazole-7-carbothioic acid S-methyl ester

(BTH) or bioinoculants, even in the absence of pathogens.

One of the key elements of SAR is the induction of PR proteins in plants, such as chitinases, glucanases, and the antifungal protein osmotin, which have antipathogen activity and may break down fungal cell walls, lysozymal activity, which suggests antibacterial functions, and nuclease activity that is effective against pathogens. Hundreds of genes express themselves differently or more frequently when SAR develops, according to microarray studies. The production of ROS and the fortification of cell walls are two important effects of these altered gene expressions. JA and ethylene are the primary regulators of ISR, whereas SAR is known to induce broad-spectrum resistance in plant tissues above ground in response to non-pathogenic microorganisms that might promote development. However, signals from SA and JA often overlap with signals from other plant hormones, including as auxin, ethylene, gibberellins, and abscisic acid (ABA). Because microorganisms have the ability to develop systemic resistance and promote development, their use in agriculture can lessen the need for harmful pesticides.

Trichoderma spp. have been used for the biocontrol of plant diseases; consequently, they have been the subject of much research, leading to the development of commercial products and bioformulations of *T. Harzianum*, *T. asperellum*, *T. viride*, *T. virens* that are currently offered for sale all over the world. According to Chakraborty *et al.* (2020), aureoviride is employed as a microbial inducer of plant immunity. *Trichoderma* produces Sm1/Ep11, an immunity-inducing protein of the cerato-platanin family, an elicitor that raises the expression of defense-related genes, hence eliciting immunity.

Plant immunity induction against phytopathogens has been associated with elicitors/MAMPs produced by *Trichoderma* spp. Other variables include increased activity of enzymes such as lipoxygenase (LOX), phenylalanine ammonia lyase (PAL), peroxidase (POX), and polyphenol oxidase (PPO), in addition to the accumulation of phytoalexins and terpenoids. According to Chakraborty (2020), crop protection is thus accomplished by inducing resistance as a result of the activation of a variety of defence mechanisms. *Acinetobacter*, *Arthrobacter*, *Bacillus*, *Burkholderia*, *Enterobacter*, *Ochrobactrum*, *Paenibacillus*, and *Pseudomonas* are just a few of the PGPR genera that have been shown to cause systemic resistance in plants, along with a number of helpful fungi, including mycorrhiza like *Rhizophagus* and *Gigaspora* (Chakraborty and Allay, 2022). The fact that the defence reactions are visible in the shoots as well as the roots has demonstrated that AMF induces systemic resistance.

The synthesis of defence enzymes including chitinases, proteases, glucanases, and antifungal substances is one of the roles of defence genes. Numerous genes from several *Trichoderma* species, including *chit 3* and *chit 42* from *T. asperellum*; *chit 42*, *chit 3*, *exc1*, *exc 2*, *bgn 13.1*, *prb1*, *ThPG1*, and *Th-Chit 42* from *T. harzianum* as well as *T. virens*' *stac1*, *tvsp1*, *TgaA*, and *TgaB*. The majority of these *Trichoderma* sp. combat soil pathogens like *Pythium ultimum*, *Fusarium oxysporum*, *Rhizoctonia solani*, and *Sclerotinia sclerotiorum*. *Thkel1*, a gene from *T. harzianum*, may control

glucosidase activity of *Arabidopsis thaliana* in response to salt and osmotic stress. Microbe-associated molecular patterns (MAMPs), also known as elicitors, set off a signalling cascade in the plant that includes gaseous signalling molecules including ethylene (ET), salicylic acid (SA), and jasmonate (JA). One of the numerous defence reactions brought on by *Trichoderma* sp. and PGPR is the increased accumulation of PR proteins downstream of the signalling by these molecules.

Bacillus megaterium was used to induce systemic resistance in tea plants against *Sclerotium rolfsii* (Chakraborty *et al.*, 2015). Additionally, Chakraborty *et al.* (2016a) showed that applying bioinoculants could trigger defence mechanisms in the som plant (*Persea bombycina*) against the leaf blight disease caused by *Colletotrichum gloeosporoides*. In addition to promoting plant growth, bacterial endophytes have been shown to cause systemic resistance in plants by activating defence enzymes like chitinase, β 1-3 glucanase, PAL, POX, and PPO (Jacob *et al.*, 2020). Although the various PGPR have many advantageous characteristics, they need to have rhizospheric competence and be able to interact with other microorganisms in a steady way in order to live and colonise in the rhizosphere.

The fact that the defence reactions are visible in the shoots as well as the roots has demonstrated the systemic induction of resistance by AMF. As an illustration, consider how AMF causes tomatoes to develop systemic resistance against the foliar necrotrophic disease *Botrytis cinerea*. Mycorrhizal leaves had comparatively less pathogen than non-mycorrhizal leaves, indicating that the pathogen's ability to spread into leaves was similarly hindered. However, the leaves of infected, AMF-colonized plants showed significantly increased expression of several defence genes, particularly those of the JA pathway (Pozo *et al.* 2010).

According to Campos-Soriano *et al.* (2012), AMF-induced resistance in rice against *Magnaporthe grisea*, the blast-causing organism, depends on both increased expression of defence effector genes during pathogen attack and the activation of genes involved in regulatory roles during host immunity. It's interesting to note that, in addition to the systemic resistance caused by AMF in aboveground sections, the induction was also visible in nearby plants. This is likely because the AMF hyphal network can transmit signals over great distances and function as a plant-to-plant communication system.

Utilising bioinoculants like AMF (*Rhizophagus fasciculatus*) and PGPR (*Bacillus pumilus*) has shown biopriming of the plants in field tests, as evidenced by growth promotion, systemic resistance induction, and other pathways. signals that Changes like callose induction, lignification, and PR accumulation are examples of ISR operations. proteins or, occasionally, certain phenolic chemicals. Fungal colonisation of AM causes in some plants, lignification entails thickening the cortical root cell and exodermis. walls that make it challenging for infections to enter. Thus it is clear that immunity is induced in different plants against phytopathogens by bioinoculants (BCA, AMF and PGPR) (Chakraborty

et al. 2014a; 2016c)

Following the induction of resistance against *Bipolaris sorokiniana* using bioinoculants (*Bacillus methylotrophicus* and *Trichoderma asperellum*), transmission electron micrographs of wheat leaves probed with PAb of chitinase and labelled with gold conjugate revealed the distribution of intense gold particles throughout the cell structure (Fig. 5A). When bioinoculants developed resistance against the spot blotch pathogen, increased activity of defence enzymes (Chitinase and 1-3 glucanase) was also noted. Fusarium root rot disease may be prevented by treating mandarin roots with both *Trichoderma harzianum* and *Glomus mosseae*. In a similar vein, the entire plant developed immunity when *Gigaspora gigantea* colonised mandarin roots and were treated with a BCA (*T. asperellum*) and PGPR (*Pseudomonas poae*). Heavy deposition of gold particles near the cell wall of the inoculated roots were evident (Fig 5B), when probed with PAb of chitinase and labeled with gold conjugate. Development of induced immunity against *Fusarium solani* after treatment with bioinoculants was indicated by enhancement of chitinase not only in roots but also in epidermal cells and mesophyll tissues of leaves.

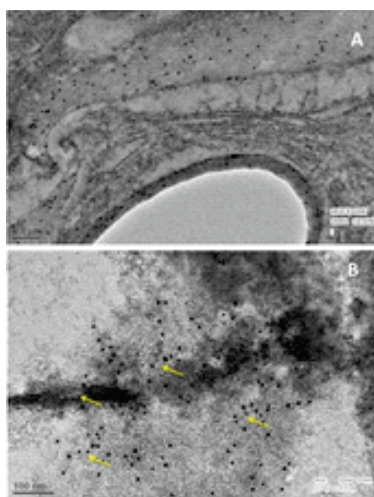


Fig.5. Transmission electron microscopy of (A)Wheat leaf, (B)Mandarin root probed with PAb of chitinase labeled with gold conjugates following application of bioinoculants and challenge inoculation with pathogen(s).

Thus, disease suppression and improvement of health status in mandarin plants have been correlated with inhibition of the pathogen (*F.solani*) directly in the soil, increased availability of nutrients and immunity developed in the host (Chakraborty *et al.* 2019). Besides interactions among the microorganisms, environmental factors such as extreme weather changes, soil characteristics or other such factors also may affect the growth and functioning of the PGPR. Defense responses are not directly activated by PGPR and other beneficial microorganisms, but the whole plant becomes primed for a faster and stronger response to pathogen attack when the defense responses become activated.

ALLEVIATION OF ABIOTIC STRESSES IN PLANTS

Numerous abiotic stresses, such as high temperatures, droughts, flooding, salt, heavy metals, insufficient soil nutrition, acidity, and more, naturally impact crops. Soil moisture is commonly recognised as the main factor limiting agricultural productivity. Since freshwater resources become less abundant and of lower quality, drought is the main abiotic stressor impacting crop productivity. This is particularly true in developing countries with inadequate irrigation infrastructure. The availability and transport of soil nutrients are similarly impacted by water constraint. Water scarcity also affects the diffusion of nutrients in the soil over short distances because water carries the nutrients to the roots. Drought stress is known to change the balance of plant hormones by lowering endogenous cytokinin levels and raising ABA levels in the leaves, which causes stomatal closure. A plant's metabolic processes are impacted by a variety of stresses, which reduces crop health and, ultimately, yield.

Changing crop schedules, creating drought and heat-tolerant cultivars, altering resource management techniques, and creating stress-tolerant plants by modifying stress-tolerant genes are some methods to deal with abiotic pressures. Besides microorganisms, notably PGPR for development of tolerance to abiotic stressors have been studied (Chakraborty and Chakraborty, 2022). These PGPR may cause chemical and physical changes in the organism, which may lead to systemic tolerance to different abiotic stressors. One of the most cost-effective sustainable agricultural approaches for enhancing plants' tolerance to many stresses is seed priming. This method encourages specific biochemical changes in response to stress events by hydrating seeds with specific chemicals (chemical priming), biotic stimuli (bio priming), or abiotic stimuli. These alterations turn into "stress memory" and operate as a signal to better successfully handle specific stressors. Water stress can alter the soil's structure, making it unsuitable for crop development and microbiological activity. However, some PGPR can produce exopolysaccharides (EPS) that protect soil microorganisms from hostile conditions and aid in their survival. By binding the bacteria to the root surface with a network of fibrillar material, they also aid in the irreversible adhesion and colonisation of microorganisms on the roots.

Biopriming with PGPR from the genera *Rhizobium*, *Bacillus*, *Burkholderia*, *Ochrobactrum*, *Paenibacillus*, and *Pseudomonas* has been found to promote plant growth and abiotic stress tolerance in a range of crops. Apart from biopriming, the use of PGPR as a soil drench has shown excellent results in lowering abiotic stresses. Numerous agricultural plants under stress from salinity, water, and temperature have been demonstrated to benefit from PGPR. Although it is well known that PGPR can shield plants from stress, the precise processes by which they increase tolerance are still mostly unknown. The following are some potential explanations: (i) ACC deaminase production, which lowers ET levels in developing plants' roots; (ii) phytohormone production; (iii) bacterial-induced systemic tolerance (IST); and (iv) bacterial biofilm formation, or

extracellular matrix Sugars, oligo- and polysaccharides, and other macromolecules that are beneficial to plant growth and development are found in the bacterial biofilm that makes up the extracellular matrix. The EPS-producing *Pseudomonas putida* strain GAP-P45 forms biofilm on sunflower seedlings' root surfaces, protecting the plants from dry stress. Additionally, it has been shown that, in most cases, tolerance seems to result from a sequence of reactions that comprised the buildup of phenolics and osmolytes, an enhancement of the antioxidative response, and high transcript levels of stress-responsive genes during stressful times. In addition to raising RWC and boosting antioxidant responses, studies using *Bacillus safensis* showed that this PGPR might increase wheat plants' height, yield, and chlorophyll content. In addition to expressing a range of redox enzymes and accumulating osmolytes, which enhanced overall thermotolerance, *B.safensis* might lessen heat stress in wheat plants (Sarkar *et al.*, 2018), which was connected to decreased ROS production and membrane damage. Because they accumulate osmolytes, preserve membrane stability by preventing lipid peroxidation, and improve antioxidant activity, *Ochrobactrum pseudogregnonense* and *B. safensis* can also promote growth and lessen the impacts of salt and drought (Chakraborty *et.al.*, 2019b; Sarkar *et al.*, 2021)

WAY FORWARD

Increasing crop yields while using fewer pesticides and fertilisers is the primary objective facing agricultural scientists worldwide. The importance of the root microbiome in this context cannot be overstated because it is clear that plants have evolved in the natural world alongside complex microbial communities that are essential to the fulfilment of plant functions including growth, vigour, and defence. A comprehensive understanding of the complex and dynamic interactions occurring at the microbial community level is essential in light of modern techniques such as next-generation sequencing-based root microbiome research. If the basic ideas behind the formation of binary plant-microbe and microbe-microbe interactions are thoroughly understood, then this is feasible. Increasing crop stress tolerance, yield, and reducing pesticide input in a sustainable and eco-friendly way requires an understanding of root microbiome processes. However, efforts to enhance these characteristics of the plant's second genome—provided by the microbiome—have not received much attention from plant development programs. The continued advancement of our understanding of the molecular and genetic basis of plant-beneficial microbe communication in the context of its evolutionary and ecological relevance will enable the development of sustainable future crops that are better able to maximise the protective and beneficial functions from beneficial microbes in their root microbiome.

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High Altitude, Vitamin D, and Health

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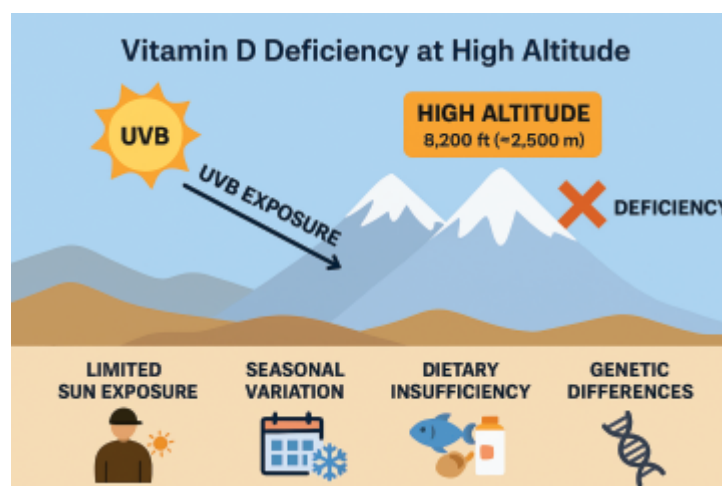
ABSTRACT

Vitamin D is a fat-soluble vitamin essential for calcium homeostasis, bone health, immune function, and overall metabolic regulation. High-altitude environments, characterized by increased ultraviolet B (UVB) radiation due to thinner atmospheric layers, provide a unique context for vitamin D synthesis. Despite higher UVB exposure, vitamin D deficiency remains prevalent among high-altitude populations due to factors such as limited sun exposure, seasonal variation, dietary insufficiency, and genetic differences. This review synthesizes current literature on the relationship between high-altitude living, vitamin D status, and associated health outcomes, highlighting the need for targeted interventions, dietary supplementation, and public health strategies to maintain optimal vitamin D levels in these populations.

Keywords: Vitamin D, High altitude, UVB radiation, Deficiency, Health outcomes, Supplementation

INTRODUCTION

Vitamin D is a fat-soluble secosteroid hormone crucial for multiple physiological processes, including calcium and phosphorus homeostasis, bone mineralization, immune modulation, and metabolic regulation [1]. It exists in two main forms: vitamin D3 (cholecalciferol), synthesized in the skin via ultraviolet B (UVB) radiation, and vitamin D2 (ergocalciferol), obtained primarily from plant sources and fortified foods. Once produced or ingested, vitamin D undergoes hydroxylation in the liver to form 25-hydroxyvitamin D [25(OH)D], the primary circulating biomarker of vitamin D status, and further hydroxylation in the kidney to produce its active form, 1,25-dihydroxyvitamin D [1,25(OH) $\square$ D] [1,3].



High-altitude environments, typically defined as regions located above 2,500 meters above sea level, present unique ecological and physiological conditions. One of the defining characteristics of high-altitude living is the increased intensity of UVB radiation due to thinner atmospheric layers, which theoretically enhances cutaneous vitamin D synthesis [2]. UVB intensity rises by approximately 10–12% for every 1,000 meters of elevation gain, suggesting that populations residing in these regions could potentially have higher vitamin D levels compared to low-altitude counterparts [2,11].

Despite this theoretical advantage, epidemiological evidence demonstrates that vitamin D deficiency is surprisingly prevalent among high-altitude populations. Several studies have documented suboptimal 25(OH)D concentrations in Andean, Tibetan, and high-altitude Middle Eastern populations, with deficiency rates often exceeding 40–50% [4,5,13]. This paradox arises from multiple intersecting factors: limited sun exposure due to cultural clothing norms or indoor lifestyles, seasonal variations reducing UVB availability, dietary insufficiencies, and genetic polymorphisms affecting vitamin D metabolism and receptor function [3-5,12,14].

Vitamin D deficiency has far-reaching health implications. Skeletal disorders, including rickets in children, osteomalacia, and osteoporosis in adults, are well-documented consequences. Beyond skeletal health, deficiency is associated with impaired immune function, increased susceptibility to respiratory infections, adverse reproductive outcomes such as preeclampsia and low birth weight, and cardiometabolic disturbances including hypertension, diabetes, and dyslipidemia [1,6-10]. For high-altitude populations, these risks may be compounded by hypoxia and environmental stressors, further emphasizing the need to understand vitamin D dynamics in these unique settings.

The aim of this review is to synthesize current knowledge on the relationship between high-altitude living, vitamin D status, and associated health outcomes. By integrating findings from observational and interventional studies, this review highlights the environmental, behavioral, dietary, and genetic factors influencing vitamin D status at high altitudes and identifies strategies to mitigate deficiency. Understanding these factors is critical for developing targeted public health interventions, dietary supplementation programs, and educational strategies to improve health outcomes in high-altitude populations.

METHODS

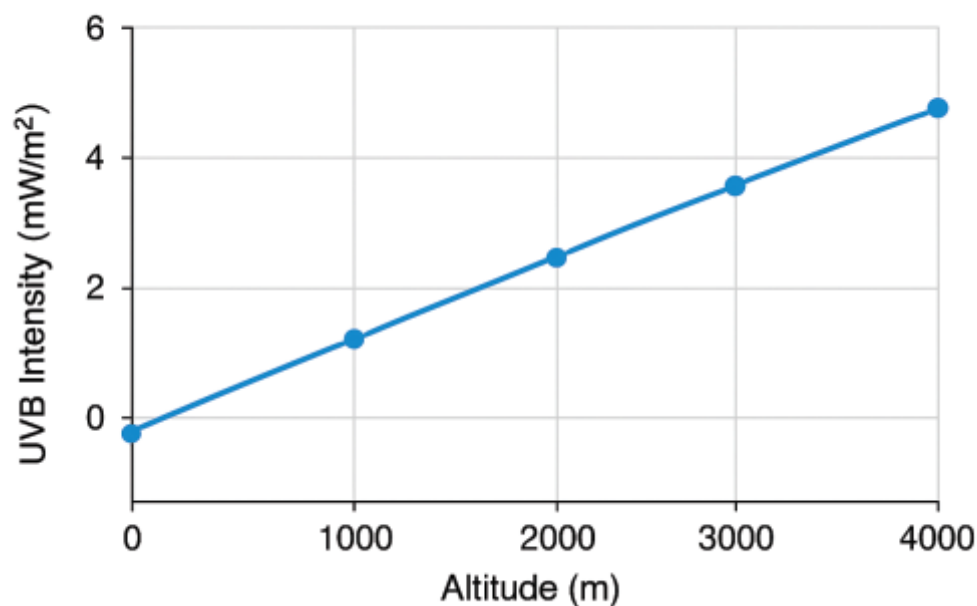
This review is based on a comprehensive literature search using PubMed, Scopus, and Web of Science databases, focusing on studies from 1980 to 2025. Search terms included: “high altitude,” “vitamin D,” “UVB radiation,” “deficiency,” and “health outcomes.” Both observational and interventional studies reporting vitamin D status, synthesis, and health effects in high-altitude populations were included. Data extraction focused on serum 25-hydroxyvitamin D (25(OH)D) levels, prevalence of deficiency, contributing factors, and associated health outcomes.

RESULTS

UVB Radiation and Vitamin D Synthesis:

High-altitude regions are characterized by thinner atmospheric layers, resulting in elevated ultraviolet B (UVB) radiation reaching the surface. UVB intensity increases by approximately 10–12% for every 1,000 meters of altitude gain, theoretically enhancing cutaneous synthesis of vitamin D₃ [2,11]. Studies also indicate that UVB exposure at high altitudes may be more effective than at low altitudes due to less scattering of sunlight by atmospheric particles. However, several factors modulate this effect. Latitude, season, and solar angle significantly influence UVB availability, with high-latitude high-altitude regions receiving less effective UVB in winter months [12]. Skin pigmentation is another crucial determinant; individuals with darker skin require longer UVB exposure to produce comparable vitamin D levels to lighter-skinned individuals [3,12]. Clothing habits and cultural practices that limit skin exposure further reduce effective synthesis despite high ambient UVB levels.

Figure 1. UVB Radiation and Vitamin D Synthesis at High Altitudes



PREVALENCE OF VITAMIN D DEFICIENCY

Despite theoretically favorable conditions for vitamin D synthesis, deficiency remains common among high-altitude populations. For example, studies among Andean populations (~3,600 m) showed mean serum 25-hydroxyvitamin D [25(OH)D] levels of 18–22 ng/mL, significantly lower than comparable low-altitude populations, with 45–60% of individuals classified as deficient (<20 ng/mL) [4]. Similarly, research in high-altitude regions of Saudi Arabia indicated a 41.8% prevalence of deficiency, disproportionately affecting males and younger adults [5]. Tibetan children residing at altitudes above 3,500 m also exhibited vitamin D deficiency rates exceeding

50%, suggesting early-life exposure to high-altitude environments may not confer protection [13,14]. These findings collectively indicate that high UVB exposure alone is insufficient to prevent deficiency.

FACTORS CONTRIBUTING TO DEFICIENCY

- **Limited Sun Exposure:** Cultural practices, indoor occupations, and clothing that covers most of the skin significantly limit UVB-mediated vitamin D production. Even in areas with high UVB intensity, these behavioral factors can result in low circulating 25(OH)D levels [1,3].
- **Seasonal Variation:** High-altitude regions frequently experience long winters and low solar angles, particularly at high latitudes, reducing the window for effective cutaneous synthesis. Studies demonstrate seasonal fluctuations in serum 25(OH)D, with levels declining by 20–30% during winter months [2,12].
- **Dietary Insufficiency:** Traditional high-altitude diets often rely on cereals, tubers, and limited animal products, providing inadequate vitamin D. Intake of fatty fish, fortified dairy products, and eggs is often low, contributing to deficiency, particularly in children and women of reproductive age [5,13].
- **Genetic Influences:** Genetic polymorphisms in the vitamin D receptor (VDR), enzymes responsible for hydroxylation, and transport proteins influence individual vitamin D status. These variations may partially explain observed differences in 25(OH)D levels among populations at similar altitudes [4,14].

HEALTH IMPLICATIONS

- **Skeletal Health:** Deficiency is strongly associated with rickets in children, osteomalacia, and reduced bone mineral density in adults. Long-term deficiency contributes to osteoporosis and increased fracture risk [3,6].
- **Immune Function:** Low vitamin D levels correlate with impaired innate and adaptive immunity, leading to increased susceptibility to respiratory infections and potentially affecting responses to viral outbreaks in high-altitude regions [1,7].
- **Reproductive Health:** Maternal deficiency is linked to preeclampsia, low birth weight, and adverse neonatal outcomes. High-altitude pregnancies are particularly vulnerable due to compounded effects of hypoxia and vitamin D insufficiency [4,9].
- **Cardiometabolic Health:** Epidemiological studies suggest associations between low vitamin D levels and increased incidence of hypertension, type 2 diabetes, and dyslipidemia in high-altitude populations [6,10].

SUMMARY OF FINDINGS

Overall, the results indicate that despite increased UVB exposure at high altitudes, vitamin D deficiency is widespread due to a combination of environmental, behavioral, dietary, and genetic factors. The prevalence of deficiency is particularly high among children, women, and certain ethnic groups, underscoring the need for targeted interventions to mitigate health risks associated with inadequate vitamin D status.

DISCUSSION

The relationship between high-altitude living and vitamin D status presents a complex paradox. While high-altitude environments theoretically favor cutaneous vitamin D synthesis due to elevated ultraviolet B (UVB) radiation, empirical evidence demonstrates a persistent prevalence of vitamin D deficiency among these populations. This paradox highlights the multifactorial determinants of vitamin D status, including environmental, behavioral, genetic, and socioeconomic factors.

ENVIRONMENTAL AND BEHAVIORAL INFLUENCES

Despite increased UVB exposure, effective cutaneous vitamin D synthesis is often limited by behavioral factors such as clothing that covers most of the skin, indoor lifestyles, and cultural practices that reduce sun exposure. Seasonal variation further compounds this issue, as high-altitude regions typically experience long winters, reduced solar angles, and shorter daylight hours, limiting the potential for UVB-mediated vitamin D synthesis [2,12]. Additionally, environmental pollutants, including dust and particulate matter, can attenuate UVB penetration, further reducing vitamin D production [11].

DIETARY AND NUTRITIONAL CONSIDERATIONS

Dietary intake plays a critical role in maintaining adequate vitamin D levels, particularly when endogenous synthesis is insufficient. High-altitude populations often rely on traditional diets that may lack sufficient vitamin D sources, such as fatty fish, fortified dairy products, or eggs [5,13]. Seasonal availability of certain foods, economic constraints, and limited food fortification programs further exacerbate nutritional insufficiency. Interventions that promote vitamin D-rich diets or fortification strategies are therefore essential, particularly in vulnerable groups such as children, pregnant women, and the elderly.

GENETIC AND ETHNIC FACTORS

Genetic variations in vitamin D metabolism and receptor genes significantly influence individual susceptibility to deficiency. Polymorphisms in the vitamin D receptor (VDR) and enzymes involved in hydroxylation can affect serum 25(OH)D levels and bioavailability, resulting in differential responses to UVB exposure and dietary intake [4,14]. Such genetic heterogeneity underscores the importance of tailored interventions that account for ethnicity and individual metabolic profiles when addressing vitamin D insufficiency in high-altitude populations.

HEALTH IMPLICATIONS

The consequences of vitamin D deficiency are broad and multifaceted. Skeletal disorders, including rickets, osteomalacia, and osteoporosis, remain critical public health concerns, particularly in regions with high prevalence of deficiency [3,6]. Moreover, emerging evidence highlights the role of vitamin D in immune modulation, with deficiency linked to increased susceptibility to respiratory infections, including viral pathogens that may pose heightened risk in high-altitude environments [7]. Reproductive outcomes are also adversely affected, with low maternal vitamin D levels associated with preeclampsia, gestational diabetes, and low birth weight [4,9]. Cardiometabolic health is similarly influenced, as deficiency correlates with increased risk of

hypertension, diabetes, and dyslipidemia [6,10].

PUBLIC HEALTH AND INTERVENTION STRATEGIES

Addressing vitamin D deficiency in high-altitude populations requires a multi-pronged approach. Public health strategies should combine dietary supplementation, fortification programs, education on safe sun exposure, and targeted interventions for high-risk groups. Seasonal supplementation during winter months and for populations with limited outdoor activity may be particularly effective. Furthermore, integrating genetic screening for polymorphisms affecting vitamin D metabolism could enhance the precision of interventions, allowing for individualized supplementation strategies.

RESEARCH GAPS AND FUTURE DIRECTIONS

Despite extensive research, significant gaps remain in understanding the interplay between altitude, UVB exposure, and vitamin D metabolism. Longitudinal studies examining seasonal fluctuations, lifestyle behaviors, and genetic factors are needed to delineate causal relationships. Additionally, clinical trials assessing the efficacy of various supplementation strategies — including dosage, frequency, and formulations — can inform guidelines for optimizing vitamin D status in high-altitude populations. Investigating the role of vitamin D in immune resilience, metabolic regulation, and reproductive health in these regions also represents an important research frontier.

In summary, high-altitude living presents a unique challenge for maintaining adequate vitamin D levels. The paradox of deficiency despite increased UVB exposure highlights the need for integrated, context-specific public health strategies. Combining dietary, behavioral, and genetic considerations offers the most promising approach to improving health outcomes and reducing the burden of vitamin D-related disorders in high-altitude populations.

CONCLUSION

High-altitude living presents a unique challenge for maintaining optimal vitamin D levels. Despite higher UVB radiation, deficiency remains prevalent due to limited sun exposure, dietary inadequacy, seasonal variations, and genetic factors. Addressing vitamin D deficiency in these populations requires integrated strategies including supplementation, dietary improvements, and lifestyle modifications. By implementing such measures, the health outcomes of high-altitude populations can be improved, reducing the burden of skeletal, immune, and cardiometabolic disorders.

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Left or Right – Which Way to Go? The Science of Chiral Separation

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ABSTRACT

Electronic Chirality is a fundamental concept in chemistry and biology, describing molecules that are non-superimposable on their mirror images. One individual molecule of the pairs of molecules that are mirror images of each other but cannot be superimposed is called enantiomer. These enantiomers, while sharing identical physicochemical properties in achiral environments, often display vastly different biological and pharmacological activities. The ability to separate and produce enantiomerically pure compounds is therefore critical in pharmaceuticals, agrochemicals, and materials science. This article discusses the scientific basis and importance of chiral separation, emphasizing chromatographic and non-chromatographic techniques, industrial applications, and emerging trends. Particular attention is given to High-Performance Liquid Chromatography (HPLC), Supercritical Fluid Chromatography (SFC), crystallization, and enzymatic resolution. Current challenges such as cost, scalability, and racemization are outlined, along with future directions involving nanomaterials, automation, and sustainable approaches.

Keywords: *Chirality, Chiral separation, Chromatography, HPLC, Pharmaceuticals.*

INTRODUCTION

Chirality, derived from the Greek word 'cheir' meaning “hand,” describes the geometric property of a molecule that makes it non-superimposable on its mirror image. Molecules exhibiting this property are called enantiomers, a subclass of stereoisomers that share the same molecular formula and connectivity but differ in the three-dimensional arrangement of their atoms.

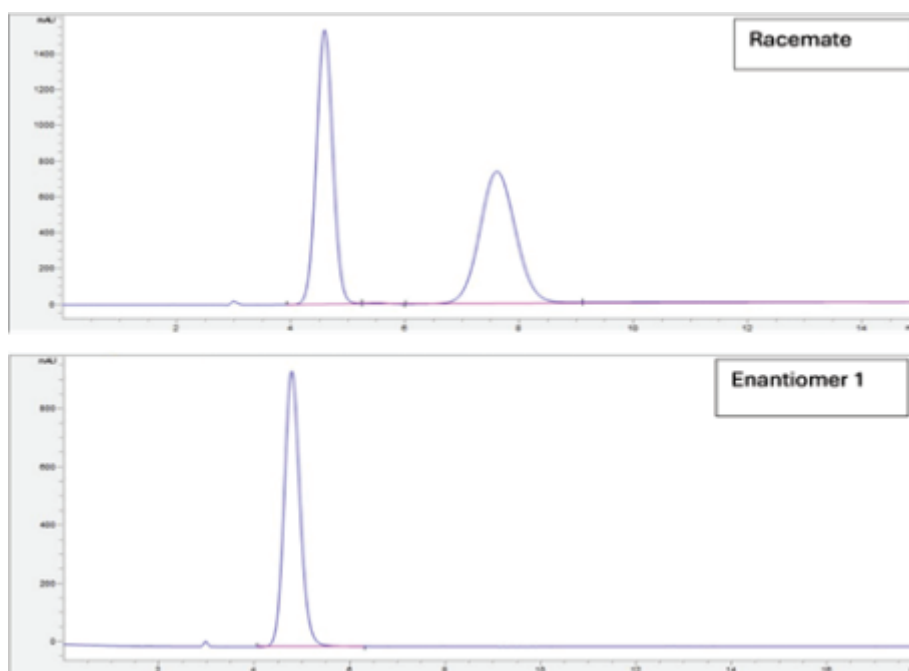
The concept was first introduced¹ by Louis Pasteur in 1848 when he manually separated the two mirror-image forms of sodium ammonium tartrate, marking the first experimental demonstration of molecular asymmetry. Over time, the importance of chirality has been recognized across multiple disciplines, particularly in biological systems and in pharmaceutical, agricultural, and industrial chemistry.

Chirality is an intrinsic feature of many naturally occurring biomolecules — including proteins, enzymes, amino acids, carbohydrates, nucleosides, alkaloids, and hormones — which typically exist in a single enantiomeric form. For example, natural amino acids occur exclusively as L-isomers (levorotatory), while natural sugars are D-isomers (dextrorotatory).

In the pharmaceutical sector, roughly 56% of marketed drugs are chiral, and about 88% of these are still sold as racemic mixtures, containing equal amounts of both enantiomers.² Although enantiomers share identical chemical compositions, they often display significant differences in pharmacological activity, toxicity, metabolism, and pharmacokinetics, owing to stereoselective interactions with biological targets.

In achiral environments, enantiomers exhibit identical physicochemical properties, such as melting point, solubility, and refractive index. However, within chiral biological environments, they interact differently, resulting in distinct pharmacological effects. A classic example is thalidomide, where one enantiomer possessed therapeutic benefits while the other caused severe teratogenicity. Even when an “inactive” enantiomer is not harmful, it can reduce overall drug potency³. Consequently, regulatory bodies such as the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMA) now mandate the evaluation or isolation of individual enantiomers to ensure safety and efficacy.

The separation of enantiomers is particularly challenging because of their nearly identical physical and chemical characteristics. Successful chiral resolution relies on exploiting subtle differences in chiral recognition through techniques such as chromatography, selective complexation, or chemical derivatization. As a result, chiral separation science, spanning both analytical and preparative scales, plays a pivotal role in pharmaceutical research, agrochemical development, and materials science. Figure 1 below shows representative chromatograms of the separation of a racemate into individual enantiomers, using a DAICEL CHIRALPAK® IG (4.6 mm ID × 25 cm L, 20µm particle size) chiral column.



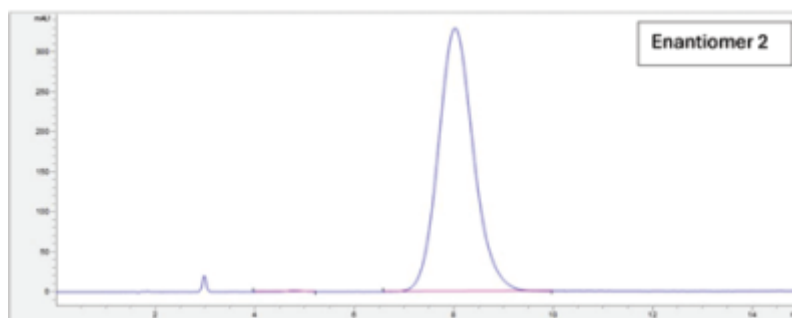


Figure 1: Separation of a racemate into individual enantiomers

METHODS AND EXPERIMENTAL OUTLINE

2. PRINCIPLES AND TECHNIQUES OF CHIRAL SEPARATION

2.1 Chromatographic Methods

Chromatographic methods remain the cornerstone of chiral separation due to their versatility and reproducibility. High-Performance Liquid Chromatography (HPLC) is the most extensively employed technique, particularly for analytical purposes. Its success depends on the design of chiral stationary phases (CSPs), which incorporate chiral selectors that interact differently with each enantiomer. Common selectors include polysaccharide derivatives (cellulose and amylose), glycopeptide antibiotics, cyclodextrins, and macrocyclic ligands. Polysaccharide-based CSPs remain the most widely used in pharmaceutical analysis owing to their broad applicability and high resolution.

Supercritical Fluid Chromatography (SFC) has emerged as a powerful complement to HPLC. SFC employs supercritical carbon dioxide (CO₂) as the mobile phase, combining the principles of Gas Chromatography (GC) and HPLC. The supercritical fluid exhibits both liquid- and gas-like properties, allowing for faster separations, reduced solvent use, and improved environmental sustainability. Despite these advantages, large-scale application of SFC remains limited by equipment cost and scalability challenges. For volatile compounds, chiral GC with specialized stationary phases is also applicable, though derivatization may be necessary to enhance volatility.

Other techniques for the resolution of chiral racemates include the following: (1) Crystallization-based methods, in which separation is achieved through diastereomeric salt formation with a suitable chiral resolving agent⁴. The resulting diastereomers exhibit distinct physicochemical properties, enabling their selective crystallization and subsequent separation. (2) Enzymatic or kinetic resolution, which exploits the stereoselectivity of enzymes or chiral catalysts to preferentially react with one enantiomer, thereby enriching the other in the reaction mixture. (3) Membrane-based chiral separations, an emerging approach that employs chiral-selective

membranes capable of differentiating enantiomers based on their asymmetric interactions with the membrane material⁶. Although less commonly applied, this technique shows potential for continuous and scalable chiral resolution processes.

2.2 Non-Chromatographic Methods

Crystallization remains the most cost-effective approach for industrial-scale resolution. Its success depends on the crystallization behavior of the racemate, which may form either conglomerates or racemic compounds. Enantioselective liquid–liquid extraction, membrane separations, and porous materials such as metal–organic frameworks (MOFs) and covalent organic frameworks (COFs) represent emerging alternatives offering tunable selectivity⁷.

Enzymatic or kinetic resolution uses a chiral catalyst or enzyme that selectively reacts with one enantiomer, converting it into a different product while leaving the other unreacted. Although this is a chemical conversion rather than a physical separation, it is widely employed in preparative organic synthesis.

3. PREPARATIVE SCALE OF PURIFICATION

In manufacturing and large-scale purification, the emphasis shifts from analytical precision to process scalability, efficiency, and cost control. Preparative chromatography (HPLC or SFC) and crystallization-based resolution dominate production workflows for enantiopure compounds. Analytical chiral HPLC is used to assess enantiomeric excess (ee), while chiroptical techniques such as circular dichroism confirm absolute configuration.

The biological significance of the enantiomeric purity of drugs is now scientifically well-established. A report mentions the separation of a racemate on 11 different CSPs—including CHIRALPAK® IA, CHIRALPAK® IB, CHIRALPAK® CHIRALPAK® IC, CHIRALPAK® AD, CHIRALPAK® AS, CHIRALCEL® OJ, Lux Cellulose 1, Lux Cellulose 2, Lux Cellulose 3, and Lux Cellulose 4, Lux Amylose-2 columns—using the 2.5 min method with methanol as the co-solvent. In another report, the DAICEL CHIRALPAK® IG-U (3 mm ID x 100 mm L, 1.6 µm particle size) column was used with a mixture of water and acetonitrile in the ratio of 60:40 with formic acid as an additive to maintain a pH of 2.0. Similarly, a LiChroCART® 250-4 ChiraDex® (4 mm ID × 250 mm L, 5 µm particle size) column was used to separate the R- and S- enantiomers of another racemate using a mobile phase consisting of acetonitrile, glacial acetic acid, and triethylamine in the volume ratio of 1,000:3:2.5 at a flow rate of 1 ml/min at 300 nm at UV detection wavelength and room temperature. The separation enantiomers using supercritical fluid chromatography (SFC), normal-phase chromatography (NPC), or reversed-phase chromatography (RPC) mode is very common.

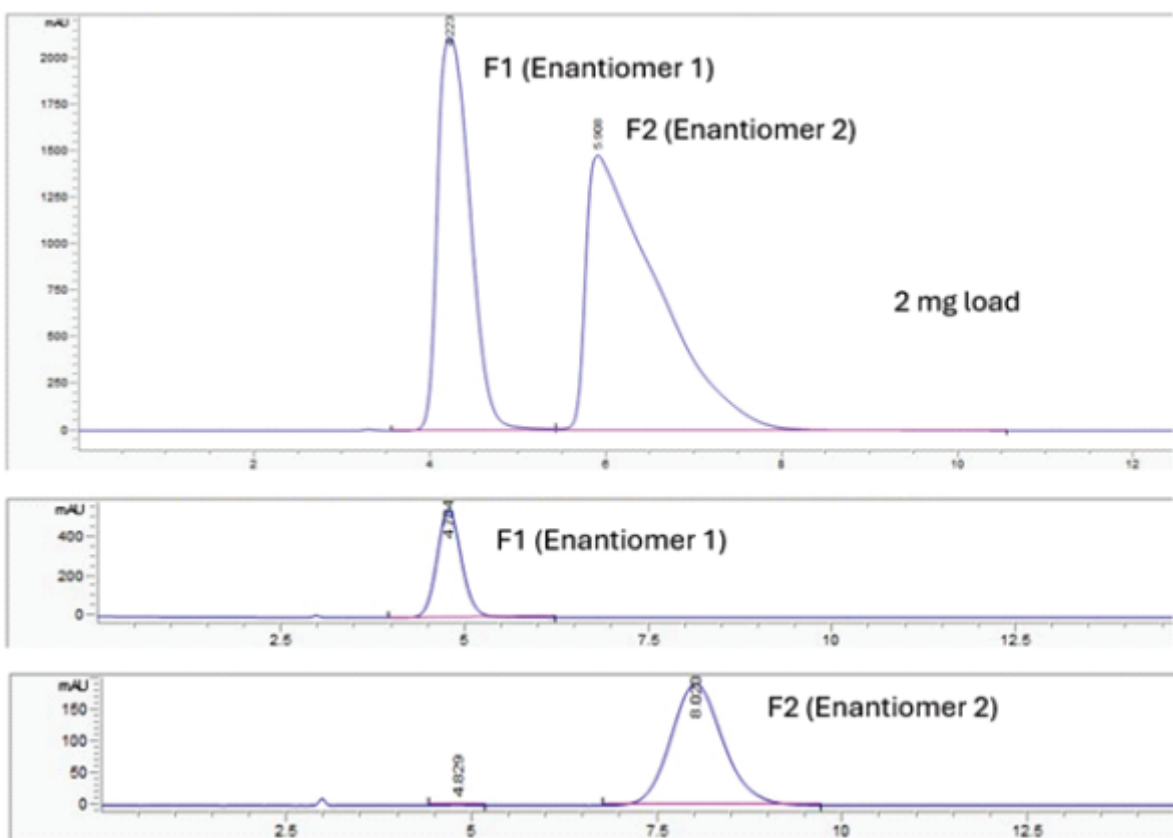
Generally chromatographic conditions mentioned in available literature reports, application notes, etc., are suitable for analytical separation. These chromatographic conditions may be

impractical in an industrial setup particularly for scale-up for large-scale purification, for a variety of reasons explained below. Moreover, in the current era of increasing environmental awareness, many solvents—such as dichloromethane (DCM)—that have been widely used in the pharmaceutical industry for large-scale liquid chromatographic purification are now either prohibited or strictly regulated, with the possibility of being completely banned in the near future. This development poses a significant challenge for separation scientists.

To successfully scale up a bench-level analytical chromatography method for industrial production, the mobile phases used at both scales must be identical, and the column chemistry should remain the same. Smaller particle sizes, such as sub-two microns, are good for analytical separation but may not be suitable for large-scale purification due to high back pressure issues. A particle size of 10–20 μm is preferred. When the method needs to be transferred from bench scale to large scale, the length of the column should remain the same as the internal diameter is increased to raise the loading capacity of the column. In the case of a simulated moving bed (SMB) chromatography technique, the back pressure issue becomes an even more important factor. In this SMB method, 5–6 columns are used in series, and the back pressures from each individual column are additive in nature. Separation at ambient temperature is economical, compared to higher temperature, but higher temperature may be necessary due to solvent viscosity and diffusivity issues of the mobile phase. Generally solvents with high viscosity are not first choice as mobile phase. Robustness of the method is critical during scale-up, as well as during production, so a single solvent mobile phase is preferred. In case there is no single solvent available for reasonable separation, azeotropes are preferred. An azeotrope (also known as a constant-boiling mixture) is a mixture of two or more liquids whose composition remains unchanged during distillation. This happens because the vapor produced by boiling an azeotropic mixture has the same composition as the liquid phase. Because of this characteristics the mobile phase composed of azeotropic composition behave like a single solvent with a constant boiling point and composition throughout the distillation process. If a good chromatographic condition using a single organic solvent, or an azeotropic mixture of two organic solvents are not available then a separation using a normal phase (NPC) is preferred over reversed phase chromatography (RPC) since the presence of water in RPC may cause the isolation of the final product by vacuum distillation difficult. Ternary mixtures of organic solvents are least preferred since it is difficult to maintain the composition within the window of robustness of the method during large-scale purification.

The separation of the enantiomers shown in the figure 1 was carried out using 100% methanol, as a single solvent. This is great, because methanol is considered as a 'green solvent', particularly if produced from renewable sources. Methanol is very commonly used as a mobile phase. It has a low boiling point making the isolation of the pure enantiomer by vacuum proving useful during isolation of the product. Some solvents such as tetrahydrofuran (THF) are not

preferred as they may need a stabilizer, which might not be removed easily during isolation of the product. Figure 1 also shows that both enantiomers are eluted within a short run time of 10 minutes. A shorter run time increases the number of cycles per hour and, thereby, the productivity. This representative method shown in figure 1 seems promising and meets the preliminary requirements for the subsequent process development (PD) study to further optimize and establish a method for large-scale purification. Figure 2 below shows the same separation with an injection 2 mg load of the racemate. Injection with higher load of 2 mg is carried out to monitor the effect of the injection load on the separation of the two enantiomers. This is commonly known as preliminary loading study. The result of this preliminary loading study shows that the two peaks are still well resolved. The high resolution between the two enantiomers during analytical scale of separation or during the preliminary loading study of ~2 mg doesn't necessarily mean the compound will be separable at large scale with high purity and yield. Full scale loading study using 5, 10, 20, 30, 40, 50 mg load will be necessary to clearly understand the behavior of the two enantiomeric peaks. This will depend on whether the two enantiomer peaks will have L-behavior or anti-L behavior, where “L” stands for Langmuir separation (in short, how they behave with the increased load). Full scale loading study will establish a method with a binding value of productivity, which in turn will give an idea whether the large scale separation using the method will be cost effective or profitable, and will satisfy the purity specification. There are many other aspects that are not discussed here, but the basic points covered here are very important to remember during method development.



As mentioned earlier, FDA regulations state that chiral compounds must be separated to their enantiomerically pure state as the individual enantiomers may have vastly different pharmacological and toxicity profiles. Figure 1 and Figure 2 confirms that DAICEL CHIRALPAK® IG (4.6 mm ID × 25 cm L, 20µm particle size) chiral column can separate R- and S-enantiomers of the racemate with high resolution using 100% methanol as a single solvent at ambient temperature without the addition of any additive. The chromatographic condition developed and reported here is expected to be suitable for further process development (PD) studies for large-scale purification.

3.1 Chiral separation in Pharmaceutical Industry

The pharmaceutical industry is the largest consumer of chiral separation technologies. Most therapeutic agents are chiral, and frequently only one enantiomer is biologically active. Preparative chromatography, enzymatic resolution, and crystallization remain the primary industrial-scale methods⁸. SFC has gained particular traction for kilogram-scale purifications due to its speed and reduced solvent requirements⁹.

3.2 Chiral separation in Agrochemicals and Flavors

In agrochemicals and flavors, chirality governs bioactivity and sensory perception. For example, only one enantiomer of a pesticide or herbicide may exhibit the desired biological effect, while the opposite enantiomer may be inactive or environmentally detrimental. Likewise, enantiomers of flavor and fragrance compounds often differ in taste or aroma, highlighting the broader industrial relevance of chiral resolution.

4. CHIRAL DRUGS AND SEPARATION TECHNIQUES – BRIEF OVERVIEW

Many drugs have chiral centers. A large number of cardiovascular agents, including drugs used in the management of hypertension, heart failure, arrhythmias, and related disorders, possess one or more chiral centers. Notable examples include β -adrenergic blockers, calcium channel antagonists, and angiotensin-converting enzyme (ACE) inhibitors¹⁰. The levo-rotatory (S-) isomers of most β -blockers exhibit significantly greater potency at β -adrenoceptors compared to their dextro-rotatory (R-) counterparts. For instance, S(–)-propranolol is reported to be approximately 100-fold more active than R(+)-propranolol¹¹. Despite this, several β -blockers such as acebutolol, atenolol, alprenolol, betaxolol, carvedilol, metoprolol, labetalol, pindolol, and sotalol continue to be marketed as racemic mixtures, while timolol and penbutolol are available as single L-isomers¹². Interestingly, both d,l-propranolol and d-propranolol inhibit the peripheral conversion of thyroxine (T₄) to triiodothyronine (T₃), unlike the L-enantiomer. Consequently, d-propranolol has been proposed as a potential therapy to reduce plasma T₃ levels in hyperthyroid patients, where conventional β -blocking therapy is contraindicated. In general, each enantiomer of a racemic β -

blocker may display distinct pharmacological profiles, ranging from inactive to antagonistic effects¹³. Many calcium channel antagonists, including verapamil, nifedipine, nimodipine, nisoldipine, felodipine, and manidipine, are administered as racemates. Diltiazem, however, exists as a diastereomeric compound containing two pairs of enantiomers¹⁴. The S(–) verapamil enantiomer is 10–20 times more potent than R(+) verapamil in producing negative chronotropic effects and vasodilation in both humans and animals¹⁵. Beyond cardiovascular therapy, verapamil has also been investigated as a modulator of multidrug resistance (MDR) in cancer treatment. Since this application requires higher doses that increase cardiotoxicity, the R(+)-enantiomer, which shows lower cardiac toxicity, is preferred for MDR modulation, whereas the S-form or racemate remains suitable for cardiovascular therapy. Most ACE inhibitors including captopril, benazepril, enalapril, and lisinopril, are chiral molecules that exist as diastereomers, with the majority marketed as single-isomer formulations. Similarly, valsartan, an angiotensin II receptor antagonist, is marketed as a pure S-enantiomer, since the R-form displays markedly lower activity¹⁶. Agents such as albuterol (salbutamol), salmeterol, and terbutaline are sympathomimetic β_2 -adrenoceptor agonists used primarily as bronchodilators in asthma therapy¹⁷. These drugs have traditionally been marketed as racemates, even though only the R(–)- or L-isomer is pharmacologically active. The inactive S(+)-isomer may contribute to adverse effects. The U.S. Food and Drug Administration (FDA) approved levalbuterol, the pure L-isomer of albuterol, as a preservative-free nebulized formulation. However, clinical evidence suggests that levalbuterol offers no significant advantage in efficacy or safety compared to racemic albuterol, despite being up to five times more expensive. In the neurological and psychiatric domains, many therapeutic agents are chiral and are often marketed as racemic mixtures. Barbiturates such as hexobarbital, secobarbital, mephobarbital, pentobarbital, thiopental, and thiohexital exist as racemates; generally, the L-isomer possesses sedative or hypnotic activity, while the D-isomer is inactive or may even exhibit excitatory effects. For instance, S(–)-secobarbital demonstrates greater anesthetic potency and produces a smoother onset of anesthesia than its R(+)-antipode¹⁸. Ketamine, an intravenous anesthetic, also exists as a chiral compound; the (+)-enantiomer exhibits higher potency and lower toxicity than the (–)-form, yet the racemic mixture remains in clinical use¹⁹. Similarly, isoflurane, an inhalational anesthetic, is used as a racemate, though its (+)-isomer is more effective in inhibiting acetylcholine-induced currents. In antidepressant therapy, S(+)-citalopram demonstrates over 100-fold higher potency as a selective serotonin reuptake inhibitor (SSRI) compared with R(–)-citalopram²⁰. Methadone, a synthetic opioid agonist used for pain management and opioid dependence, is administered as a racemic mixture²¹. The R(–)-isomer displays 25–50 times greater analgesic activity than the S(+)-isomer due to its higher affinity for μ -opioid receptors.

Therapeutic Class	Example Drugs	Primary Method	Notes
Cardiovascular	Warfarin, Propranolol, Metoprolol	Chiral HPLC / Preparative Chromatography	S-enantiomer more active
CNS Drugs	Escitalopram, Venlafaxine, Selegiline	Chromatography / Crystallization	S-enantiomer more effective
Anti-Infectives	Levofloxacin, Ofloxacin	Chiral Chromatography	Levofloxacin is the active form
NSAIDs	Ibuprofen, Naproxen, Ketoprofen	Crystallization / Enzymatic Resolution	S-enantiomer therapeutically active
Anticancer/ Immuno-modulatory	Thalidomide, Lenalidomide	Chromatography / Asymmetric Synthesis	Enantiomeric purity critical for safety
Others	Omeprazole / Esomeprazole	Crystallization + Chromatography	Esomeprazole = active S-enantiomer

5. CHIRAL MARKET LANDSCAPE

The global chiral chemicals market was valued at approximately USD 77 billion in 2024 and is projected to reach over USD 125 billion by 2030. The pharmaceutical sector dominates, representing 45–70% of the total market²². Within this, chiral separation technologies—including chromatography, crystallization, and enzymatic methods—form a key subset. The chiral chromatography column market is estimated at USD 100 million annually, with roughly 70% attributed to pharmaceutical applications²³. The expansion of chiral small-molecule drugs, stricter regulations, and technological advancements continue to drive market growth.

6. CHALLENGES AND FUTURE OUTLOOK

6.1 Current Challenges

There are many challenges in chiral separation business. No universal chiral selector or No single CSP resolves all racemates; so screening a number of CSPs for method development remains empirical²⁴. Techniques optimized for analytical applications may not be viable at production scale. Some compounds interconvert during processing, compromising enantiomeric purity which is one of the big challenges. The molecular basis of chiral recognition in CSPs and membranes is still under investigation, mechanistic understanding is still incomplete. Increased synthesis of chiral molecules has expanded the need for efficient, scalable separation methods.

6.2 Future Perspectives

Metal organic frame work (MOF) and covalent organic framework (COF) based CSPs with advanced materials and nanotechnology and membranes with tailored pore chirality show great

promise²⁵. Integration of racemization, crystallization, and chromatography can enhance yield and process efficiency as hybrid processes. In this era of AI, an AI-driven optimization and high-throughput screening can accelerate method development²⁶. Finally the green chemistry concept can be helpful to develop a sustainable processes using recyclable materials and minimal solvent are increasingly emphasized. Spin-based methods, such as chirality-induced spin selectivity (CISS), represent innovative frontiers in enantioseparation and emerging as a new physical phenomena²⁷. Chiral molecules are increasingly used to design chiral nanostructures. Their “handedness” can control the optical, electronic, and magnetic properties of materials. Chiral plasmonic nanoparticles that selectively interact with circularly polarized light, are useful in sensors and advanced optics²⁸. Drug delivery systems where chirality guides molecules to specific targets in the body can play important role. Catalytic nanomaterials can accelerate reactions in a more selective and efficient way. In automated chemical and pharmaceutical processes, chirality plays a key role in precision and selectivity. Automated synthesis platforms can use chiral catalysts and reagents to consistently produce the desired enantiomer. Robotic high-throughput screening can test chiral molecules quickly to identify the most effective drug or material candidate³⁰. Machine learning and AI can predict chiral outcomes, reducing trial-and-error in chemical manufacturing. Chiral molecules contribute to greener chemistry by improving efficiency and reducing waste. Asymmetric catalysis can produces only the desired enantiomer, minimizing by-products. Biocatalysis using enzymes (naturally chiral) can avoid harsh chemicals and energy-intensive processes. Some chiral nanomaterials can be recovered and reused, cutting down environmental impact. Overall, chiral separation will continue to evolve for greater good.

CONCLUSION

Chiral separation remains both a scientific challenge and an industrial necessity. From Pasteur's pioneering crystallization of tartaric acid to modern supercritical chromatography and automated screening, the field has evolved dramatically. The “left or right” dilemma continues to underpin drug safety, efficacy, and material performance. Despite notable advancements, improved CSPs, nanomaterial-based membranes, and integrated processing—further progress is needed in universality, scalability, and sustainability. The future of chiral separation lies in the intelligent integration of analytical precision with industrial practicality. The question may soon evolve from which hand to which pathway—chromatographic, crystallization, membrane, or hybrid—to achieve enantiopure materials in the most efficient and sustainable manner.

More than half of the pharmaceuticals in current clinical use contain chiral centers, and approximately 90% of these chiral drugs are still marketed as racemic mixtures, consisting of equal proportions of two enantiomers³⁰. Despite sharing identical chemical compositions, the enantiomers of a chiral drug often display significant differences in their pharmacological, toxicological, and pharmacokinetic behaviors, as well as in their metabolic pathways. These

distinctions arise from the stereoselective interactions of each enantiomer with biological targets such as enzymes and receptors.

Given these variations, the separation and analytical characterization of enantiomers have become essential in both the pharmaceutical industry and clinical practice. Effective chiral resolution allows the removal of undesirable isomers from formulations and aids in achieving optimal therapeutic outcomes with improved safety profiles.

Author has no Conflicts of Interest. All the data are available with the author and may be obtained on request.

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Exploring Higher Secondary School Teachers' Attitudes Toward Life Skills Education: A Study of Personal Variables in Siliguri, West Bengal

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ABSTRACT

Life Skills are abilities that help in promotion of mental and social wellbeing, and competence in young children to face the realities of life. The ultimate aim of education is the overall development of a child's personality which cannot be achieved without exposing to various components of life skills. The purpose of conducting this study was to find out the attitude of higher secondary school teachers towards life skill education in relation to some personal variables (Age, Gender, Academic Streams and Locale). A sample of 120 higher secondary school teachers from Siliguri were selected through Simple Random Sampling technique. The findings of the study revealed that there is no significant difference in the attitude of male and female higher secondary school teachers towards life skill education, Significant difference was found in the attitude of higher secondary school teachers from rural and urban areas & age wise variation towards life skill education. Significant difference was found in the attitude of higher secondary school teacher's Academic streams towards life skill education.

Key Words: Life Skill Education, Attitude, Personal variables

INTRODUCTION

In the era of globalization human beings encounter numerous challenges especially during adolescence stages which mark the period of transition from childhood to adulthood. These challenges may be related to physiological, psychological, social and economic which may render the youth vulnerable to social and health risks, such as drug abuse, irresponsible sexual behaviour, increased in crime, violence, school dropout, teenage pregnancy and general indiscipline among adolescence. Hence, life skills are one of the methodologies which are adopted by many developing countries to cope up with the developed ones. Over the last decade there has been an increased interest among mental health professionals and educationist in the area of life skills. Varied views and definitions have been propounded by different professionals and world bodies. Life skills are problem solving behaviours used appropriately and responsibly in the management of personal affairs. They are a set of human skills acquired via teaching or direct experiences that are used to

handle problems and questions commonly encountered in daily life. World Health Organization (WHO) in 1993 defined life skills as "the abilities for adaptive and positive behaviour that enables individuals to deal effectively with demands and challenges of everyday life. Positive behaviour refers to a positive outlook even in the most difficult situations or anticipating of a "way out" in the difficult situation. UNICEF (2005) defines life skills as, "a behaviour change or behaviour development approach designed to address a balance of three areas: Knowledge, attitude and skills". Powell (1995)) define life skills as the life coping skills consonant with the development processes namely those skills necessary to perform tasks for given age and gender in the following area of human development psychological, physical, sexual, vocational, cognitive moral and emotional. Life Skills are abilities which enable an individual develop adaptive and positive behaviour deal effectively with challenges and demands of everyday life. The development of life skills as an individual is a lifelong process that starts in early childhood and continues throughout one's life (UNESCO, 2003). Essential life skills include such things as being able to recognize and describe one's feeling, giving and receiving feedback, recognizing assumptions, setting realistic and attainable goals, and employing problem-solving strategies. Thus, life skills are essentially those abilities that help promote mental wellbeing and competence in young people as they face the realities of life. Life skills have been defined as follows: "Personal and social skills required for young people to function confidently and competently with themselves, with other people and with the wider community"

The world bodies such as UNICEF, UNESCO and WHO have identified the ten core Life Skills with three main dimensions as discussed hereunder;

Social Skills: Social skills include the skills related to recognition of self, communication and interpersonal relationship.

Self-Awareness: Self Awareness includes recognition of 'self, our character, Our strengths and Weaknesses, desires and dislikes. Developing self-awareness can help to recognize when we are stressed or feel under pressure. It is often a prerequisite to effective communication and interpersonal relations, as well as for developing empathy with others.

Effective Communication: Effective communication means that we are able to express ourselves, both verbally and non-verbally, in ways that are: appropriate to our cultures and situations. This means being able to express opinions and desires, and also needs and fears. And it may mean being able to ask for advice and help in a time of need.

Interpersonal Relationship: Interpersonal relationship skills help to relate in positive ways with the people we interact with. This may mean being able to make and keep friendly relationships, which can be of great importance to our mental and social well-being. It may mean keeping, good relations with family members, which are an important source of social support. It may also mean being able to end relationships constructively.

Thinking Skills: Thinking Skills are of four types. They include critical thinking creative thinking, decision making and problems thinking skills.

Critical thinking: Critical thinking is an ability to analysis information and experiences in an objective manner. Critical thinking can contribute to health by helping us to recognize and assess the factors that influence attitudes and behaviour, such as values, peer pressure and the media.

Creative thinking: Creative thinking is a novel way of seeing or doing things that is characteristic of four components fluency (generating new ideas), flexibility (shifting perspective easily), originality (conceiving of something new), and elaboration (building on other ideas).

Decision making: Decision making helps to deal constructively with decisions about our lives. This can have consequences for health. It can teach people how to actively make decisions about their actions in relation to healthy assessment of different options and, what effects these different decisions are likely to have.

Problem solving: Problem solving helps to deal constructively with problems in our lives. Significant problems that are left unresolved can cause mental stress and give rise to accompanying physical strain.

Emotional Skills: Emotional skills include empathy, coping with stress and managing emotions.

Empathy: To have a successful relationship with our loved ones and society at large, we need to understand and care about other peoples' needs, desires and feelings. Empathy is the ability to imagine what life is like for another person. Without empathy, our communication with others will amount to one-way traffic. Worst, we will be acting and behaving according to our self-interest and are bound to run into problems. No man is an island, no woman either! We grow up in relationships with many people - parents, brothers and sisters, cousins, uncles and aunts, classmates, friends and neighbours. When we understand ourselves as well as others, we are better prepared to communicate our needs and desires. We will be more equipped to say what we want people to know, present our thoughts and ideas and tackle delicate issues without offending other people. At the same time, we will be able to elicit support from others, and win their understanding. Empathy can help us to accept others, who may be very different from ourselves. This can improve social interactions, especially, in situations of ethnic or cultural diversity.

Coping with Stress: means that we take action to reduce the sources of stress, for example, by making changes to our physical environment or lifestyle. It also means learning how to relax, so that tensions created by unavoidable stress do not give rise to health problems.

Coping with emotions: includes skills for increasing the internal locus of control for managing emotions, anger etc.

Attitudes, values and social and psychological skills to an individual to enable him/her develop their full potentials. Thus, the Life Skills approach is an interactive, educational methodology that not only focuses on transmitting knowledge but helps the youth to explore their attitudes, feelings, opinions and values thereby developing psychosocial competencies to face life's challenges

effectively. Attitudes have a topic (the object); are relatively long lasting (thus the readiness) to respond. This definition is quite general and the social psychologists who are interested in attitudes have tried to refine the concept. Attitudes comprise components corresponding to three domains namely, cognitive, affective and conative (Oscamp, 1977). In the present study, the term attitude was accepted as an enduring system of positive or negative evaluation, emotional feeling, and pro and con action tendencies with respect to life skills. This operational definition was accepted in the tool used for study. Therefore, the present study was focused on the following aspects in which teachers were expected to develop positive attitudes. The topic life skills being emerging area of the study was accepted very recently as a popular term in the context of transferable skills, emotional, intelligence, social skills or intelligence which are synonymous with life skills.

REVIEW OF RELATED LITERATURE

Keya, John & Wycliffe (2021) studied on teachers' perceptions on the influence of life skills education on moral behaviour among students in secondary schools in Emuhaya sub county - Kenya. The objective of the study was to establish the extent to which teachers are trained to teach life skills education with an emphasis on moral behaviour. The findings indicated that Heads of Department and teachers slightly agree on the influence of teachers training in life skills education with the emphasis on moral behaviour.

Mairaj (2021) studied that there is an unusual increase in the cases of child abuse, early marriages, suicide, physical and mental violence causing a large number of school dropouts in elementary classes. This calls for the requirement to investigate or evaluate the perceptions of teachers about life skills education in public sector elementary schools. The study was conducted using qualitative interviews from twelve teachers of two public schools where life skill education is being taught. Thematic analysis was used for data analysis. The findings of the study revealed that teachers are aware and have a positive attitude towards life skills education.

Wangdi (2022) examined the attitude of Bhutanese teachers towards implementing Life Skills Education in different level of Schools. The researcher used quantitative research approach with descriptive survey design. Simple random sampling technique was employed to select a total sample of 100 teachers from the Eastern part of Bhutan. The data collected were analysed using both descriptive and inferential statistics. The findings revealed that the teachers with science background hold comparatively higher attitude towards imparting Life Skills Education compare to non-science teachers and significant difference was also found between the teachers holding post graduate and B.Ed. qualification towards infusing Life Skills Education.

Rationale of the study.

In the context of present change in social order, the younger generations is swayed by the modern technological innovations and are in the attempt of experimenting with new ideas. This makes the pupils vulnerable to many bad habits. Ancient cultures which was the strength of human life, and

respect to elders, respect for the social norms, proper reading habits for acquisition of knowledge by developing thinking, reasoning and creativity are missing. Even pupils are facing hard situation to make right decision. Hence worldwide there appeared value crisis. In order to infuse value laden thoughts, UNIESCO, UNICEF and WHO have thought of inculcating life skills from the early ages. Therefore, a need has arisen to assess the responses of teachers towards the instruction of life skills in school curriculum.

OBJECTIVES OF THE STUDY

- To study the significant difference in the attitude of higher secondary school teachers towards Life Skill education in relation to age variation.
- To study the significant difference in the attitude of higher secondary school teachers towards Life Skill education in relation to gender variation.
- To study the significant differences in the attitude of higher secondary school teachers toward Life Skills Education in relation to Academic Streams variation.
- To study if there exist significant differences in the attitude of higher secondary school teachers toward Life Skills Education in relation to Rural and Urban place.

STATEMENT OF HYPOTHESES

Ho1: There will be no significant difference in the attitude of higher secondary school teachers towards Life Skills Education in relation to age variation.

Ho2: There will be no significant difference in the attitude of higher secondary school teachers towards Life Skills Education in relation to gender variation.

Ho3: There will be no significant difference in the attitude of higher secondary school teachers towards Life Skills Education in relation to academic streams variation.

Ho4: There will be no significant difference in the attitude of higher secondary school teachers towards Life Skills Education in relation to locale variation.

OPERATIONAL DEFINITIONS

Attitude: is the degree of positive or negative effect associated with some psychological object. (Thrustone 1948). An inclination to respond to Life Skills Education as a subject in a generally favourable or unfavourable manner.

Life Skill Education: is a structured programme of needs and outcomes- based participatory learning that aims to increase positive and adaptive behavior by assisting individuals to develop and practice psycho-social skills that minimize risk factors and maximize protective factors."(UNICEF 2003).

Higher Secondary School Teachers: Teachers who work in Government Higher Secondary school in Siliguri.

Personal Variables: it refers age, gender, academic streams and locale variables.

Delimitation of the Study: The study was delimited to study the attitude of higher secondary school teachers towards Life Skill Education of Siliguri.

Methodology of the study

Design: A normative survey method was adopted for the present study to obtain pertinent and precise information concerning current status of phenomenon. It was based on what exists at present in the form of conditions, practices, trends and attitudes. The attitude towards life skill education was studied in relation to their age, gender, academic qualifications and locale variations. Therefore, descriptive survey method was used in the present study.

Sample: The target population of this study included 1200 Higher Secondary School teachers serving Higher Secondary Schools of Siliguri. 120 teachers were selected using simple random sampling technique as a sample for study.

Tools Used: Self-developed tool was used for the present study to order to generate appropriate evidence and information. It consists of 25 statements based on 5-point Likert scale. The reliability for scale was calculated by using the formula Cronbach's Alpha which is 0.71 which is a highly reliable tool. Before collection of data the questionnaire was given to different experts to validate the items.

RESULTS AND DISCUSSION

Descriptive and inferential statistics were used to analyze the data.

Age wise difference of Attitude of Higher Secondary School Teachers towards Life Skill Education:

One of the objectives of the study was that whether there is any age wise difference in the attitude of higher secondary school teachers towards life skill education; therefore, the null hypothesis was stated that there was no significant difference in the attitude of higher secondary school teachers towards life skill education in relation to Age variation.

Variation	Contrast	Number	Mean	SD	SE _D	't'	df	Remarks
Age	Above 40 years	60	110.5	9.84	1.80	9.52	118	Significant
	Below 40 years	60	91.18	9.51				

Table 1: Calculation of "t" for Age variation sub sample wise of higher secondary school teachers

In case of age difference on attitude of higher secondary school teachers towards life skill education, the calculated “t” 9.52 was found to be significant as its value greater than the table value. This was 1.98 at 0.05 level and 2.62 at 0.01 levels in 118 degrees of freedom. Thus, the null hypothesis H_{01} there was significant difference in the attitude of higher secondary school teachers towards life skill education in relation to age variation was rejected. So, from the study it was revealed that difference in age among higher secondary school teachers affect their attitude towards life skill education. This finding was in conformity with the study conducted by Rose Savati Keya, John Agak O, Odiwuor Wycliffe H. (2021) & Bushra Mairaj (2021).

Gender wise difference of Attitude of Higher Secondary School Teachers towards Life Skill Education :

One of the objectives of the study was that whether there is any gender difference in the attitude of higher secondary school teachers; therefore, the null hypothesis was stated that there was no significant difference in the attitude of higher secondary school teachers towards life skill education in relation to gender variation.

Variation	Contrast	Number	Mean	SD	SE _D	‘t’	df	Remarks
Gender	Female	60	105.03	15.43	2.7	4.61	118	Significant
	Male	60	102.30	13.02				

Table 2: Calculation of “t” for Gender variation sub sample wise of higher secondary school teachers

In case of gender difference on attitude of higher secondary school teachers towards life skill education, the calculated “t” 4.61 was found to be significant as its value more than the table value. This was 1.98 at 0.05 level and 2.62 at 0.01 levels in 118 degrees of freedom. Thus, the null hypothesis H_{02} there was no significant difference in the attitude of higher secondary school teachers towards life skill education in relation to gender variation was rejected. So, from the study it was revealed that gender difference among higher secondary school teachers affects their attitude towards life skill education. This finding was in conformity with the studies conducted by Vinay Kumar Cherukuri, C. Grace Indira. (2020) & Khadija Sittar, Sumaira Munawar and Misbah Malik (2020).

Academic streams wise difference of Attitude of Higher Secondary School Teachers towards Life Skill Education:

One of the objectives of the study was that whether there is any Streams difference in the attitude of higher secondary school teachers; therefore, the null hypothesis was stated that there was no significant difference in the attitude of higher secondary school teachers towards life skill education in relation to variation in academic streams (science, commerce and arts).

Source of Variations	SS	Df	MS _v	'F'	Remarks
SS _A	2958.5	2	1479.25	6.79	Significant
SS _B	25345.5	117	216.63		
SS _T	28304				

Table 3 : Calculation of “t” for Academic Streams variation sub sample wise of higher secondary school teachers

In case of Streams difference on attitude of higher secondary school teachers towards life skill education, the calculated “F” 6.79 was found to be significant as its value greater than the table value. This was 3.07 at 0.05 level and 4.78 at 0.01 levels in 2 and 117 degrees of freedom. Thus, the null hypothesis H_{03} there was significant difference in the attitude of higher secondary school teachers towards life skill education in relation to Streams variation was rejected. So, from the study it was revealed that difference in academic streams among higher secondary school teachers affect their attitude towards life skill education. This finding was in conformity with the study conducted by Rose Savati Keya, John Agak O, Odiwuor Wycliffe H. (2021) & Bushra Mairaj (2021).

Locale wise difference of Attitude of Higher Secondary School Teachers towards Life Skill Education:

One of the objectives of the study was that whether there is any locale difference in the attitude of higher secondary school teachers; therefore, the null hypothesis was stated that there was no significant difference in the attitude of higher secondary school teachers towards life skill education in relation to locale variation.

Variation	Contrast	Number	Mean	SD	SE _D	't'	df	Remarks
Locale	Rural	60	99.24	14.01	2.91	4.05	118	Significant
	Urban	60	95.38	13.12				

Table 4 : Calculation of “t” for Locale variation sub sample wise of higher secondary school teachers

In case of locale difference on attitude of higher secondary school teachers towards life skill education, the calculated “t” 4.05 was found to be significant as its value greater than the table value. This was 1.98 at 0.05 level and 2.62 at 0.01 levels in 118 degrees of freedom. Thus, the null hypothesis H_{04} there was significant difference in the attitude of higher secondary school teachers towards life skill education in relation to locale variation was rejected. So from the study it was revealed that difference in locale among higher secondary school teachers affect their attitude

towards life skill education. This finding was in conformity with the studies conducted by Vinay Kumar Cherukuri, C. Grace Indira. (2020) & Khadija Sittar, Sumaira Munawar and Misbah Malik (2020).

FINDINGS OF THE STUDY:

The major findings of the study were presented briefly in the following manner:

- The sample mean, median, mode is found to 102.29, 100.5 and 96.92 respectively.
- The skewness was found 0.36 and kurtosis was 0.31 as against the normal value of 0 and 0.263 respectively. Thus, the investigator concluded that the scores obtained by attitude towards life skill education scale deviates slightly from normality. The whole distribution was positively skewed and tending to leptokurtic.
- Age difference on the attitude towards life skill education of higher secondary school teachers play significant role in their attitude towards life skill education.
- Gender difference on the attitude towards life skill education of higher secondary school teachers plays significant role in their attitude towards life skill education.
- Academic stream difference on the attitude towards life skill education of higher secondary school teachers plays significant role in their attitude towards life skill education.
- Locale difference on the attitude towards life skill education of higher secondary school teachers plays significant role in their attitude towards life skill education.

CONCLUSION

There is a significant relationship between Attitude and life skills education as they are complementary to each other in various ways. It helps in promoting effective communication, thinking skills, collaborative skills, teamwork, interpersonal relationship, self-awareness and make the adolescents more motivated and engaged in constructive tasks and thus minimizes the risky behaviours. It fills the gap between theoretical knowledge and real-life applications of life skills and prepares the adolescents for educational, professional and personal lives and make them competent enough to face the challenges of the present world. At the same time life skills supports lifelong learning.

IMPLICATIONS FOR FURTHER RESEARCH

Researches are never complete. One research opens various new directions for further researchers and this way knowledge expands. The present study opens up certain avenues for further research, which are:

- The present study can be replicated in different parts of the country with large sample and with teachers of higher education and students of various age groups.
 - The present study can be replicated on a large and more representative sample, so that the result obtained may be more reliable.
 - Similar studies can be conducted on the primary school, middle school and university teachers.
 - The study of the same nature can be undertaken for the different states of the country.
 - A similar study can be conducted by taking into consideration other variables such as
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achievement in profession, Aptitude in teaching, Attitude towards digitalization in education etc.

- A comparative study of relationship between gender, academic qualification and teaching experience on attitude towards life skills can be undertaken among teachers of different states and different countries.
- A number of studies are also needed to evaluate the effectiveness of teachers in terms of their attitude towards life skills & their understanding of it.

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Darjeeling Sikkim Hill Calendars: A History of Time Measurement

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ABSTRACT :

Time keeping has been important to any developed society. Agriculture requires knowledge of changing weather, which can be understood only by knowing the solar cycle. The growing of trees, taking care of animals, rearing children and other activities require an idea of the passing of days. In the sphere of religion, it is required to fix days and hours for different rituals. Calendars are developed in every society from such requirements. Different societies developed different ways to calculate time and accordingly designed their calendars. This led to many kinds of calendars around the world. This article attempts to concentrate on the Lepcha, the Limbu and the Rai calendars from the Sikkim Darjeeling hills.

Keywords: Indigenous Calendar, Solar Calendar, Luni –Solar Calendar

INTRODUCTION :

Can we guess when mankind first thought of measuring time? Was it first observed that night comes after day and day after night? The conscious and intelligent ones must have noticed the moon going through its phases and the changing of seasons. Once cultivation began; an estimate of the onset of rains and the commencement of winter must have become necessary. A precise calendar was, perhaps, still not needed. When the machinery of governance came up, a precise idea of time was required, the time of tax collection, salary payment etc. had to be fixed. Religions developed and priests also needed to measure time. Thus, perhaps, time keeping evolved and resulted in the modern calendars.

The complication in configuring calendars arises from the difficulty in finding a suitable unit. Nature has provided three intervals of time [1].

- day-night period or day, the time the earth takes to rotate around itself,
- month, the time moon takes to go round the earth, and
- year, the time the earth takes to go round the sun.

Any calendar to be useful should be able to keep track of all the three quantities mentioned above. However, there is no simple relation between the three. A rough estimate of a year is 365 days or 12 months, and a month is 30 days. More accurately, a month is a little less than 30 days (29.530588 days). The year is again slightly more than 365 days (365.2422), also more than 12 months.

Functioning calendars all over the world use many different techniques to correlate the three intervals of time, giving many calendars. The article first discusses the standard and well-known calendars in the world.

SOLAR CALENDAR

One year is 365 days, with a 366 day year once in 4 years. The year is divided into 12 months, totally ignoring lunar phases, individual month length is immaterial. To keep the number of months 12 each month has 30 or 31 days. Examples are the Gregorian calendar, Nepali calendar, Bengali calendar etc. A very unusual solar calendar is the Mayan calendar, which has no months. There are 18 units of 20 days, followed by a 5 day period which is not in any of these units.

LUNAR CALENDAR

This calendar follows lunar phases, one month is the duration between successive new or full moons, ~29 or 30 days. 12 months become 354 or 355 days, which is a year. The calendar does not match changing seasons. The only functioning Lunar Calendar today is the Islamic Calendar.

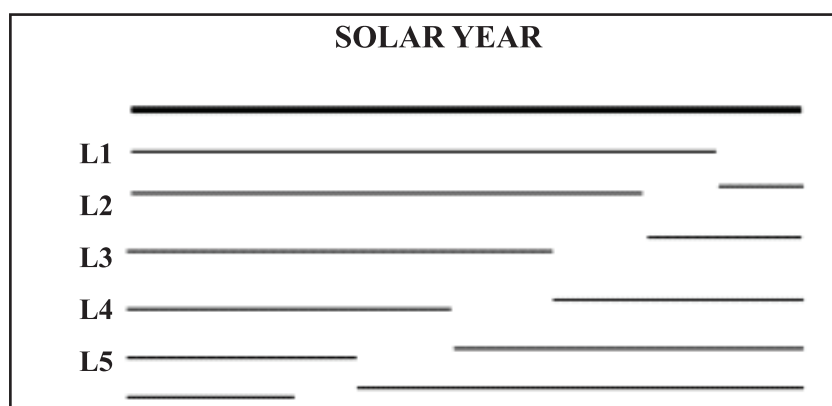


Figure 1: Comparison of Solar and Lunar Years.

The solid line is the solar year. L1 L2, L3, K4 and L5 are consequent lunar years. Since the Lunar Year is smaller, L1 begins with the solar year ends before the solar year ends. The next year, L2 starts where L1 ends, and ends even before the end of the solar year and this shift continues. After some years, say L5, totally loses its connection with the seasonal cycle.

Table 1 gives the dates of Eid ul Fitr over the last few decades in the Gregorian calendar. Every year, the festival advances by around 10 or 11 days. In the year 2000, there were two Eid ul Fitr. This shows that the Lunar year is shorter than the Gregorian solar leap year by 11 days.

Year	Date of Eid Ul Fitr	Year	Date of Eid Ul Fitr
1990	27 April	2008	01 October
1991	16 April	2009	20 September
1992	04 April	2010	10 September
1993	25 March	2011	30 August
1994	14 March	2012	19 August
1995	03 March	2013	08 August
1996	21 February	2014	28 July
1997	09 February	2015	17 July
1998	30 January	2016	06 July
1999	19 January	2017	25 June
2000	08 January and 27 December	2018	15 June
2001	16 December	2019	04 June
2002	05 December	2020	24 May
2003	25 November	2021	13 May
2004	13 November	2022	02 May
2005	02 November	2023	21 April
2006	23 October	2024	10 April
2007	13 October	2025	31 March

Table 1: Dates of Eid ul Fitr in successive years [2]

LUNI SOLAR CALENDAR

This calendar also follows lunar phases, and starts at full or new moon, so one month is 29 or 30 days. 12 months make a year with 354 or 355 days. The year is smaller than the solar cycle by around 10 days. To compensate for that, an extra month, called the intercalatory month, is added every 3 years. Examples of this calendar are Chinese calendar, Tibetan calendar, Marathi calendar, Jewish calendar etc. The working of a Luni Solar calendar is shown in **Figure 2**.

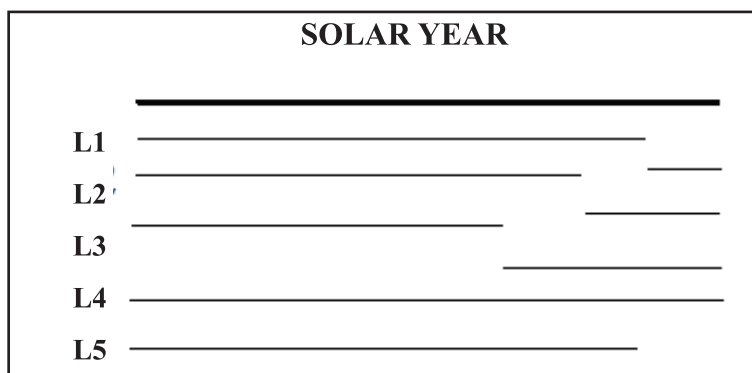


Figure 2: The Luni Solar Calendar. The black line on the top is the Solar year. The Luni Solar years, LS1 LS2 and LS3 are smaller, and move a little off from the Solar Year. After three years, an extra month is added to compensate for that. Hence LS4, the final Lunar year is longer than the Solar year. The next year, LS5 in the cycle is like LS1.

In order to appreciate this calendar, one has to follow the changing dates of a festival, like Vijaya Dashami, as shown in Table 2. The date of Vijaya Dashami also changes every year. Unlike Eid ul Fitr, it goes back and forth and remains within October of the Gregorian year. This effect has been shown graphically in Figure 3. This back-and-forth movement is due to the addition of the extra month, which keeps the two calendars synchronised. The Luni-Solar calendar thus maintains a correspondence with seasonal changes.

Year	Date	Year	Date
1996	21 October	2011	06 October
1997	11 October	2012	24 October
1998	01 October	2013	13 October
1999	19 October	2014	03 October
2000	07 October	2015	22 October
2001	26 October	2016	11 October
2002	15 October	2017	30 September
2003	4/5 October	2018	19 October
2004	23 October	2019	08 October
2005	12 October	2020	25 October
2006	02 October	2021	15 October
2007	21 October	2022	05 October
2008	09 October	2023	24 October
2009	28 October	2024	12 October
2010	17 October	2025	02 October

Table 2: Dates of Vijaya Dashami in successive years [3].

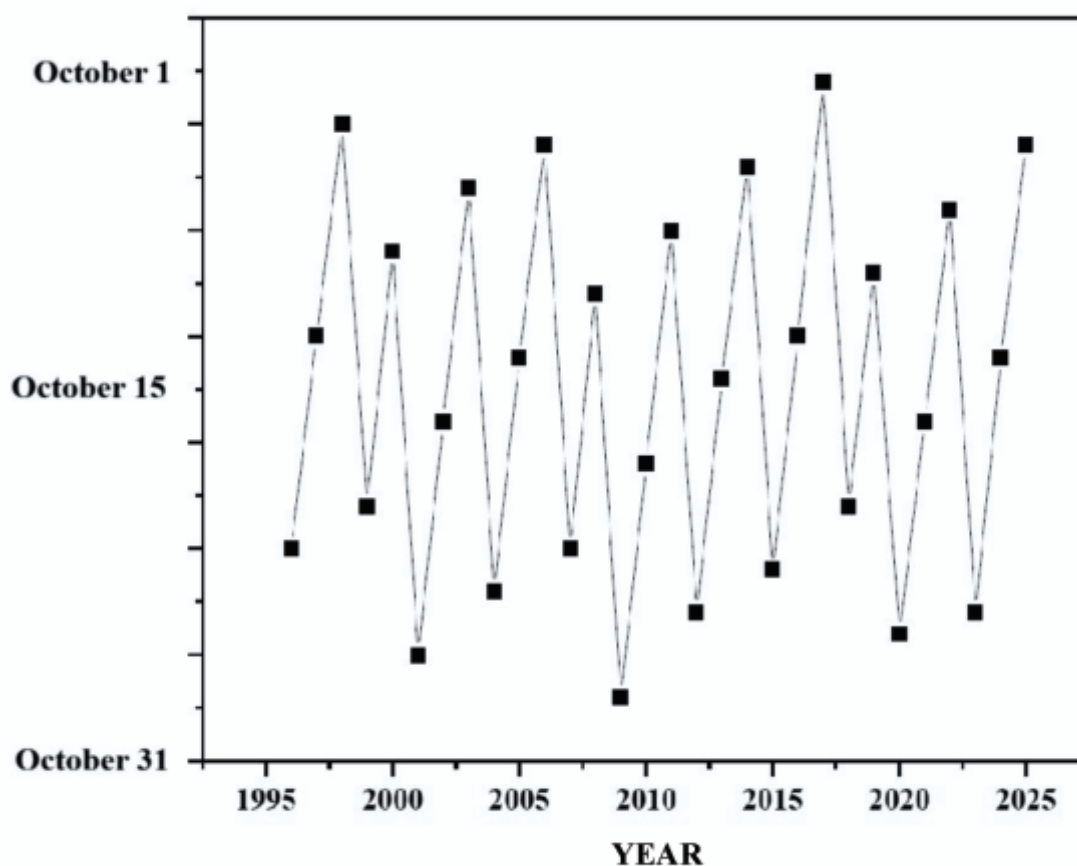


Figure 3. Pictorial Representation of the dates of Vijaya Dashami on the Gregorian Calendar. The dates change, but remain within 30th September and 31st October.

CALENDARS OF THE HILLS

The indigenous calendars of the Darjeeling Sikkim Hills impress in their variety. Luni-solar and Solar calendars are both in use in these communities. There are no purely lunar calendars in this whole region. This is expected from agrarian societies who are very close to nature and want to follow the seasons.

The calendars also follow a 12 year cycle like the Chinese/Tibetan calendar. These cycles are again dedicated to the five elements. This brings a grand cycle of 60 years, considered sacred.

Such variation in configuration of calendars gives an idea of the diversity of the land. The calendars follow seasons accurately, to the extent of predicting the flowering of certain plants. However, different communities solve time measurement problems in totally different ways.

LIMBU CALENDAR:

The Limbu people, also called Yakthung or Yakthum, meaning “Heroes of the Hills” are a major Sino-Tibetan ethnolinguistic group indigenous to the Himalayan region of eastern Nepal, Darjeeling and Sikkim Himalayas, and western Bhutan. Their self-designation reflects their ancestral connection to the hills (yak = hill, thung/thum = heroes). They are also known as Limboo, Subba, and

Yakthumba. Their belief system centres on animism and nature-worship, though over time they have absorbed influences from Hinduism, Buddhism and Christianity.

As per Limbu folklore, the calendar was first created by Yehang Makassam or Yamaksamba, a person with divine knowledge, by observing a spider's web. The web, shown in Figure 4, had 12 sectors and each represented a month. This also gave the idea of the 12 year cycle.

Known as Yalambar Era, Limbu calendar is a Solar Calendar with 12 months, and starts on Makar Sankranti [4]. The present year is 5085. There are 12 months, the year has 365 days. Every fourth year has an extra day, which is added to the first month, Kokphewa. Hence the calendar follows the solar cycle and the seasons faithfully. In modern times, the calendar was conceptualized and compiled first by Shri R B Yakthung Chum. It is now compiled by his son in law Mr. Prem Limbu [4]. The twelve months in the calendar are given below :

❖	Kokphewa	29 days + 1
❖	Sapherwa	30
❖	Charengnam	30
❖	Therengnam	31
❖	Kapnempa	31
❖	Thapmempa	31
❖	Sisekpa	32
❖	Tesekpa	31
❖	Sisekro	29
❖	Thesekro	30
❖	Senchengla	29
❖	Sisekla	31

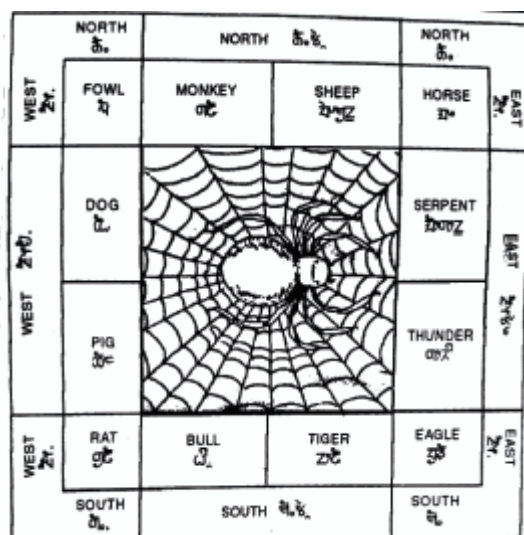


Figure 4. Figure of Spider and net that gave rise to the 12 month and 12 year cycle [4]

The first Limbu calendar in Sikkim was designed and printed in 1989 by Jash Hang Subba, P. B. Subba and Tej Man Subba [5]. The calendar is published by Timburbong, Soreng District, Sikkim. This calendar has the same months as the one by Shri R B Yakthung Chum, but the days in every month is different. According to this calendar, the present year is year 5085, a leap year with 366 days. Many societies and members of the Limbu community continue to print the calendar to this day, and still follow the Yalambar Thongbey system, which is 3,060 years ahead of the Gregorian calendar. In the Limbu calendar, the name of each month carries a significant meaning, representing something unique and symbolic. The calendar begins in mid-January and ends in mid-January of the following year, with each month corresponding to a combination of two half months of the Gregorian calendar. The first day of the Limbu calendar typically falls in the middle of January, on the 14th or 15th.

The period between mid-January and mid-February is known as Kokfekwa (कोकफेक्वा), signifying the blooming of Magnolia. From mid-February to mid-March, the period is called Saffekwa (साफफेक्वा), which denotes the time for planting seeds. Mid-March to mid-April is known as Cherengnam (चेरेङनाम), meaning sunny days. The span from mid-April to mid-May is Therengnam (थेरेङनाम), while mid-May to mid-June is Kapmeppa (काप्मेप्पा), symbolizing cloudy and rainy days. The month from mid-June to mid-July is Thakmeppa (थक्मेप्पा), the season of cultivation. The month from mid-July to mid-August is Seseekpa (सेसेक्पा), the sowing of seeds. The interval between mid-September and mid-October is termed Seseekro (सेसेक्रो), meaning the time of mist. Mid-October to mid-November is Thesekro (थेसेक्रो), the harvest season when crops are gathered and offerings made to God. The period from mid-November to mid-December is Sensengla (सेन्सेङ्ला), the delightful days, and finally, mid-December to mid-January is Seseekla (सेसेक्ला), representing the cold days [6].

The days of the week also have their own traditional names. Sunday is called Teneba (तेनेबा), Monday is Foraba (फोराबा), Tuesday is Mikhangba (मिक्हाङ्बा), Wednesday is Kesukba (केसुक्बा), Thursday is Kuruppa (कुरुप्पा), Friday is Fesuppa (फेसुप्पा), and Saturday is Sensrengba (सेन्सेङ्बा). These names are used in Limbu community to mark the days of the week. A leap year was observed in the year 5084, which corresponds to year 2024 in the Gregorian calendar.

Interesting Point:

The calendar follows a 12 year cycle like the Chinese calendar, though it is a solar calendar. Each cycle is dedicated to one of the five elements of fire, earth, wind, water and sky. This makes a large cycle of 60 years.

RAI CALENDAR

The Rais are an ethnolinguistic group belonging to the Kirat family and primarily Sino-Tibetan linguistic ethnicity. They are indigenous to the eastern parts of Nepal, Sikkim, Darjeeling Hills and in southwestern Bhutan. Their religion is based on animistic nature and ancestor worship. Rais do not believe in heaven or hell, and there is no religious hierarchy.

The community is divided into many clans and they follow different calendars. The Rai calendars studied by us are Solar Calendars. The calendar first seen by us showed the year 2019 as Yalam era 5079. Like the Limbu calendar, this Rai calendar also starts on Makar Sankranti and has 365 days [7]. An extra day is added every 4 years, which makes the first month, Leenappa, of 30 days. This keeps that calendar true to the solar cycle. The months of the calendar are as given below.

- Leenappa 29 + 1
- Halchuwa 30
- Phurkicha 30
- Guluma 31
- Beetheema 32
- Geeta 30
- Tekhree 31
- Saawaalaa 32
- Mulumee 30
- Puksumee 30
- Saankuruwaa 30
- Khaandeeree 30

This calendar also follows the 12 year cycle, and is thus pretty similar to the Limbu calendar. However, the names of the months are different and the division of the days in each month is also different [7, 8].

The calendar by the All India Kulung Sotang Association or Akhil Bharatiya Kirat Khambu Kulung-Sotang Rai Sangh, Sikkim mentions 2025 as Yale Dong 5085 [9]. This calendar starts mid September and each year has 365 days and was first published in 2017. Every fourth year has an extra day. The months have different names, namely

- Khandiri 30
- Tekri 30
- Sawaal 30
- Chakchakur 30
- Lonappa 29
- Lonamma 30
- Hals 30
- Botongali 31
- Leel 32
- Seel 31
- Bul 32
- Greet 31

The month names have cultural and seasonal significance [10]. Khandiri, the first month, corresponding to the period from mid September to mid October, refers to new life. This may be due

to the beginning of the new year or the end of the monsoon, signifying new beginnings. The next month is Tekri, which refers to drying mud, dry forests and a mild and beautiful climate. Sawaal, the next month refers to the end of harvest and offerings to Gods. Chakchakur, the next month refers to the cold, when nothing sprouts from the land. This month is considered inauspicious, when marriages are not held. The next two months, Lonappa and Lonamma refer to the Uttarayan or northern movement of the Sun. The first month is masculine and the second one feminine. Hals refers to the warming of the days or the spring, while Batongali signifies the new leaves and flowers that come at this time. The next months, Leel and Seel refer to the summer and the associated hot weather. Bull refers to the heavy rains, increase in the sources of water and flooding. Greet refers to rains and floods, a time when every place is muddy and it is impossible to move out. The week has seven days, named as given

- Neenamlei Sunday
- Lalei Monday
- Dudulei Tuesday
- Wachhilei Wednesday
- Parulei Thursday
- Ruwalei Friday
- Pumalei Saturday

The names of the week are also significant. Neenamlei refers to Nam or the sun, while Lalei refers to La or the moon and is considered good. Dudulei refers to Dudu or strong while Wachhilei refers to water. Parulei refers to the teacher and is also considered auspicious. Ruwalei refers to Shukra or Venus and Pumalei to the snake god, considered not good. All religious rituals start normally on Lalei and Parulei.

The Kirati Bhitte Patro, published by Sumnima-Paruhang Mangkhim, Sitong, Kurseong, West Bengal, India is a solar calendar beginning on Makar Sankranti [11]. The months have different names here.

- Nangchung 30
- Hakayi 29
- Hakyung 31
- Hakdi 30
- Wayung 32
- Walen 31
- Walum 32
- Wachung 31
- Wakhat 30
- Wahang 30
- Chasumala 30
- Chungchi 29

This calendar also has 365 days, with the provision to add one more day every four years.

The week has seven days, namely

- Namlen Sunday
- Lalen Monday
- Khamlen Tuesday
- Sukmulen Wednesday
- Parulen Thursday
- Ruwalen Friday
- Pulen Saturday

The names of the days of the week are similar to the calendar by All India Kulung Sotang Association.

LEPCHA CALENDAR

The Lepchas, also “Rong” or “Rongkup,” are recognized as the earliest inhabitants of the region of Sikkim, Darjeeling Hills, and adjacent Nepal and Bhutan. Their distinct language and cultural heritage are facing increasing pressures from modernization and changing socio-economic dynamics. Originally practitioners of animistic and nature-centred belief systems, many Lepchas have recently adopted Tibetan Buddhism and Christianity, often retaining elements of ancestral religious traditions.

Unlike the Rais and the Limbus, the Lepchas follow a Luni Solar Calendar. 2025 corresponds to Parvatak era 2345. The month begins on the first day of the bright half of the moon (shukla paksha) and ends on a new moon. The months are of 29 or 30 days. The calendar compiled by Renjyong Mutanchi Rong Tarzum (Sikkim Lepcha Association)[12], conceptualized by Late Lha Tshering Lepcha in the 1980s [13], has these months.

- Karnik Nyoumu 29
- Kursong Nyoum 30
- Dhoun Nyoum 29
- Lakaa Nyoum 30
- Sa aam Nyoum 29
- Namasam Nyoum 30
- Balung Nyoum 29
- Na amka am Nyoum 30
- Parwin Nyoum 29
- Go Nyoum 30
- It Nyoum 30
- Raa Nyoum 29
- Maar Nyoum 30

The fourth month Lakaaa Nyoum is the intercalatory month, which appears every three years.

The week has seven days, namely

- Panjeg Sayyak Sunday
- Faat Sayyak Monday
- Mee Sayyak Tuesday
- Sakmat Sayyak Wednesday
- Oong Sayyak Thursday
- Laung Sayyak Friday
- Kung Sayyak Saturday

This same calendar is now being compiled by the Renjyong Mutanchi Ringmom Kurnom or Sikkim Lepcha Literary Organisation, Gangtok, Sikkim[14]. The names of months are similar, but a little different. The numbers of days in each month are different, as given below.

- Kurneet 30
- Kursong 30
- Thon 29
- Som 29
- Numcham 30
- Blung 29
- Numkum 29
- Purvim 30
- Glu 29
- Ith 30
- Raa 29
- Maar 30

This calendar also has seven days in a week. The names are also same as before.

There is another Lepcha calendar compiled by Indigenous Lepcha Tribal Association based in Kalimpong [15]. It mentions the present year as Porthak Era 2345. The names of the months are different. An interesting point of this calendar is that the week consists of six days, namely

- Faat Sayyak
- Laung Sayyak
- Oong Sayyak
- Mee Sayyak
- Sokmut Sayyak
- Kung Sayyak *Points of Interest*

There are actually two Lepcha calendars in use. According to the calendar from Gangtok, 2019 had 13 months and 386 days. The extra or intercalatory month is Lakaa Nyoum, the fourth month in the list. The previous year had 12 months, totaling 356 days. The years follow the 12 year animal cycle, like the Chinese /Tibetan calendars. The calendar from Gangtok has a seven day week while the one from Kalimpong has a six day week. The names of the days of the week are similar, but they do not come in the same order.

CONCLUSION

The calendars of just three indigenous communities show a lot of variety. These communities have lived together for centuries, and have still maintained their different calendars. Many more such calendars are in circulation, and need to be studied before they are lost. Such variation gives an idea of the diversity of the land. In spite of the differences, all the calendars are tuned to follow the seasons accurately.

The communities developed different ways to measure time. The influence of Chinese/Tibetan calendars is particularly noticeable; as seen with solar calendars following the 12 year cycle of the Chinese/Tibetan luni-solar calendars.

The calendars of other indigenous people should also be studied. Correlating them with the calendars of indigenous people around the country and the world would give interesting insights into the minds of the people.

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Study of drying lakes in Himalayan region: *A case study in Uttarey Lake*

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ABSTRACT

Sikkim lies over a fragile geo-environmental condition, in a tectonically active area and spring discharges in this region are decreasing day by day, resulting in scarcity of drinking water in several areas, especially during the dry season (November to mid-May). With global warming, climate change, and receding glaciers, the water budget of the state has become a matter of concern. Accordingly, the study is aimed to investigate the reasons for drying up of the lakes, water resources, and the methods to revive such dried-up lakes in the Himalayan region. Uttarey Lake is a natural lake within a depression formed either by block faulting or glaciation. Detailed geo-physical investigations have been carried out by 2D-electrical resistivity tomography method to determine the reasons for drying and to recommend revival methods.

Key words: Geology, hydrology, dried-up lakes, rainwater, Electrical resistivity tomography, Uttarey Lake.

INTRODUCTION

The Himalayas are known to be young fold mountains formed recently in the earth's history compared to the older mountain ranges like the Aravallis in India and the Appalachian in the United State of America. Himalayan ranges extend for 2500 kms in length (S K Nath et.al 2005) from Kashmir in the West to Auranachal Pradesh in the East with series of parallel ridges or folds and thrust/faults. According to the theory of continental Drift developed by Alfred Wegener (1912) about 250 million year ago our all the continents of the earth formed a huge single landmass called "Pangea" surrounded by one large ocean "Panthalassa". The super continent Pangea divided into two parts viz., Laurasia and Gondwana after 225 million years. Later, other continents started drifting apart in different directions and many continents were further formed. About 35 million years ago the collision of Indian plate and Eurasian plate occurred and as a result the Himalayas were formed. The, then existing ancient shallow sea "Tethys" got rapidly submerged with sediments and begun to rise into longitudinal ridges and valleys. About 25 million years ago during the middle Miocene period, another phase of Mountain building took place which lead to the formation of the lower

Shiwalik ranges. The periodic process of mountain building is an ongoing and continuous process. Although, the major upheaval of the Himalayas has passed, yet the Himalayas are still rising. The Indian plate is continuously moving North at the rate of about 2cm per year as a result the Himalayas is rising at the rate of about 5mm per year. This indicates that the Himalayas are still geologically active and structurally unstable, characterized by frequent occurrence of earthquakes in the entire Himalayas region (Tashi.T, et.al, 2001-02).

Preliminary study regarding the decreasing discharge of water through the mountain springs and few cases of drying up of the lakes in Sikkim were taken up. The loss is remarkable however, programmes like 'Dhara Vikas Yojana' of Government of Sikkim is dealing to address the problems but still detailed geological/scientific study and solutions are required for rejuvenation of the water reserves in mountain areas. The loss of water would result in scarcity of drinking water and for other uses especially in upper mountain reaches.

The name "Uttarey" has been derived from the flow direction of drainage in the area. It is a bean shaped with approximate length of 280 meters and maximum width at the centre around 140 meters having the surface area of 40,000 sqm approximately. The catchment area of the lake is 1.5 sq. km, having a gentle to moderate slope with medium thick to thick soil cover (<5m - >15m) underlain by competent rock strata. On the catchment area no slope modification/ slope failure is noticed except slope failure due to road cutting. Presently the lake is turned into marshy land due to deposition of silt derived from the catchment area.

GEOLOGICAL FORMATION OF THE AREA

Geologically, the Uttarey area falls under the high-grade metamorphic sequence of the Chungthang Formation represented by streaky gneiss, banded gneiss, quartzite, and veins of pegmatite. Bedding/foliation generally strikes NE–SW, dipping NW at 10°–40°. Rocks are weathered and jointed, covered by thick slope wash material, with bedrock expected beyond 15 m depth. The samples pictures taken during field survey has been shown in figure 1.

Some of the area in the south, west and east districts of Sikkim are relatively and water scarce areas. Due to the tectonic activity and openings in the rocks, the surface or sub surface water tend to percolate down thereby depleting the ground water table in the geo-environmental condition as present in Sikkim.

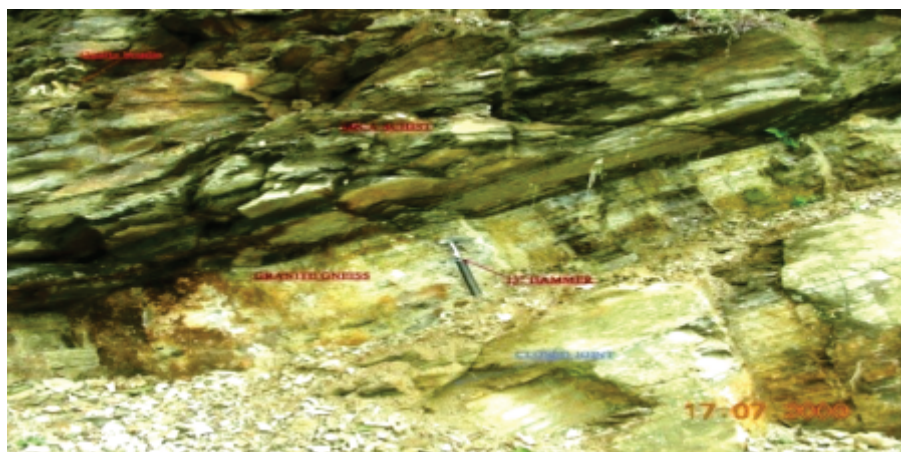


Fig. 1: Highly jointed rock exposures in the Uttarey area, a standard hammer has been placed for the comparison.

MATERIALS AND METHODOLOGY

Two-dimensional (2D) electrical imaging surveys are used to map areas of complex geology where conventional resistivity methods are inadequate. Data are processed into pseudo-sections and interpreted using 2D Resistivity Imaging software. The SSR-MP1 resistivity meter was used to obtain data up to 20–30 m depth, employing a hybrid Wenner–Schlumberger array for better resolution. Multi-electrode profiling and GPS positioning ensured accuracy. Data inversion and topographic correction were performed using GEOTOMO's Res2Dinv software (Loke & Barker, 1996), with five iterations for each inversion.

A total of three resistivity tomography profile were carried out in Lake area, PS-01 and PS-01 was conducted across the outlet of the lake which is towards Eastern side of the Uttarey Lake (As marked in figure 2). PS-02 and PS-02 was carried out along East - West direction across the road side and PS-03 and PS-03' was carried out at NE-SW direction, which is across the lake and dividing the lake from mid-position (shown in the location map) The adopted contour color code provides the key information on parameters of deposited material like presence of low resistivity clayey/silty sand horizons, wet sandy soil horizons and the depth of bed rock. Tentative true resistivity versus subsurface depth is inferred from geological literature (Telford et al. 1990). The data so obtained are used in the preparation of subsurface lithological sections along each profile and also inferred geol-hydrological regimes were carried out.

Similarly, Electrical resistivity is measured by injecting current through electrodes and recording the resulting potential difference to determine subsurface resistivity. This method helps interpret geological and hydrological conditions, revealing groundwater movement, bedrock depth, and saturated zones (Bogoslovsky et al., 1977; Caris & Van Asch, 1991). Electrical Resistivity Tomography (ERT) has become widely used in lake investigations due to its efficiency and reliability (Osazuwa & Chii Chii, 2010). While traditional vertical electrical soundings provide point data, 2D resistivity imaging offers high-resolution subsurface profiles (Griffiths & Barker, 1993).



Fig. 2 location map of the Uttarey Lake showing the electrical resistivity Profiling.

RESULTS AND DISCUSSIONS

The loss of surface/sub-surface water in the geo-fragile environment of Sikkim can mainly be attributed to the openings in rocks such as faults, open joints, foliation of rocks or any other such openings like cracks on soil profile etc. These openings get activated in times of seismic tremors and sometimes vibrations caused by landslides. There are cases where the perennial springs suddenly dries up and have re-appeared at lower elevations and sometimes disappeared leaving the people of upper reaches without spring water source for drinking water. A case was attended by the authors at Lamsal Dhara at Central Pendam Village, East Sikkim where the spring source suddenly disappeared which followed the fault line and re appeared at about three hundred mts. downslope of the area. There have been cases of disappearance of surface water reserve due to anthropogenic activities through un-scientific modernization of slope or by making underground openings. A typical case of drying up of a lake was investigated by the authors at Uttarey, West Sikkim where the water body from the lake had suddenly disappeared. Interviews were conducted with local people and were made known that the water had percolated down in the stream through piping (G. C Khanal 2010) (shown in figure 3). Lakes which dried up due to Geological failure (T. Tashi, et.al) are located at Nagidara, Namthang, South Sikkim and Poison Lake at Rinchenpong, West Sikkim as shown in figure 4. As a result of mountain building processes rocks are highly fractured and depending upon the orientation of such structural elements water finds access to lower elevation under thrust/fault environment and sub-surface accumulation of water is remote.



Fig. 3 Pictures from Uttrey Lake West Sikkim



Fig. 4 Left- Dried up lake at Namthang, West Sikkim and right-Dried up lake at Rinchenpong, South Sikkim.

In hilly terrain, springs, stagnant lakes and seasonal rain are the main source of water supply. The already dried up lake can be refilled after closing in the fracture/joints planes (using various geo-technical methods) in case openings are wider and water seepage through these planes exist. In springs the discharge can be increased by modification of collector wells and plantation of moisture retaining plants in surrounding, mainly at around upper catchment of springs where rocks foliations are dipping towards spring. In the villages, where spring sources are giving poor discharge, cleaning of spring channel and increasing the dimension of collector well is suggested. The Stagnant lakes which are the only source of drinking water supply in some areas the size of the lake can be increased without disturbing the existing one. Some open wells need to be constructed in the weathered residuum. Water seepages from bedding planes, joints, fracture etc. need to be collected in the conservation tank. The existing capacity of the tank should be increased for supply of sufficient amount of water to the Consumers depending upon the discharge of the springs.

Dhara Vikash practice by digging pits and trenches in hill slopes to retain the water and recharging spring is viable scheme subject to provision of geological input which can suggest for proper water retention and for recharging springs at downslope or otherwise wrong selection of site may trigger landslides along the slope. Hence, Dhara Vikas Yojana needs to be implemented in a proper and scientific manner which can recharge the springs at lower elevations. The reasons for disappearance of spring water sources in hills need to be studied thoroughly and techniques for conservation should be made. The perennial springs which are not yet tapped properly may be developed for sustainable water supply in respective areas.

Social awareness has to be created at all levels to educate and to bring awareness among the people about the adverse impact of wastage of water and the benefit of its conservation.

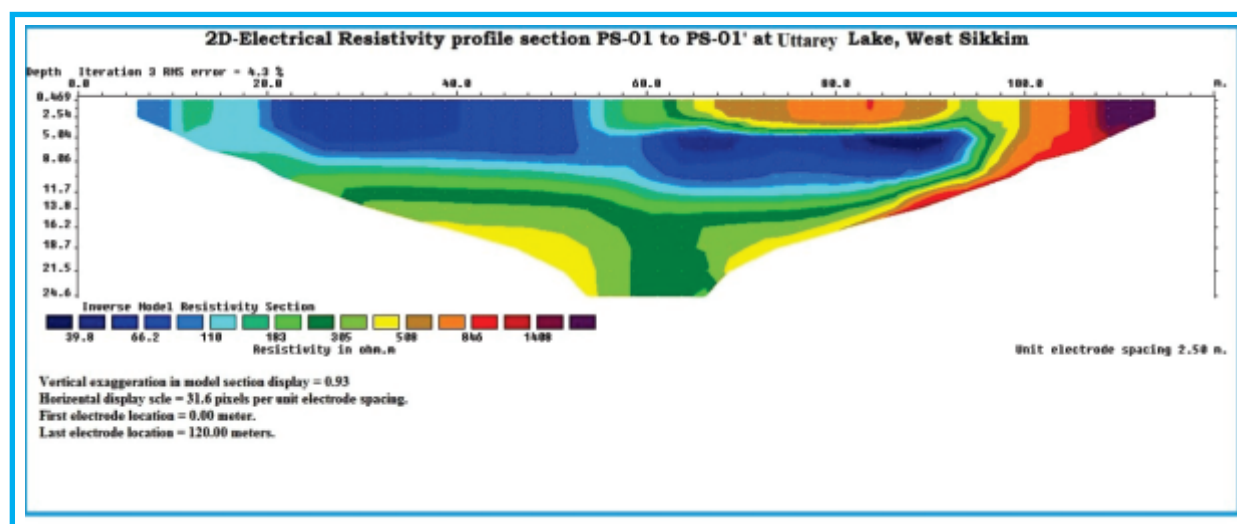


Fig. 5 : 2D-Electrical resistivity tomography of Uttarey Lake along section PS01-01.

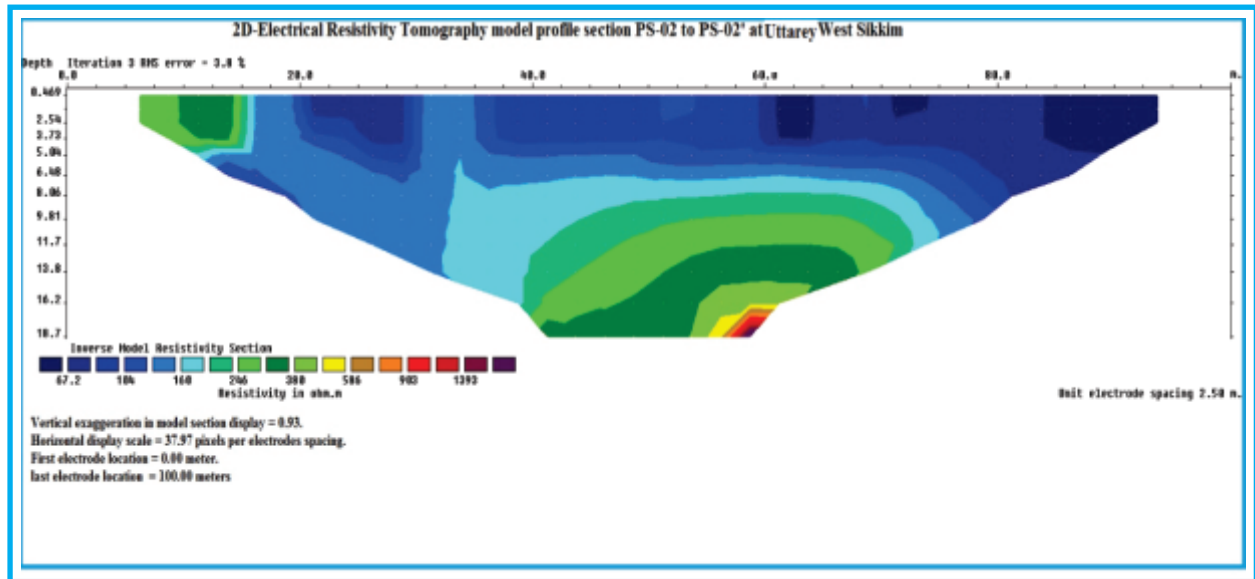


Fig 6 : 2D-Electrical resistivity tomography of Uttarey Lake along section PS02-02.

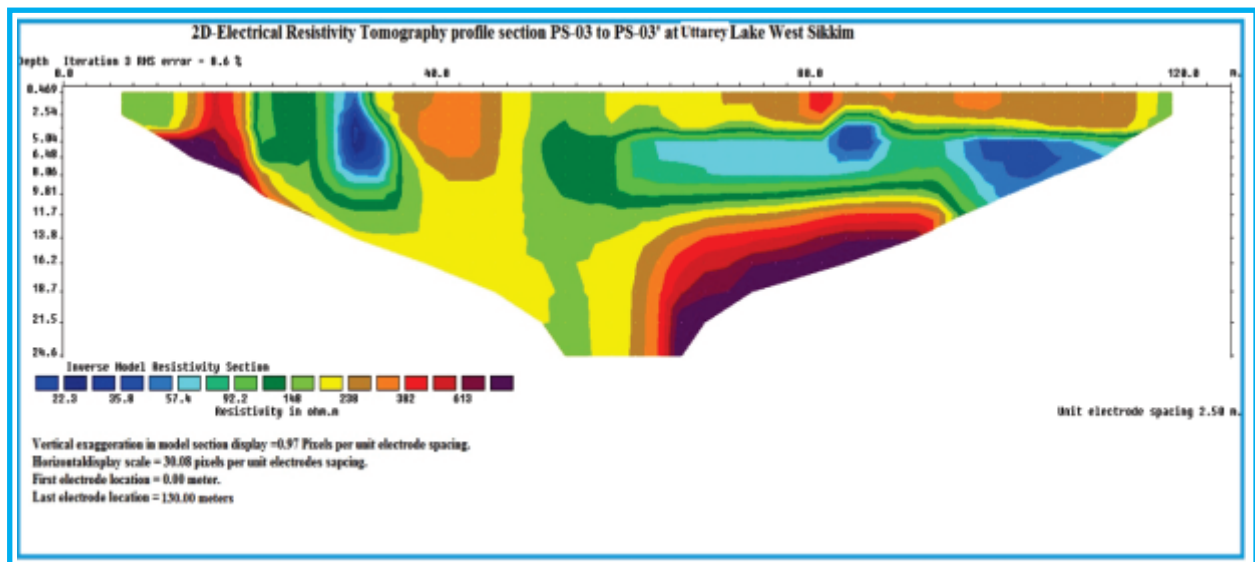


Fig. 7: 2D-Electrical resistivity tomography of Uttarey Lake along section PS03-03.

The 2D Electrical Resistivity Imaging technique used to delineate zones weakness, depth of saturation/water bearing zone, siltation overburden materials, weathered rock/depth of rock strata etc. The observed images for all three sites described in methodology section namely, PS01-01, PS02-02, PS03-03 have been shown in figure 5, figure 6 and figure 7 respectively. From the 2D-resistivity section it is revealed that top 2 meters (average) thickness consists of recently deposited silty materials. The thickness of siltation may increase few meters at the edge boundary/ jhora section which feeds the lake. The water bearing zone up to depth of 8 meters in average exists in the lake area consisting of saturated silty clay layer followed by highly compacted clayey layer of approximate thickness of 4-5 meters is present, except at middle portion, which may be at greater depth underlain

by highly weathered basement rock after 15 meters in boundary portion of the lake is inferred during geo-physical investigation. It is established fact that due to capillary action, the water rises to higher level than the existing water level on the lake. During investigation, information was collected from the newly construction building about the water table in the foundation. As per the available information water bearing zone is much above the existing water level in the lake. Under such circumstances, there is chances of withdrawal of sub-surface water with internal erosion of the materials in the periphery area is high at the time of removal of filling materials from the lake. This may led to damage of existing structures in the vicinity. Taking in consideration of above facts, proper rim treatment or sheet piling to break the interaction between lake water and sub-surface water of upslope area is pre-requisite. The siltation materials from the lake can be removed manually or by using light machinery with caution. At the outlet of the lake (to conserve the water on the lake) low height dam can be constructed with foundation of at least 15meter depth or depending upon compressive strength of the strata/load factor. For this purpose, the samples of the excavated material be tested at the time of execution from the rock zone.

CONCLUSION:

The 2D Electrical Resistivity Imaging (ERI) of the Uttarey Lake area indicates subsurface water-bearing zone, mainly composed of saturated silty clay with compact clayey layers and weathered rock beyond 15 m. The blue-coloured zones in the resistivity sections clearly indicate stable, non-porous strata retaining water. The study suggests that the dried lake can be effectively revived by controlling seepage through fracture and joint planes, implementing rim treatment or sheet piling, and adopting desiltation measures with caution. Additionally, the Dhara Vikas scheme, involving pits and trenches for hill-slope water recharge, offers a suitable approach if executed with proper geological inputs to prevent instability. Enhancing spring discharge, improving collector wells, and increasing conservation tank capacity can further augment water availability. Thus, the integrated geophysical and geotechnical findings confirm strong potential for sustainable revival of the Uttarey Lake.

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

Keshar Kumar Luitel: Formal analysis (lead); Investigation (lead); Methodology (equal); Validation (equal); Writing – original draft (lead). Passang Sherpa, Tikendra Hari Sharma, Goley Eden Bhutia, Brajesh Gurung: Data curation (supporting); Formal analysis (supporting); Investigation (supporting); Methodology (supporting); Validation (supporting). Homnath Luitel: Methodology (Supporting); Writing – original draft (lead), editing and proofreading (lead).

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Political Ideas of Mahatma Gandhi : Beyond Non-Violence

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This article offers a comprehensive review and critical analysis of Mahatma Gandhi's political thought, focusing on his concepts of non-violence (ahimsa), satyagraha, the moral foundations of politics, and his vision of an ideal state (Ram Rajya). Drawing upon Gandhi's own writings and major secondary sources, the paper explores his conviction that politics must be rooted in ethics, spirituality, and service to humanity. Gandhi rejected the realist conception of politics as a struggle for power and instead proposed a model grounded in truth, moral discipline, and self-sacrifice. His insistence on the inseparability of religion and politics stemmed from the belief that morality, tolerance, and compassion are essential for good governance. The study also examines Gandhi's critique of the modern state and Western democracy, which he viewed as inherently coercive and materialistic, contrasting it with his idea of decentralised, self-sufficient village communities. While Gandhi's ideals of non-violence and moral politics remain profoundly influential, the article critically assesses the limitations and challenges of applying these principles within contemporary political systems dominated by centralisation, economic inequality, and state violence. The analysis concludes that Gandhi's political philosophy continues to offer a timeless ethical framework for rethinking democracy, development, and justice in the modern world.

Keywords: *Gandhi, non-violence, Satyagraha, Ram Rajya, state, religion, and politics.*

INTRODUCTION

Mohandas Karamchand Gandhi (1869-1948), one of the most influential leaders of the 20th century. Gandhi was a great individual, a spiritual reader, a writer, a freedom fighter, and most importantly, a mass leader who had played a vital role in the struggle for freedom, which ultimately liberated the country of India from colonial rule. He was born on 2nd October 1869, in the small state of Porbandar, Western India. His educational background gives the picture that he received his early education in the village, and studied Law in England. After his return to India after completing his studies in England, he went to South Africa to work as a lawyer for the Indian company. Gandhi was shocked to find the racial discrimination practised by the British Government against Indians and other non-white people in South Africa. Being educated in Britain, Gandhi was very much aware of the English culture (Gandhi, 1997; Dalton, 2012). He decided to stand against this inhuman practice and organised the Indians together and started a non-violent agitation against racial discrimination.

The earlier political philosophy of Gandhi was based on passive resistance. Realising the power of the state and the foundation of modern state being based on violence, he accepted that there is no other means to fight against state power except non-violence. The state is well organised and will use all its machinery to curb any kind of violent movement against it. According to Gandhi, "Man has a soul, but the state is a soulless machine." Gandhi believed in the adoption of non-violence as an instrument to fulfil the cause. Gandhi further argued that the state is based on violence because violence creates only counter-violence, and the state is well capable and always prepared to crush it in the name of law and order. Gandhi had deeply realised that the modern state is a soulless machine and if we want to fight against it, then we have to use our soul power; in other words, one has to follow the path of non-violence. (Guha, 2019; Parel, 2016).

Gandhi believed that the modern state is based on violence, and it is always well prepared to handle any kind of violent activity against it. But Gandhi said, the state has no means to tackle any non-violent movement because the state does not know how to tackle non-violent agitation. To Gandhi, non-violence is the only way to fight against the modern state, and the only way to success. Gandhi said the path of non-violence should be followed in every sphere of life: social, economic, and political fields. Gandhi used non-violence as a political weapon to fight against the British government. The non-violent move led to the removal of racial discrimination by the Britishers in South Africa.

Gandhi's return to India in 1915 marked a new beginning in the real practice of his thoughts and philosophies of non-violence. In India, the condition of the Indian people was not very different as compared to the Indians who were living in South Africa. Gandhi saw so much poverty, hunger, communal tension, and the authoritarian nature of British rule in India. Seeing this, he decided to devote his life to liberating his countrymen from colonial rule through the weapon of non-violence by converting it into a satyagraha. Gandhi was not a political leader of a conventional type. He was a spiritual man and a social reformer. But, while fighting against British rule in South Africa as well as in India, Gandhi provided one of the most important and unique types of political leadership before the world: the leadership of spirituality, the leadership of non-violence, leadership of morality, the leadership of ethics, and most importantly, the politics of moral force.

My sincere attempt in this article is to find out the answer to very fundamental questions in

M.K. Gandhi's political thought, that is, what is politics? What is the main reason for moral and ethical crises in present-day politics? Why is politics of non-violence effective and necessary in today's world? What is the relationship between religion and politics? What is the relationship between means and ends?

METHODOLOGY

This study is based on a qualitative systematic review, as the subject of Gandhian thought is inherently philosophical and interpretative in nature. Given the limited availability of prior systematic reviews in this area, a preliminary methodological framework had to be developed specifically for this research. The review followed a structured research design that involved an extensive online search of relevant literature using specific keyword combinations across major

academic databases. The keywords employed in the search were: "Gandhi and non-violence," "Gandhi and political thought," "satyagraha", and "Gandhi and modern state." The initial search was conducted using Google Scholar, which yielded a large amount of literature. Among them, only the well-established and well-known literature, including the autobiography of Gandhi himself, was taken into consideration. This review is completely based upon these books and my own understanding and interpretation.

GANDHIAN POLITICAL PHILOSOPHY: CORE PRINCIPLES

Gandhi's political ideology is rooted in ethical, spiritual, and moral principles, shaped by the teachings of Jainism, Hinduism, Christianity, and influences from thinkers such as Thoreau, Tolstoy, and Ruskin. The fundamental tenet of ahimsa, non-violence, serves as both a principle of personal conduct and a method for achieving social justice (Gandhi, 1997; Borman, 1986). For Gandhi, ahimsa requires an active principle of love and compassion for all living beings, extending beyond abstaining from physical harm to promoting inclusive societal frameworks (Chakrabarty, 2011; Dalton, 2012). "Public service is the means to attainment of God, because God is infused in everyone; therefore, the service of community is service of God" (Gandhi, 1997). This is how Gandhi used to say about politics; for him, the ultimate aim of human life is the realisation of God, and public service is the only means to attain it. For Gandhi, politics was not something for personal need or selfish ends; it had greater aims and objectives. The main aim of politics, according to Gandhi, is to remove every tear from the eye of the common citizen. The present meaning of politics provided by realist thinkers, as if politics is nothing but a continuous struggle for power, has no place in Gandhian thought. The present form of power politics, which is very separate from morality and ethics, only increases narrow and selfish interests in leaders. Gandhi totally rejects the politics advocated by realistic thinkers, like Niccolo Machiavelli, Thomas Hobbes, and H. J. Morgenthau, who reject the ethical and fusion between religion and politics. Gandhi advocated the ethical and moral view of politics. For Gandhi, politics is not something like a struggle for power. But it is the means of public welfare and service of God; he said, service of humanity is service of God.

Gandhi devoted his entire life to the struggle for individuals' rights and freedom. Gandhi was a spiritual person, and his political thinking was also very much influenced by his religious views. He said, "When I was in South Africa, a lot of my friends left me because they thought that my political action was very much influenced by religion. Later, I realised that they were right; not only is my political action influenced by my religion, but all my activities are influenced by religion". Gandhi said that those who think that politics is different from religion do not know the actual meaning of politics, because religion is the whole source of morality, goodness, tolerance, and humanity; therefore, there is no politics without religion. Gandhi said, today politics has its dirty nature because all God-loving people, religious people, and moral people are thrown away from politics. Therefore, for Gandhi, politics is not a power struggle, nor is it an instrument which can be used to fulfil personal interests, but it is the means to provide a greater service to the community; it is the means to the attainment of God, because according to Gandhi, God is infused in everyone. Therefore, service of the community is service to God. So, Gandhi provides a very positive and moral nature of politics. For Gandhi, politics is self-sacrifice, self-delegation, and self-commitment

to the service of the nation and service to humanity. "If I seem to take part in politics, it is only because politics today encircles us like coils of a snake from which one cannot get out, no matter how one tries. I wish to wrestle with a snake", said Gandhi, "I am trying to introduce religion into politics." Gandhi said that his struggle in South Africa and even the struggle of India is also religious freedom.

But, for Gandhi, religion is something different which we practice in our daily life. He said, "For me, religion is not something which people practice in temples and churches, but the religion which accommodates all the religions of the world." Gandhi later said, "My whole life struggle is the struggle for religious freedom". "I could not live even a single second without religion". "All the activities of men must be derived from their religion, because religion means being bound to God, that is to say, God rules your every breath. If you recognize this truth, naturally God regulates every activity of yours". For Gandhi, politics means service of the community, and therefore service of God, because God is infusing in everyone. Gandhi said — *"those who talk about religion and politics are two different things, actually did not know the actual meaning of politics, I do not think so"* (Desi, 2013).

When Gandhi was in England in 1932 for the Round Table Conference, one reporter asked him, Gandhi, tell us what quality do you think that the present leaders must have? Gandhi said, "realisation of God in every second in 24 hours". Gandhi believed that true politics cannot and should not be separated from religion, because the purpose of both religion and politics is the same: to serve humanity. For Gandhi, religion is the source of morality and ethics; all religions have the same purpose, but the approach is different. No religion in this world is completely perfect, but all are in their evolving processes. Gandhi said, God is one, but the approaches are different to see him. All religions have the same purpose. For Gandhi, Christianity is full of humanity; it teaches us to love others, to serve others, kindness, and non-violence. Islam teaches brotherhood, he said. Islam is the symbol of universal brotherhood, and Hinduism is the symbol of tolerance. Gandhi does not think Buddhism and Jainism are different from Hinduism. Gandhi never blindly followed any religion, but he used to practise all religions. He clearly said, a true Hindu can only become a true Muslim, and a true Muslim can only become a true Hindu. For Gandhi, there is no contradiction among the religions because all religions are imperfect, and none of them completely knows the absolute truth. God is one and we are all children of the same God, therefore there is no monopoly on truth. No religion can say what is actually true, but all know the partial truth. He said, until we know the complete truth, we have to live with partial truth, because the complete truth is God. According to Gandhi, all the religions of the world have the same purpose and all have the same aim, to attainment of God. Religion is the source of morality, ethics, and human goodness. Religions teach us kindness to help the helpless, to treat all our fellow beings equally, not to harm others, and most importantly, to act in a non-violent manner. So, for Gandhi, the question of difference does not arise in religion and politics. Both religion and politics have the same purpose, and that is to serve humanity. Gandhi said, "Today politics is dirty, it is only because the religious and God-fearing people have thrown away from politics. All God-fearing and religious people should be involved in politics and purify it from inside" (Desi, 2013). This was the view of Gandhi about politics and religion. He not only says there

is a close relationship between religion and politics, but there will be no pure politics without religion, because both have the same purpose to the realisation of truth, and that is God, through the public service and non-violence. **Critique of Modern State and Democracy**

Gandhi was against the centralisation of power and the coercive nature of the modern state. He characterised the state as a "soulless machine" and as an organisational embodiment of violence (Dalton, 2012; Gandhi, 1997). Unlike anarchists, however, Gandhi did not seek the total abolition of the state but envisioned a stateless democracy—a federation of satyagrahi village communities based on voluntary cooperation and peaceful co-existence (Guha, 2019; Jahanbegloo, 2020). His vision calls for individual and collective self-governance, decentralisation, and a bottom-up model where authentic power resides with local communities rather than centralised authorities (Gandhi, 1997; Parel, 2016; Chakrabarty, 2011).

As such, he believed in the right of freedom and equality of individuals, which are possible in a democratic society. He spent his entire life safeguarding the democratic freedom of individuals. He always stood for the rights of the individual. He firmly believed that power belongs to people. He said, "Truth is that power which resides in the people, and it is entrusted for the time being to those whom they choose as their representatives. Parliament has no power or even exists independently of the people." Although Gandhi was a strong supporter of democracy, he was not a blind follower of it. He strongly criticised the working of democracy in a Western type, which has the nature of capitalism and imperialism. To him, Western democracy as it functions today is undiluted Nazism or Fascism. Hence, Gandhi did not see any good features of democracy working in a Western type. He said, "The European democracies are to my mind a negation of democracy". Total surrender of power in the hands of the prime minister/president and the ruling party is not appropriate, as it often lacks honesty and integrity. He insists that Western democracy is dominated by the ruling class, who try to fulfil their own selfish interests in the name of the common good. He stated that "People of Europe no doubt political power, but no SWARAJ".

GANDHIAN DEMOCRACY VS. WESTERN MODEL

<u>Feature</u>	<u>Gandhian Democracy</u>	<u>Western Democracy</u>
Structure	Decentralised, village-based	Centralised, parliamentary
Basis	Moral/spiritual, non-violent	Political force permissible
Minority Rights	Emphasised, protected	Often subsumed by majority rule
Form of Governance	Self-rule, voluntary cooperation	Electoral, competitive
Economic philosophy	Sarvodaya, equity	Capitalist, inequality tolerated

GANDHI'S IDEAL STATE: RAM RAJYA

Ram Rajya, Gandhi's concept of ideal governance, refers to a decentralised, stateless society characterised by economic equality, moral rule, and absence of religious or class conflicts (Guha, 2019; Dalton, 2012). It is not tied to any one religion but reflects universal principles of justice and peace, prioritising social harmony over legal coercion and vesting power in self-sufficient villages

(Borman, 1986; Gandhi, 1997). While Ram Rajya remains an inspiring vision, many scholars regard it as utopian, noting practical challenges of implementation in complex nation-states (Parel, 2016; Guha, 2019).

Democratic Decentralisation: The ideal state for Gandhi is based on the principles of decentralisation. Gandhi believed in democratic decentralisation. Power must flow from bottom to top; each village must have complete freedom to take decisions in their affairs which directly affect their life. Gandhi gave the slogan "Back to the village." So, the first important principle of Gandhi's ideal state is democratic decentralisation.

Economic equality: Ram Rajya will be a society of economic equality. Gandhi wrote, "There will be no Ram Rajya in the present state of inequalities in which a few rolls in wealth and the masses do not even have enough to eat. Even distribution will be a feature of the society. It will be characterised by mutual confidence and spontaneous organisation. People will be public- spirited and devoted to the ideals of justice, peace, and rights. Non-violence will be the rule of society. It will aim towards the realisation of international peace. There will be no place for war in it." So, Gandhi's ideal state is the symbol of economic equality for all its citizens.

Rule of the moral spirit: The Gandhi concept of Ram Rajya is not only a concept of political ideas, but it is the representation of the moral spirit. It is the state in which complete harmony exists within various communities. There will be no class conflicts, no religious conflicts, no discrimination by men against men, on the basis of caste, creed, religion, etc. In Ram Rajya, everybody earns an honest living; there will be no distinction between physical and intellectual labour, and equal pay for both physical and mental labour.

Perfect society: The ideal state advocated by Gandhi represents the perfected society. It is the society rather than the state. It is more of a social organisation than a legal organisation. In the ideal society, the citizens have moral and ethical obligations, rather than legal obligations. As far as Gandhi's ideal state is concerned, it is a very moral organisation, rather than just a legal organisation like the modern state.

Non-violent state: The most important feature of Gandhi's ideal state is based on the principles of non-violence. In fact, all the philosophy of Gandhi is based on the principles of non-violence; Gandhi believed that the political system based on the principles of non-violence is the perfect state. Gandhi rejects the idea of state sovereignty and the coercive power use by the modern state in the name of law and order. He said, no democratic society could attain without the help of violence. Gandhi desires a non-violent state based on the principles of equality, liberty, freedom, fertility, and justice to all the communities for both minorities and the majority. He said, the question of whether the ideal state is practicable or not depends on the will of the society to act in a non-violent manner and the moral will of the various communities. If we want to conclude the ideal state advocated by Gandhi, then it is the state of non-violence in its entire sphere, like social, political, and economic affairs.

MEANS USED BY GANDHI TO ACHIEVE HIS POLITICAL GOAL: NATIONAL FREEDOM

The means used by Gandhi to achieve his political objective is non-violence, which Gandhi called Satyagraha. For him, Satyagraha means two things: Satya and Agra. Satya means truth, and Agra means insisting on something without becoming obstinate or uncompromising. In other words, Satyagraha means holding a truth in any situation, truth in thought, truth in speech, and truth in action. Satyagraha is the political implication of Gandhi's political ideas. It is the method to achieve his political objective, that is, Indian independence. For Gandhi, there is no contradiction between means and ends; a good end cannot be attained by wrong means. End means India's freedom, and means is non-violence, i.e. Satyagraha. According to Gandhi, Satyagraha is the political weapon of the strong and not the weak. It is not the weapon of weak people against the unlawful government. He successfully used this means of Satyagraha against the unjust rule of the British in India.

The following are the essential qualities given by Gandhi to become a true satyagrahi:

1. **Truth:** According to Gandhi, a true satyagrahi is one who always holds on to truth, and the follower of truth should be truth in thought, truth in speech, and truth in action.
 2. **Non-violence:** A Satyagrahi is one who always acts in a nonviolent manner. For Gandhi, violence is the nature of brute and non-violence is the nature of human beings. Gandhi said a true Satyagrahi never fears to face death; he is always ready to face death, but he never uses violence and force.
 3. **Brahmacharya :** The concept of Brahmacharya provided by Gandhi is controversial sometimes, as it opposes married life and sexual intercourse, which is against the natural law, and very hard to follow. However, Gandhi did not universalise this concept. He said, India has the culture of Brahmacharya from ancient times, the great Indian heroes like Shankar, Swami Vivekananda, Ramakrishna, and many others follow this principle and contribute most to society and human beings. Therefore, Gandhi said, it is better to be Brahmacharya so that he can fully concentrate on his mission and duty of Satyagraha.
 4. **Control of plate:** According to Gandhi, the Satyagrahi must have control over his plate; otherwise, he or she cannot succeed in his mission. A true Satyagrahi is one who has strong self-control over his plate.
 5. **Non-stealing and Non-possession:** This means not to take anyone's things or goods without his or her permission. In addition, do not use the resources more than what is our immediate requirement. Gandhi said, this world has enough resources to meet all human needs, but it has no capacity to meet the greed of even a single man, so Gandhi's main focus is the need and not greed. A Satyagrahi is one who uses natural resources according to his need and not according to his or her greed.
 6. **Bread- Labour:** The main focus of Gandhi is the production by mass and not the mass production. He said one must earn bread at least for oneself. Gandhi said, No individual remains without doing work. Living without working is not worth living; he or she is a burden on society.
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Therefore, everyone should work so that they can produce for themselves and for societal needs.

7. **Fearlessness:** Fear is the main reason for human misery, so one should work without fear. Gandhi said, "Fearlessness connotes freedom from all external fear; fear of diseases, bodily injury and death, or dispossession, losing one nearest and dearest, or losing reputation and so on." So, according to him, a seeker of truth, that is, a satyagrahi, always works courageously.

8. **Swadeshi:** Swadeshi means to use goods made by one's own countrymen. By doing this, one can help the poor farmers and the indigenous industry, which ultimately leads to the progress of the village and country. To Gandhi, "Swadeshi is that spirit within us that restricts us to use any service of our immediate surroundings to the exclusion of the more remote." Further, he said that a satyagrahi is one who always uses the goods made by his own fellow citizens.

9. **Swadharma:** It means respect for all individuals and their dignity. In other words, it denotes that one should hear and receive the ideas from all the corners of society. Gandhi said, "I do not want my house to be walled on sides and my windows to be stuffed. I want cultures of all lands to be blown in my house as freely as possible, but I refuse to be blown off my feet by any one of them." So, according to Gandhi, a satyagrahi is one who gives respect to all other cultures and religions, takes the good values and shares them with others.

SATYAGRAHA CAN BE USED IN THE FOLLOWING MANNER :

1. **Non-violent movement:** According to Gandhi, a true satyagrahi is one who is always ready to protest against unjust laws made by any government in a non-violent manner, or in other words, the citizens have every right to protest against the arbitrary acts and activities of the government. But the way of protest must be different, that is, non-violent movement.

Non-violent movements include resigning from government services; honours and posts, non- participation in any government functions, closing all educational institutes funded by the government; resigning from all government posts and organisations, and forming institutions like Panchayati Raj, to boycott all the foreign-based services that are protected by the government; to popularise the swadeshi and boycott of foreign goods. So, for Gandhi, non- violence is the most effective weapon that can be used by a satyagrahi to fight against an unjust government.

2. **Civil Disobedience:** Civil disobedience is disobedience of the unjust laws made by the government. However, the essential criteria before launching a civil disobedience movement is that there must be support from the people, and due notice must be given to the opponent of the launch. The satyagrahi, before launching the civil disobedience, must make people aware about the unjust law. The movement is civil in the sense that it must have a social interest, and be supported by the masses. Gandhi further said, "If the civil disobedience movement is taking a form /shape where innocent people are losing their lives and if satyagrahi is realising the fact that it is going to be uncontrollable, then it would be better to take the movement back".

3. **Strike:** Gandhi also supports the method of strike for better working conditions of the labour group. But it should be remembered that his method of strike is different from the present-day strikes. The strike suggested by Gandhi is totally non-violent in nature.

4. **Fasting:** Gandhi also supported and practised fasting to protest against the unjust rule of the British. According to him, fasting is the last weapon to be used by a satyagrahi. When all other means of protest fail, the satyagrahi can use a public fast. According to Gandhi, mere physical strength is not a criterion for a fast; it is the soul force, it is the use of the inner strength of a satyagrahi. It is the most powerful instrument to change the heart of the opponent. Earlier, fasting was considered a private activity, but Gandhi first used it for a public purpose. He used public fasting as the most powerful weapon to fight against the unjust British rule.

5. **Hazrat:** Hazrat is another and last instrument in the hand of the satyagrahi. According to Gandhi, Hazrat really means to leave the place of exploitation by his own consent. Satyagrahis should leave the place of exploitation in order to preserve their self-respect and self-esteem.

So, Gandhi tries his best to provide new ways of protest in the modern world. He not only talks and writes his thoughts and philosophies, but he also used to fight against the British rule in India. Gandhi faced criticism for being an idealist who did not give importance to practical means in solving contemporary issues and problems. But, for Gandhi, he was the practical man who used the means like civil disobedience, non-cooperation, satyagraha, and fasting as a political instrument to fight against unjust foreign rule.

LEGACY AND CONTEMPORARY RELEVANCE

Gandhi's doctrines continue to influence movements for social justice and civil rights worldwide. His concepts of moral politics, non-violent resistance, and decentralisation of democracy have inspired successful campaigns beyond his time, including India's independence and modern protests against state repression (Dalton, 2012; Guha, 2019; Jahanbegloo, 2020). However, contemporary scholars urge careful appraisal of Gandhi's ideas, balancing their ethical appeal with practical realities and contextual adaptations (Parel, 2016).

In our day-to-day life, we come across many protests and movements going on, but ultimately, they are crushed by the state by using its coercive power, or they fail because ultimately those movements turn into violence. Gandhi was successful in many movements carried out against the British rule because all these movements were based on non-violence.

After Gandhi, many movements became successful in India and other parts of the world. To cite some: In India, in 1974, the J. P. Movement was launched against the autocratic rule of former Prime Minister Indira Gandhi. The 2012 anti-corruption movement launched by social activist Anna Hazare was a non-violent protest against the then-government.

Gandhian ideals of non-violence and satyagraha were not only confined within India, rather it also inspired and grew into one of the most influential moral forces of the modern era, shaping various democratic moments and social transformations across the world. Gandhi's vision focused on the power of truth, compassion, and moral strength over violence and hatred, offering a profound alternative to oppressive systems. His approach of peaceful protest and civil disobedience against injustice was adopted by prominent leaders across the world, such as Martin Luther King Jr. in the United States of America, Nelson Mandela in South Africa, to challenge the many autocratic regimes with dignity and patience. The lasting significance of Gandhian philosophy lies in its belief

that real and lasting change can be possible only through self-discipline, empathy, and respect for the humanity of opponents' forces.

More than a century ago, Gandhi clearly understood the violent nature of the modern state and its threat to individual rights and freedom. With his far-sighted vision, he adopted non-violence as the guiding principle of India's freedom struggle, through which the country ultimately achieved independence by peaceful means. As a result, Indian citizens became accustomed to expressing their demands through non-violent means. In contrast, Nepal attained its democracy through violent uprisings and armed struggle against autocratic rule. Consequently, the culture of expressing dissatisfaction through violence became ingrained in Nepali society. The recent political instability, along with the violent and destructive activities associated with the Gen Z movement, stands as a reflection of this continuing trend (The Guardian, 2025).

Apart from all these adoptions of his ideas and principles by various leaders across the world. The United Nations General Assembly in the year 2007 declared 2nd October, which is the birth anniversary of Mahatma Gandhi, as the International Day of Non-Violence (United Nations General Assembly, 2007). This day is observed every year to remember his legacy and to promote the universal peace, tolerance, and non-violence that he championed his entire life. It also serves as a reminder of his continuing influence on global movements for justice and his view on the peaceful transformation of power.

CRITICISMS

Although Gandhi's political thoughts were very influential, they face a significant critique regarding their selective relevance in diverse social and political contexts. His belief in universal human goodness sometimes overlooks the corrupt or violent aspects of human nature (*Ambedkar, 1945*). The idea of spiritualised politics may also appear impractical to those outside his ethical or religious framework. Moreover, his fusion of religion and politics, though intended to purify public life, risks deepening sectarian divisions in pluralist societies. As *Parel (2016)* argues, Gandhi's principles of truth and non-violence require contextual adaptation rather than rigid application; they are not absolute doctrines but dynamic moral instruments meant to evolve with changing political realities. Similarly, *Jahanbegloo (2020)* alerts that uncritical attachment to Gandhian ideals may puzzle the structural injustices of modern states and the necessity for rational resistance. Gandhi's model of non-violence, therefore, while morally compelling, may underestimate the realities of power and the potential legitimacy of force in self-defence. Furthermore, the moral adversity demanded by *satyagraha* and *Ram Rajya* often implies that these ideals are unattainable for ordinary citizens (*Dalton, 2012; Guha, 2019; Brown, 2008; Nandy, 1998*).

CONCLUSION

M.K. Gandhi was not a political thinker like Plato, Aristotle, Hobbes, Locke, Rousseau, and Chanakya, who provided a complete theory of the origin of the state, its sovereign power, and its relation with citizens. Gandhi was a social and political activist rather than an activist who fought for individual rights and freedom throughout his life. His political thought represents one of the most profound moral critiques of the modern state. While he did not construct a systematic theory of the

state like the classical political thinkers, his reflections on power, politics, non-violence remain deeply relevant in the twenty-first century. This review has highlighted that Gandhi viewed the modern state as fundamentally coercive in nature, a “soulless machine”, and sought to humanise politics through moral restraint, empathy, and truth. His vision of *swaraj* and *Ram Rajya* offers not merely an alternative model of governance but also a spiritual framework for justice, one grounded in self-rule, moral accountability, and service to humanity.

The key contribution of this study lies in its reinterpretation of Gandhi's ideas as a living moral framework over a fixed political ideology. It focuses on how Gandhian thought can still lighten present global challenges, viz., the misuse of state power, ecological degradation, corruption, and the moral crisis in politics. By emphasising non-violence as both a personal discipline and a political instrument, Gandhi advocated a model for ethical resistance against injustice, which is relevant not only to India's freedom struggle but also to contemporary movements seeking peace and dignity across the world. Future research should focus on how Gandhian ethics and moral ideas can be adapted to address the complexities of digital governance, environmental sustainability, and social division. In an age of rising authoritarianism and violent political expression, as seen, for instance, in South Asia's emerging protest cultures, Gandhi's insistence on inner transformation before outer reform is crucial. His philosophy makes us realise that true political freedom cannot exist without moral freedom, and Gandhi's greatest legacy is his belief that politics, when grounded in truth and non-violence, can become an instrument of human liberation.

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Politics and Ethics of Language Endangerment : — a dossier

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ABSTRACT

In the background of the UN resolution regarding language endangerment, indigenous languages and peoples, the linguistic scenario in Sikkim and Darjeeling is discussed in the light of linguistic vitality under biocultural diversity. It is followed by an assertion that the politics and ethics of language-script endangerment are to mitigate the endangerment and vitalise the linguistic ecology. Following biopolitics and its *extended disciplinary institutions*, other collateral and detrimental factors that affect the linguistic vitality of Sikkim and Darjeeling are discussed and addressed as dossiers invoking stable, constructive, perpetual activism for diversity and dignity.

Keywords: Indigenous languages, language and script endangerment, biopolitics, community grammar, public policy

I

The recognition of one's language as a marker of distinct identity has been one of the catalysts since time immemorial. In the contemporary scenario in Sikkim and Darjeeling, it is embedded and has evolved to be a defining factor of various political assertions (see Sinha & Thapa 2006; Sinha 2008: 1; Sinha & Turin *in press*). Along with the formation of present day Sikkim and Darjeeling, 'Nepali,' in its distinct regional variety from that of Nepal (see Dahal 1978; Subba 2002; Hutt 1997; Niroula 2022) also emerged as a lingua-franca, medium of education, media and governance, and pioneered in defining ethnicity¹, history, literature and inclusive politics (see Gurung 2003; Golay 2006).

Despite multiple linguistic identities and affinities, the speakers conceive themselves in the language they speak (see Miyaoka 2001). In turn, the emergence of the Nepali language as a symbolic badge of membership and distinctiveness leads to the widening of the Nepali speech community², comprising other ethnicities also. On the contrary, this paradigm led to language denial, particularly of the communities with the Nepalis in the then context. Following Turin (2004), Sinha (2020: 15) observes a multilevel alliance of ethnicities/communities with language in the contemporary context, as:

¹ I have conceptualised ethnicity based on Royce (1982:18), who defines ethnic identity as 'the sum total of feelings on the part of group members about those values, symbols, and common histories that identify them as a distinct group.' Ethnicity 'is simply ethnic based action.

² A group of speakers (not necessarily of the same language) who share a set of norms and rule for the use of language(s) (Gumperz 1968) (See Suzanne Romaine 1980 for further details)

- i. **Single-to-many:** Rai at the basic level is a single constituent member. Each sept (or *thara* and *pāchā*) speaks a range of at least 15+ languages from each other, such as Bantawa, Puma, Chamling, Rokdung, Thulung, Kulung, Sampang, Dumi, etc.
- ii. **One-to-one:** Magar, Tamang, Gurung, Thami, etc., each has a language of their own, irrespective of their septs.
- i. **Many-to-single:** All the septs of Newar; Chettri, Bahun, Kami, Damai, etc. share a single language.
- ii. **All-to-one:** Nepali by all the members of the wider Nepali speech community.

Beyond its relation with an individual, society, culture and environment, language thrives on domains of its use and the demographic, socioeconomic, political, and technological breakthroughs that affect domains of language use as well as vocabulary and grammar. Similarly, the linguistic objects are also controlled by the sociocultural experiences of their speakers, and consequently, the linguistic systems are affected by the socio-economic, politico-cultural conditions and socio-cultural aspirations of individuals and of the governance that decides intergenerational language transmission (see Rai 2020 for the Kulung language in Sikkim). Thus, language is also a reflection of a total of such accumulative influences or manipulations. Consequently, languages exist in an environment that is either friendly, hostile or indifferent. In other words, a language can be scaled to be healthy or endangered or moribund or folklorised (Fishman 1991) or extinct or as heritage, or with various possibilities of revival (see Bhujel 2022).

Language endangerment, owing to the plethora of reasons, is a global epidemic. Of interest, India's share in the UNESCO's interactive online *Atlas of the World's Languages in Danger*³ is the largest, with 196 languages, particularly concentrated in the Eastern Himalayas, including Sikkim, Darjeeling and Doars, where indigenous languages, mostly belonging to the demographically smaller indigenous⁴ communities, are endangered in various degrees and domains. In addition to it, there are many mother tongues that are yet to be explored and identified. Thus, in response to achieve the goals of the 2030 Agenda for Sustainable Development and UNESCO's call regarding language endangerment, there are global-scale initiatives, national and local programmes and ground-level actions to arrest it.

At a parallel plane, often at a common folks' comfort, language is identified in accordance with script, which has major social, political, educational, aesthetic, and ritual significances among others. In the context of Sikkim and Darjeeling, the script and its orthography of various languages have been crucial to perpetuate ethnic, linguistic, political, religious and territorial claims. There are several efforts on Graphic Politics (see Choksi 2021) — to invent new graphic symbols (custom scripts for Brookes 2021) and systems (for cosmetic modification, see Sinha 2021), as well as the resignification of already existing ones.

This is further supported by the *Atlas of Endangered Alphabets*, which shows that 85% of the

³ <http://www.unesco.org/culture/languages-atlas/UNESCO/2019>.

⁴ Beyond popular references and connotations regarding indigenous, the United Nations' criterion of self-identification is followed in this paper.

world's writing systems are on the verge of vanishing due to denial, discouragement and dismissal, and are forced to abandon the traditional script, resulting in the loss of embedded knowledge and identity. Sikkim and Darjeeling are not an exception despite the graphic politics. To sum up, the linguistic scenario, a reflection of a total of such accumulative influences or manipulations, in Sikkim and Darjeeling points to language and script endangerment.

On the fine-grained level, despite being engaged with language and script endangerment in a single linguistic ecology⁵ with shared history, culture and demography resulting in a micro linguistic area⁶ as well as common aspirations, there are contrasting linguistic scenarios between Sikkim and Darjeeling. Sinha (2024) attributes the differences to the different socio-political backgrounds and aspirations, institutional support and governance issues. Unlike in Sikkim, where the state is sufficiently engaged with the host communities regarding language deendangerment, broadly in Darjeeling, there is no such role of the state, as well as in the other forms. Thus, governance tends to influence (or manipulate) language both its wealth and health.

II

At another level, the dyadic power relation between a nation-state and the population can be, loosely, stated as Biopolitics, a term borrowed from the social theorist Foucault's concept of Biopower (see Foucault 1997), to denote control of the population through societal disciplinary institutions⁷ (see Roche 2024 for language oppression in Tibet). Here, it is important to note that, in this paper, I shall extend the notion of *disciplinary institutions* to various other governmental-legal-technological tools and practices that are present, absent and dormant that control language in a nation-state like India and states like Sikkim and West Bengal.

In its Biopolitical practice through a governmental understanding of language, the primacy of script over speech cannot be ignored regarding language in general and de/endangerment in specific. In essence, the governmental understanding of language is pivoted fundamentally on script⁸, rather than on the orality of language and its health, mother-tongue speakers and their enumerations, etc. Through this *disciplinary institution*, the script gains prominence over speech in contrast to the popular conception of the primacy of speech over script. It is an acknowledged fact that script, as well as orthography, plays an important role in defining linguistic identity and can be a causal factor, too, at both the governmental as well as the community's dimensions. This shows the centrality of the *graphic* dimension of language in the contemporary biopolitics of Sikkim and Darjeeling, as well as within the community.⁹

In this section, I will explore three *extended disciplinary institutions*, viz. the West Bengal Official Language Act, 1961 and the Sikkim Official Language Act, 1977, pedagogical programmes

⁵ Linguistic ecology is any given language's environment i.e. society.

⁶ Emeneau (1956) identified India as a Linguistic Area with several linguistic features shared between languages due to convergence. Sikkim and North Bengal can be identified as a micro-linguistic area with more than forty languages belonging to four major language families in various levels of endangerment, with both sub- and supra- language strata.

⁷ The *disciplinary institutions* are architectural institutions like prisons, barracks, schools and hospitals or residential institutions like quarters, hostels, long-house or apartments where regimented life is maintained.

⁸ Script, a set of graphic/manual/code symbols used to represent language, is a socio-cultural invention.

⁹ Choksi (2021) makes an interesting intervention on language, script and autonomy in the recognition of an identity of the Santal-speaking Adivasis of West Bengal, Orissa, Jharkhand and other regions.

and the Census(es) to examine the proceeds of the contemporary biopolitics of Sikkim and Darjeeling.

The West Bengal Official Language Act, 1961 adopted that “in the three hill subdivisions of the district of Darjeeling, namely, Darjeeling, Kalimpong and Kurseong, the Bengali language and the Nepali language shall be the language or languages to be used for the official purposes of the State of West Bengal...” By “three hill subdivisions,” Siliguri subdivision of Darjeeling was linguistically bifurcated into cartographic category of hills and plains (see Golay 2025), and there was language denial for the Nepali speaking populace of the subdivision. The cherish came at a cost.

Sikkim is a linguistic mosaic of more than thirty-four languages, which are also spoken in Nepal, Bhutan, and other Indian states. However, only 12 languages, viz. Nepali, Bhutia, Lepcha, Limbu, Bhutia, Rai, Gurung, Newari, Magar, Tamang, Sherpa, Sunuwar and Bhujel have been accorded status as the Sikkim Official Languages. Additionally, English “for transaction of business in the Legislative Assembly of Sikkim, in addition to the official languages of the State” is widely used and heard (see Sikkim Government Gazette, No.5/LD/1990, 9 April 1990), and Hindi is also used in other *disciplinary institutions*. Although these 12 languages was meant to “be used for the official purpose of the State of Sikkim,” it was later amended to include “for transaction of business of the state Government” and “to join in any post in a regular service/cadre... must have proficiency in Nepali language or in any of the official languages...” (see Sikkim Government Gazette, No. 219, 14 June 2017). Paradoxically, except Nepali, all other State Official Languages are endangered to various degrees (see Sinha 2014, 2017, 2020), blurring the distinction between the State Official Language and non-official languages. This points out that, even after forty-five-plus years, these languages continued to be endangered in Sikkim. Hence, the governmental-legal-technological tools and practices can be made into a good practice for their sustainability, but not solely enough for the long run to develop and evolve.

In a similar spirit, Rai (2020) writes that Bantawa, a clan/sept language of the Rais belonging to the Bantawa sept, has been adapted as Rai, signifying the language of the Rais, obliterating the other clan/sept languages of the Rais in Sikkim, leading to language denial. In contrast, other sept languages of the Rais, like Kulung [ISO 639-3 kle], are accepted as the clan/sept languages of the Rais as well as a heritage language of the Kulung sept, but it is a *non-existent language* of Sikkim, as there is no mention of the language in any state official apparatus in Sikkim (see Rai 2022). Further, she mentions that Kulung in Sikkim is in a moribund state, and the recognition of Rai as the language of the Rais has resulted language shift to Rai after being shifted to Nepali earlier. Consequently, she writes that “Kulung is an *incrementally endangered* language that ceases to exist as mother tongue in Sikkim if such waves of language shifts ... and language policy are not reversed or directed to the optimal condition enabling sustenance and promotion.” In other words, language shift towards the recognised languages has led to *incremental endangerment* of other smaller, indigenous languages both in Sikkim and West Bengal. There is no doubt that such *institutionalisation* has its own pragmatic reasons, yet such collateral damages need to be mitigated.

As the governmental policies are translated into the pedagogical practices, language and script-orthography ideologies, demographic strength, availability of literary materials and human

resources, etc., play a significant role (see Sinha *ms.* for tribal languages of Sikkim). Apart from these factors, other factors also determine how high these languages can be subject and/or medium of education. In Sikkim, Bhutia, Lepcha and Limbu are taught till the universities, whereas other languages are limited to primary, secondary, and senior secondary schools and colleges. To be specific, in the selected government schools¹⁰, Gurung, Rai, Tamang and Sherpa are taught till Class X, whereas Newari, Sunuwar and Magar are up to Class VIII. Bhujel, recognised as the Sikkim Official Language in 2022, has progressed to Class III¹¹. Paradoxically, Hindi, Sanskrit and English are taught in almost all the universities in the state, whereas Sikkim's official language and one of the 8th Scheduled languages, Nepali, even as a subject, is not taught in many established universities in Sikkim. As an *extended disciplinary institution*, the Sikkim Board of Indigenous Languages, established by the Sikkim Board of Indigenous Languages (SBIL), Sikkim Act, 2022 aims to provide continuity to higher education in these languages.

As a policy and its practice, the government's pedagogical initiatives contribute to deendangerment, at one level. Turin (2012) observes that the teaching of State Official Languages as subjects in school has been an encouragement and a help to enhance their status. His observation is a positive indicator of a good beginning to address the issue. On the other hand, many individuals/parents/communities/schools find the government's efforts incomplete on account of the lack of continuity in the higher standards. Hence, there is a tendency to pull back from opting for such courses in the school system. In many cases, it has come to light that many languages do not fulfil the necessary conditions for recognition for secondary and senior secondary examinations¹². Further, the National Curriculum Framework for School Education (NCF-2023), which aims to realise the goals of the National Education Policy (NEP) 2020, the Central Board of Secondary Education emphasise “the home language or mother tongue as the medium of instruction in early education and the structured introduction of additional languages through a multilingual approach.”¹³ In demographically smaller communities, such as those in the northeast or Sikkim, particularly, an *extended disciplinary institution* needs to be practised in its true spirit. The same spirit of the NEP 2020 can be followed by other school systems too, though there are pragmatic considerations to address before its implementation.

Sinha & Turin (*in press*) have commented on 100 years of Surveys and Census Data in Sikkim in detail. They observed that “data on language has not been returned with any consistency in the censuses and ... the linguistic scenario of Sikkim has been in constant flux over the last 100 years.” In essence, it points out that variables like education, economic statuses and urban-rural divide have resulted loss of language retention, resulting language shift. In addition to it, other major linguistic studies, including Devy & Pandey (2018), the Centre for Endangered Languages, Sikkim University

¹⁰ Considering several factors, these languages are taught in the selected government schools in Sikkim. There is a contemporary legend that a Rai language teacher was driven away by the local community members in Assam-Linzey, as the latter favoured their mother tongue over Rai.

¹¹ Gangi Maya Manger (pc)

¹² See https://cbseacademic.nic.in/curriculum_2025.html for languages included by the Central Board of Secondary Education.

¹³ https://cbseacademic.nic.in/web_material/Circulars/2025/30_Circular_2025.pdf

reports, Sociolinguistic Profiles and others, amplify the fact that the languages of Sikkim are in various levels of endangerment with minimal documentation except the studies by the Centre for Endangered Languages, Sikkim University.

III

From the previous two sections, it is evident that language is a social fact, but it is driven by various factors and policies which determine intergenerational transmission. As long as intergenerational transmission was/is viable, the issue of endangerment was/is not at the forefront. However, the loss of language retention and shifts leading to its endangerment are hardly acknowledged in the background of several factors, among them pride and/or lack of real understanding of the linguistic scenario. At the same time, with the passage of time, pedagogical ideologies, market forces, urbanisation, displacements, etc., along with the *extended disciplinary institutions*, reduced language maintenance to be more of the state's prerogative rather than a community's affair. This withdrawal or amnesia has further led to the language endangerment, and has turned into a belief fostering a language ideology. In sharp contrast, optimistically, I would like to counter *reduction, withdrawal or amnesia* with another belief that linguistics can address contemporary problems by translating them into terms which our tools specially equip us to address (Dasgupta 1999).

Language endangerment is not just an empirical or theoretical concern in linguistics (see Hale 1992), but a concern at par with AIDS, COVID or climate change. There are larger, deeper and wider nets that are cast to address it, considering the praxis. In this section, I will highlight a synopsis of these approaches that a community can employ.

1. Language rights are an existential issue for the political and cultural survival of individuals and communities worldwide. The Constitution of India safeguards Linguistic Human Rights at two levels: the individual and the collective. The individual's rights are to have an identification with his /her mother tongue, and to have that identification respected by others. It necessarily entails the right to learn, and the right to use his/her mother tongue. The collective right is the right of minority groups to exist, i.e. the right to be different. Any restriction on these rights is considered an infringement of fundamental Linguistic Human Rights. If the community wishes to assert it, this provision can be awakened from its dormancy.
 2. Language has been associated with various metaphors and similes, and one of them — ecology (Haeckel's term coined in 1866) is a metaphor. Haugen (1972: 325) proposes that “the study of interactions between any given language and its environment (*society*)” (*parentheses mine*); later came to be known as ecolinguistics. Haugen (1972) proposes ten ecological questions to ascertain the vitality of languages. These questions need to be responded to by every community if the community is interested in safeguarding their respective languages. This can be an initial checklist.
 3. To address the issues of language and script endangerment, Anderson & Harrison (2006)'s
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“language hotspot” model, based on a biodiversity hotspot model¹⁴, that represents areas with a greater language endangerment, with a greater diversity in terms of language family, and a low levels of documentation — writing systems, grammars, dictionaries, texts, and audio and video materials, can be invoked. It is primarily designed to visualise, track the trend, and to prioritise resources. They have identified many hotspots globally, and Sikkim, Darjeeling and Doars can be considered as one of them (see Sinha 2020: 100). Drawing parallelism to “language hotspot,” Sikkim and Darjeeling are a “script hotspot” (see Sinha 2021 for details). However, this approach is not applicable uniformly across neighbouring communities and their languages. It is important to take note of Mühlhäusler's (2002: 376) *precaution* that “empowering languages and making them more competitive by giving them grammars, lexica, writing systems, and school syllabi is a recipe that ignores a basic ecological fact: *what supports one language may not support another*. Each language requires its own ecological system.”

4. Since linguistic diversity reflects human accommodation to complex environmental conditions, the changes in society affect linguistic diversity. Therefore, besides efforts on individual languages, a coordinated effort towards vitalising linguistic ecology is a prerequisite for a healthy biocultural diversity. To put across simply, it is social policy rather than language policy that is needed to maintain it (Nettle 1999). This leads to including *language and script endangerment as a public service* akin to public health, public transport, etc. Importantly, *biocultural diversity* becomes a public, social discourse. The Sikkim Board of Indigenous Languages can be made more proactive towards this direction.

5. Some of the most disturbing facts that one often finds from linguistic communities are about grammar, dictionary, script and pedagogical materials. It is often the case that the community, on account of its absence, assumes and delegitimises the status of their mother tongue. Further, it attaches negative connotations to the language and also to the community. Many of the communities in Sikkim and North Bengal easily relate to this form of *amnesia*. This is largely due to a lack of awareness about language and its nature and function. A lack of a tangible, printed grammar book is often cited to have *no or lack of grammar* of the language. Similarly, a lack of script leads them to be identified as a dialect, rather than a language; and consequently, the lack of pedagogical materials suggests a lack of teaching/transmission of such languages. In order to eradicate such a form of *amnesia*, linguistic research, including academic degrees, projects and documentation efforts, has restored and rehabilitated communities and their languages. Bhujel (2014, 2016), Rai (2022), Manger (2019), Sunuwar (2021), Tamang (2018), Thapa (2018), among others, are community-member-driven initiatives in academia. The Centre for Endangered Languages, Sikkim University, is geared towards this challenge. Similarly, in Nepal, Amrit Yonjan Tamang¹⁵ and his team members, including Pratigya Regmi, have initiated a “community grammar” writing program of the various communities whose languages are still undocumented. A similar initiative was taken up by the various communities, viz. Rai and Lepcha, regarding language learning through the online medium in Sikkim and Darjeeling. Such a method can be explored in the context of Sikkim and Darjeeling to make an initial foothold towards language deendangerment.

¹⁴ A biodiversity hotspot is a biogeographic region with a significant reservoir of biodiversity that is threatened with destruction.

¹⁵ <https://www.youtube.com/watch?v=iIFSdvI26dw>

In this write-up, the proposition that biocultural diversity, a total of biodiversity, linguistic diversity and cultural diversity, is essential for sustainable existence by enhancing creativity and adaptability. It is also asserted that politics and ethics of language-script endangerment are not harping on the issue, but to look out for mitigation that leads to deendangerment. Following biopolitics and its *extended disciplinary institutions*, and other collateral and detrimental factors that affect the morale of the speech community, linguistic vitality in Sikkim and Darjeeling is discussed and addressed as dossiers in the hope that common people including language enthusiasts, language / cultural / community activists, linguists, policy makers, environmentalists, and glossophiles are made aware of stable, constructive, perpetual activism for the vanishing biocultural diversity and linguistic dignity.

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A Study on Cycle-Free Vertex — Connectivity in Graphs

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ABSTRACT

Graph connectivity helps us to understand how strong and reliable a network is. This project introduces the concept of cycle free vertex-connectivity of graphs which represents the minimum number of vertices that should be removed to make the graph cycle free and either it is K_1 or K_2 or it has at least two components. It is denoted by $K_{fc}(G)$ for a graph G . The cycle free vertex-connectivity number has been calculated for graphs such as cycles, complete graphs and trees and also identified graphs G for which $K_{fc}(G) = n$, for a given positive integer n .

Keywords: Up to 6 keywords or key phrases

INTRODUCTION

Graph theory is a fundamental mathematical tool used in various fields including data science, communication networks, transportation system etc., to analyse and explore problems related to networks and connectivity. The connectivity of graphs is an essential aspect of graph theory which reflects on how well a graph is connected. One important measure of this is vertex connectivity. This study introduces the concept of cycle free vertex-connectivity of graphs and it is particularly significant in systems where acyclic structures are necessary.

1.1 Basic Definitions

A graph G consist of a finite non-empty set V , the set of vertices and a collection E , the set of edges which are subsets of V and each E has cardinality 2. A graph's order is determined by the number of vertices, and its size is determined by the number of edges. A simple graph is a graph which does not contain any self-loop and parallel edges. In this study, simple graphs G with vertex set $V(G)$ and edge set $E(G)$ are being considered.

Let $e \in E(G)$ and $x, y \in V(G)$ such that $e = \{x, y\}$ then the edge e is said to be incident

with x and y and the vertices x and y are said to be adjacent to each other. The neighbourhood of any vertex y , is defined as $N_e(y) = \{x \in V(G) \mid \{x, y\} \in E(G)\}$. The degree of a vertex x in a graph G is the number of edges incident with x in G . The maximum (or minimum)

degree $\Delta(G)$ (or $\delta(G)$) of a graph G is the maximum (or minimum) degree of the vertices in

G . A graph M is said to be a subgraph of a graph G if $V(M) \subseteq V(G)$ and $E(M) \subseteq E(G)$. If $V(M) = V(G)$, then M is called the spanning subgraph of G . A walk is a sequence of vertices $x_1, x_2, \dots, x_k$ if x_i is adjacent to x_{i+1} for $i = 1, 2, \dots, k-1$. A trail (or path) is a walk where no edges (or vertices) are repeated. A cycle is a non-empty path where the first and last vertices

are the same, and no other vertices are repeated. The length of a path or trail or cycle or walk is the number of edges and the girth is the length of the shortest cycle. A cyclic graph is defined as a graph that contains at least one cycle.

A graph G is said to be a complete graph if each vertex in G is adjacent to every other vertex of it. K_n is used to denote the complete graph with n vertices. A graph G is said to be r -regular if each vertex in G has degree r . A graph G is considered bipartite if the set of vertices of G can be partitioned into two disjoint sets such that there are no edges connecting vertices within the same set i.e., every edge in the graph must connect a vertex from one set to a vertex in the other set. A complete bipartite graph is a bipartite graph where each vertex from one set is connected to every vertex in the other set. A graph G is said to be connected if there is a path between each pair of vertices in G . If G is not a connected graph then it is said to be a disconnected graph. If a graph's connectivity is equals to its minimum degree then it is said to be maximally connected.. A component is known as a maximal connected subgraph of a graph. A graph G is said to be separable if it is either disconnected or can be disconnected by removing one

vertex. A tree is a connected acyclic graph. A spanning subgraph which is also a tree is called a spanning tree. In a graph G , a vertex-cut (or edge-cut) is a subset X of the vertex (or edge) set of G such that the removal of X disconnects the graph. For more basic definitions, we can check [1].

Definition 1.1. The edge (or vertex) connectivity of a graph G is the smallest number of edges (or vertices) that must be removed in order to make the graph disconnected. It is denoted by $\lambda(G)$ (or $\kappa(G)$).

Definition 1.2. A graph where every vertices have degree 3 is said to be a cubic graph.

Definition 1.3. The Cartesian product $G \times M$, of two graphs G and M is the graph with vertex set $V(G) \times V(M)$, and any two vertices $(x_1, y_1), (x_2, y_2)$ in $G \times M$, are adjacent if and only if

- either $x_1 = x_2$ with $y_1 y_2 \in E(M)$
- or $y_1 = y_2$ with $x_1 x_2 \in E(G)$

2 LITERATURE REVIEW

In graph theory, connectivity is a basic concept which shows how strongly a graph is connected. One of the key principles of connectivity in graph theory is Menger's Theorem [1] which states that in a finite graph, the size of the minimum set of edges that should be removed to disconnect any of the two vertices is equal to the maximum number of disjoint paths that can be found between any two vertices. It was proved by Karl Menger in 1927. Since then, connectivity has been an important factor of graph theory. The two fundamental concepts of connectivity in undirected graphs are edge connectivity and vertex connectivity. In real-world situations, they are used to measure the reliability and strength of the network, that is whether the network can keep working even if some points or connections stop working. However, vertex or edge connectivity alone may not fully represent a network's connectivity. Therefore in order to overcome this issue, the concept of cyclic edge and vertex connectivity was proposed. In 1880, Tait introduced the idea of cyclic edge connectivity [2] while seeking the proof of four-color theorem and also paved the way for the idea of cyclic vertex-connectivity. Later on, it was introduced by Peroche [3] and the interest of this concept has been steadily increased over the years.

2.1 Cyclic Edge Connectivity(CEC)

Definition 2.1. [5] An edge subset X of the $E(G)$ is a cyclic edge-cut of a graph G if $G \setminus X$ has at least two components which contains cycles. G is said to be cyclically separable if it has a cyclic edge-cut. The cyclic edge connectivity is the size of the minimum cyclic edge-cut of G . It is denoted by $\lambda_c(G)$. If G does not have any cyclic edge-cut then $\lambda_c(G) = \infty$.

Definition 2.2. [6] A graph G is called cyclically n -connected (or m -connected) if every vertex-cut set (or edge-cut set) X of G that breaks the graph into two or more components containing cycles has size at least n (or m).

2.2 Known Results for CEC

Lou et al. [7] has developed an efficient algorithm to established the cyclic edge connectivity of cubic graphs and k -regular graph for $k \geq 3$. They have also proved the correctness of the algorithms and evaluated their time complexity.

Furthermore, Lou together with Holton [6] provided a minimum value for the cyclic edge connectivity related to the n -extendability of regular graphs. They proved that for any positive

integer m and $k \geq 3$, the graph (m, k, k) is bipartite. Additionally, they established the existence of a bipartite graph $(k^2 - 1, k + 1, k + 1)$ that is not k -extendable and also the existence of a graph $(m, k + 1, k + 1)$ which is not n -extendable, where $n \geq 2$, $k \geq 2$ and m is a positive integer.

Definition 2.3. [6] A graph is said to be (n, m, k) graph if it is cyclically n -connected, m -connected and k -regular.

Definition 2.4. [6] In a graph G , if every matching of size n in G is contained within a perfect matching of G then the graph is said to be n -extendable.

Theorem 2.5. [6] Suppose there is an $(4n^2 + 4n, n + 1, n + 1)$ bipartite graph with finite cyclic edge connectivity for $n \geq 3$. Then, there exists $(n^2 - 1, n + 1, n + 1)$ bipartite graph that is not n -extendable.

Theorem 2.6. [6] If there is a k -regular bipartite graph with finite cyclic edge connectivity satisfying $\lambda_c \geq (k - 2)(2m + 4)$, then there exists a cyclically m -edge-connected k -regular graph that is not 2-extendable, where $m \geq 2$ and $k \geq 3$.

Wang and Zhang [5] proved that for any cyclically separable graph G , the cyclic edge connectivity of G is less than or equal to $\zeta(G)$, where $\zeta(G)$ denotes the minimum number of edges that has one endpoint in Z and the other in $V(G) \setminus Z$ such that Z forms the shortest cycle in G . A cyclically separable graph G is said to be cyclically optimal if $\lambda_c(G) = \zeta(G)$.

Definition 2.7. [8] A graph G is said to be vertex-transitive if for any two vertices x and y there exists an automorphism f such that $f(x) = y$.

Definition 2.8. [8] A graph G is said to be edge-transitive if for any two edges $\{x, y\}$ and $\{w, z\}$ of G , there exist an automorphism f of G such that $\{w, z\} = \{f(x), f(y)\}$.

Theorem 2.9. [5] Every cyclically separable graph G satisfies $\lambda_c(G) \leq \zeta(G)$.

Theorem 2.10. [5] If G is a connected, k -regular and vertex-transitive graph with $k \geq 4$ and girth of G is greater than or equals to 5, then G is cyclically optimal.

Theorem 2.11. [5] If G is a connected edge-transitive graph with at least 6 vertices and $\delta(G) \geq 4$, then G is cyclically optimal.

There are several other results that has been obtained based on this concept [9,10,11,12].

2.3 Cyclic Vertex-Connectivity

Definition 2.12. [13] For a graph G , a vertex subset X of $V(G)$ is said to a cyclic vertex-cut if $G \setminus X$ has at least two components which contains cycles. The size of the minimum cyclic vertex-cut of G is

called the cyclic vertex-connectivity of G and it is denoted as $\kappa_c(G)$. A κ_c -cut is a cyclic vertex-cut X whose size is equal to the cyclic vertex-connectivity of G .

2.4 Known Results for CVC

Liu et al. [14] has established that for any integer $n \geq 4$, the n -dimensional star graph SG_n has $\kappa_c(SG_n) = 6(n - 3)$.

Definition 2.13. [14] Consider S_n which is the symmetric group of order n consisting of every permutations of n elements. Then the n -dimensional star graph SG_n is defined as the graph with vertex set $V(SG_n) = S_n$ and any two vertices x and y are adjacent in SG_n if and only if y can be obtained from x by replacing the first element with the element in the position i , where $2 \leq i \leq n$. The edge connecting x and y is labelled as $(1i)$.

Lemma 2.14. [14] For any $i \in \{1, 2, \dots, n\}$, $N_{SG_n}(SG_{n-1}^i)$ forms an independent set of size $n-1(n-1)!$ and for any $j \neq i$, $|N_{SG_n}(SG_{n-1}^j)| = (n-2)!$.

Lemma 2.15. [14] Let C be a 6-cycle of n -dimensional star graph, where $n \geq 4$. Then

$N_{SG_n}(C)$ is a cyclic vertex-cut of SG_n .

Theorem 2.16. [14] The cyclic vertex-connectivity of n -dimensional star graph for any integer $n \geq 4$ is $6(n - 3)$.

Qin et al. [13] has further extended this concept and provided results on cyclic vertex-connectivity of Cartesian product of two graphs.

Lemma 2.17. [13] Let G_2 be a maximally connected k_2 -regular graph with $k_2 \geq 2$ and girth of G is greater than or equals to 4. Then for $m \geq 3$, the cyclic vertex-connectivity of the Cartesian product $K_m G_2$ is at most $3k_2 + m - 3$.

Lemma 2.18. [13] Let G_2 be a maximally connected k_2 -regular graph with $k_2 \geq 2$ and has girth $g(G_2) \geq 5$. If the cyclic vertex-connectivity of the Cartesian product $K_m G_2$ is at most $2x_1 3k_2 + m - 3$ for $m \geq 3$, then there is a copy G_{2x_1} of G_2 denoted by G_{2x_1} in the product such that after the removal of the cyclic vertex-cut X , the remaining sub graph G_{2x_1}' for $x_1 \in V_1$ is connected and contains at least three vertices.

Theorem 2.19. [13] Let G_2 be a maximally connected k_2 -regular ($k_2 \geq 2$) graph with girth at least 5. Then the cyclic vertex-connectivity of the Cartesian product $K_m G_2$ is $3k_2 + m - 3$ for $m \geq 3$.

Lemma 2.20. [13] Let G_1 and G_2 be maximally connected k_1 -regular and k_2 -regular graphs with $k_1, k_2 \geq 2$ with girth at least 5. Then

- (a). The cyclic vertex-connectivity of the Cartesian product satisfies $\kappa_c(G_1 \times G_2) \leq 4k_1 + 4k_2 - 8$.
- (b). For all κ_c -cut X of $G_1 \times G_2$, $X_x = X \cap V_{2x}$ is non-empty for every $x \in V_1$.

Theorem 2.21. [13] Suppose G_i is a maximally connected k_i -regular graph with $k_i \geq 2$, $i = 1, 2$ and has girth at least 5. Then the cyclic vertex-connectivity of the Cartesian product $G_1 \times G_2$ is given by $\kappa_c(G_1 \times G_2) = 4k_1 + 4k_2 - 8$.

For more additional findings related to cyclic vertex connectivity, one may refer [15, 16, 17, 18, 19].

Based on these concepts of connectivity, motivation arises to investigate how a graph changes when certain vertices are removed, resulting in an acyclic structure and an increased number of cycle-free components. This observation led to the study of the cycle free vertex-connectivity of graphs which makes the graph acyclic, and it is either K_1 or K_2 or contains at least two components and also represented the cycle free vertex-connectivity number.

3 RESULTS

3.1 Cycle Free Vertex-Connectivity

Definition 3.1. For a graph G , a set of vertices $S \subseteq V(G)$ is said to be a cycle free vertex-connectivity set of G , if $G \setminus S$ is cycle free and it is either K_1 or K_2 or it has at least two components. The cardinality of the smallest cycle free vertex connectivity set of G is called its cycle free vertex-connectivity number and it is denoted by $K_{fc}(G)$.

Let us consider a graph G shown by Figure 1.

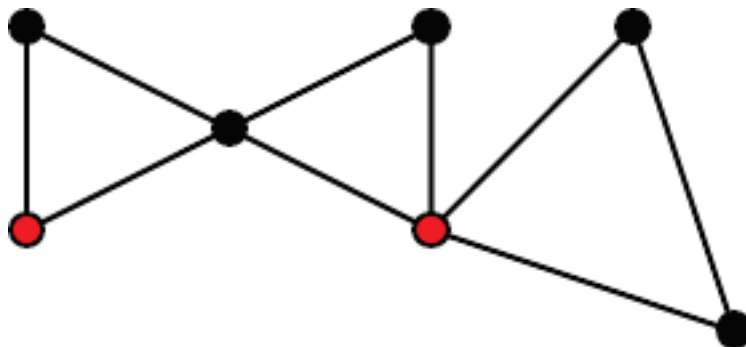


Figure 1: A graph G with cycle free vertex-connectivity number 2

In Figure , removal of the red vertices eliminates all its adjacency with the other vertices. Thus G becomes acyclic and contains at least two components. Hence the cycle free vertex- connectivity number of G is 2.

3.2 Main Results

In this section, K_{fc} for cycles, complete graphs and trees has been computed. For a given positive integer n , graphs G have been identified such that $K_{fc}(G) = n$.

$$\textbf{Theorem 3.2. } K_{fc}(C_n) = \begin{cases} 1 & \text{if } n = 3 \\ 2 & \text{if } n \geq 4 \end{cases}$$

Proof. Let us consider the following cases.

Case 1: $n = 3$

From the graph C_n , where $n = 3$, it is enough to remove only one vertex since the resulting graph reduces to K_2 .

Therefore, $K_{fc}(C_n) = 1$, for $n = 3$.

Case 2: $n \geq 4$

Since there are $n \geq 4$ vertices which forms a cycle. So removing only one vertex makes the resulting graph acyclic and connected. Thus, we need to remove another vertex with $\Delta(C_n) = 2$ from the graph.

Hence, the result follows.

$$\textbf{Theorem 3.3. } K_{fc}(K_n) = \begin{cases} 0 & \text{if } n = 1 \\ n - 2 & \text{if } n \geq 2 \end{cases}$$

Proof. Consider the following cases.

Case 1: $n = 1$

Clearly by definition 3.1, $K_{fc}(K_n) = 0$, for $n = 1$.

Case 2: $n \geq 2$

For $n = 2$, by definition 3.1, $K_{fc}(K_n) = 0$.

Since in a complete graph K_n for $n \geq 3$, every set of 3 or more vertices forms a cycle. So to make the graph acyclic, we must remove $n - 2$ vertices from K_n . But removal of $n - 2$ vertices from K_n will

reduce it to K_2 . Therefore, the minimum number of vertices that needs to be removed from K_n is $n - 2$.

Theorem 3.4. *If T is a tree on n vertices then $K_{fc}(T_n) = \begin{cases} 0 & \text{if } n = 1, 2 \\ 1 & \text{if } n \geq 3 \end{cases}$*

Proof. Let T_n be a tree with n vertices. For $n = 1, 2$, T_n is K_1 and K_2 .

Therefore, $K_{fc}(T_n) = 0$ for $n=1,2$.

Now, for $n \geq 3$. Since by definition of a tree, T_n is already acyclic. So it is enough to remove a vertex v with $\deg(v) \geq 2$ such that $T_n - v$ is disconnected and has at least two components. Hence, $K_{fc}(T_n) = 1$ for $n \geq 3$.

Theorem 3.5. *If G is a graph on n vertices. Then $K_{fc}(G) = 0$ if and only if G is either K_1 or K_2 or it is a disconnected acyclic graph.*

Proof. Let us assume that $K_{fc}(G) = 0$. That is, no vertex is required to be removed from G to be acyclic and satisfy the component conditions. This implies that G is either K_1 or K_2 or it is a disconnected acyclic graph.

Conversely, let G be either K_1 or K_2 or a disconnected acyclic graph. From definition 3.1,

$$K_{fc}(G) = 0$$

Theorem 3.6. *If G is a connected graph with n vertices. Then $K_{fc}(G) = 1$ if and only if one of the following holds*

- (a). G is C_3 .
- (b). G is a tree with at least 3 vertices.
- (c). G is an unicyclic graph with $\Delta(G) \geq 3$.
- (d). G has a vertex that appears on every cycle and any two cycles are edge disjoint.

Proof. Let G be a connected graph with n vertices. First assume that $K_{fc}(G) = 1$ i.e., $\exists v \in$

$V(G)$ such that $G - v$ is acyclic and it is either K_2 or it has at least two components.

If $G - v = K_2$, then G is either C_3 or P_3 that is, either (a) or (b) holds. Next assume that $G - v$ is not K_2 . That is, $G - v$ is acyclic and has at least two components. Clearly, G is not C_3 . If G is a tree with 3 or more vertices we are done.

So let G is not a tree. Then G must have a cycle and so $\Delta(G) \geq 2$.

If G is unicyclic then either G is a cycle other than C_3 or $\Delta(G) \geq 3$. Since, for a cycle other than C_3 , K_{fc} is 2. So, $\Delta(G) \geq 3$.

If G has more than one cycle then removal of a single vertex should make the graph acyclic. Therefore, G must have a vertex that appears on every cycle. If G has a pair of cycle sharing an edge, then removal of a vertex v from G will never make it disconnected. So, G must satisfy (d).

Conversely, let us assume that one of the conditions from (a) to (d) holds. If G is C_3 , then from **Theorem 3.2**, $K_{fc}(G) = 1$.

If G is a tree with at least 3 vertices, then from **Theorem 3.4**, $K_{fc}(G) = 1$.

If G is a unicyclic graph with $\Delta(G) \geq 3$, then $\exists$ a cyclic vertex v such that $\deg(v) \geq 3$.

Then $G - v$ is an acyclic graph with at least two components. Therefore, $K_{fc}(G) = 1$.

If G has a vertex v which is on every cycle of G and any two cycles are edge disjoint, then

$G - v$ is a disconnected acyclic graph with at least two components. Since any two cycles are edge-disjoint, it ensures that no other cycles remains in $G - v$. Therefore, $K_{fc}(G) = 1$.

Theorem 3.7. *If G is a connected graph with n vertices. Then $K_{fc}(G) = 2$ if and only if one of the following holds*

- (a). G is C_n with $n \geq 4$.
- (b). G is connected, cyclic and has a vertex v such that $G - v$ is a tree.
- (c). G is connected, cyclic and has a vertex v such that $G - v$ has exactly one cyclic component that has a unique vertex common to every cycle and any two cycles are edge disjoint.

Proof. Let G be a connected graph with n vertices. First assume that $K_{fc}(G) = 2$ i.e., $\exists u, v \in V(G)$ such that $G - \{u, v\}$ is acyclic and it has at least two components.

Then G may be a cycle or a connected cyclic graph. If G is a cycle, clearly G is not C_3 then (a) holds.

Next assume that G is not a cycle then it must be a connected cyclic graph. Since, $G - \{u, v\}$ has at least two components so $G - v$ is either a tree or it has a cyclic component.

If $G - v$ is a tree then (b) holds.

Assume that $G - v$ has a cyclic component. If $G - v$ has more than one cyclic component then removal of one vertex will not make the graph acyclic. Therefore, $G - v$ must have exactly one cyclic

component that has a unique vertex. If $G - v$ has a pair of cycles that shares an edge, then removing a vertex u from $G - v$ will not make it disconnected. Hence the result follows.

Conversely, let any one of the conditions from (a) to (c) holds. If G is C_n with $n \geq 4$. Then from Theorem 3.2, $K_{fc}(G) = 2$.

If G is connected and cyclic and has a vertex v such that $G - v$ is a tree then $G - v$ must have at least 3 vertices. Then, from Theorem 3.4, $K_{fc}(G - v) = 1$. Therefore, $K_{fc}(G) = 2$.

If G is a connected and cyclic graph that has a vertex v such that $G - v$ has exactly one cyclic component which has a unique vertex common to every cycle and any two cycles are edge disjoint then removing the common vertex from $G - v$ breaks all cycles and disconnects the graph. So, $K_{fc}(G - v) = 1$. Hence, the result follows

Conjecture 3.8. *If G is a connected graph on n vertices. Then $K_{fc}(G) = 3$ if and only if one of the following holds*

- (a). G is K_5 .
- (b). G is connected, cyclic and has vertices u and v such that $G - \{u, v\}$ is a tree.
- (c). G is connected, cyclic and has vertices u and v such that $G - \{u, v\}$ is a unicyclic graph with $\Delta(G) \geq 3$.
- (d). G is connected, cyclic and has vertices u and v such that $G - v$ has one cyclic component which has exactly two cycles and are edge disjoint.

CONCLUSION

In this study, a new parameter called the cycle free vertex-connectivity of a graph is introduced and the corresponding cycle free vertex-connectivity number has been determined for standard graphs like cycles, complete graphs and trees. Furthermore, graphs G have been identified for which $K_{fc}(G) = 0, 1$ or 2 . In addition, a conjecture has also been proposed for a graph G such that $K_{fc}(G) = 3$. This study contributes a new perspective on how graphs can be made acyclic by removing certain vertices.

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ADDITIONAL INFORMATION

All additional information including supplementary documents are available with author and may be obtained on request.

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Load Invariants, Character Theory, and Spectral Analysis of Automorphism Groups of Recursive Graphs

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ABSTRACT

This study explores the automorphism groups of recursively constructed cactus graphs and their algebraic structures that emerge from their symmetries. For the family of Iterated Cycle Cactus Graphs ξ^k (obtained along the outer layer), $\text{Aut}(\xi_p^k) \cong C_{p-1} \text{ wr } \cdots \text{ wr } C_{p-1} \text{ wr } D_p$, where the wreath product (denoted wr) is iterated $k - 1$ times. Thus, a Wreath Cycle Decomposition is introduced, and a hierarchy of invariants, such as Territory, Yade-Class, and Load, leading to the Load-Orbit Graph, is established. Further, a Load Character Table is constructed that organizes irreducible character values along wreath-cycle components, and preliminary spectral applications to Cayley graphs are discussed.

Keywords: Automorphism, Wreath Product, Cactus Graph, Wreath Cycle, Load Invariant.

INTRODUCTION

Recursively defined self-similar structures arise naturally in mathematics and the sciences, and their algebraic symmetries often exhibit a deeply recursive character. This paper explores an algebraic-combinatorial framework for studying the symmetries of a recursively constructed graph family, “the Iterated Cycle Cactus Graphs ξ_p^k ” illuminating the connection between recursive geometry and iterated wreath products.

The automorphism group of the graph ξ_p^k $\text{Aut}(\xi_p^k) \cong \underbrace{C_{p-1} \wr \cdots \wr C_{p-1}}_{k-1 \text{ times}} \wr D_p$ is proved, by

The central result is the identification of the automorphism group of the iterated cactus graphs. We show that $\text{Aut}(\xi_p^k) \cong C_{p-1} \text{ wr } \cdots \text{ wr } C_{p-1} \text{ wr } D_p$, where the wreath product (wr) is iterated $k - 1$ times over C_{p-1} and D_p denotes the dihedral group of order $2p$. Although wreath products are classical objects, their conjugacy and representation theories remain areas of active investigation [2, 3, 8]. Based on this relationship between the graph and group, the following is introduced:

- Wreath Cycle Decomposition for elements of $\text{Aut}(\xi_p^k)$;
- the invariant Territory, Yade-Class, and Load, together with the Load-Orbit Graph, which is proposed as a conjugacy invariant (Conjecture 3.3).

- a *Load Character Table* whose entries factorize over wreath cycles, yielding structured computation of irreducible characters;
- spectral applications to Cayley graphs: explicit eigenvalue formulas, an explicit expander family via controlled load profiles, and a Hamiltonicity criterion building on solvable-group structure and abelianization checks [4, 1, 10].

Section 2 defines ξ_p^k and proves the wreath-product description of $\text{Aut}(\xi_p^k)$. Section 3 develops the load invariants and proves conjugacy classification. Section 4 constructs the Load Character Table and proves character factorization. Section 5 derives spectral consequences for Cayley graphs, including expanders and Hamiltonicity. Section 6 sketches generalizations to other recursive block graphs and outlines complexity questions.

2 ITERATED CYCLE CACTUS GRAPHS AND THEIR SYMMETRIES

2.1 Definition and basic properties

Definition 2.1 (Iterated Cycle Cactus Graphs). Fix $p \geq 3$. Let $\xi_p^1 = C_p$. Given ξ_p^{k-1} , obtain ξ_p^k

by attaching, to every vertex x that is newly introduced at layer $k - 1$, a new copy of C_p glued at a single vertex identified with x . Each new C_p shares exactly one vertex with the existing graph.

Table 1: Summary of selected graph-theoretic properties of ξ_p^k

Property	Value/Formula
Planarity / Outerplanarity	Yes / Yes for all $p \geq 3, k \geq 1$
Girth	p
Bipartite	iff p is even
Chromatic number	2 (even p), 3 (odd p)
Min / Max degree	2 / 2 if $k = 1$, else 4
Diameter	$\Theta(k \lfloor p/2 \rfloor)$
Hamiltonian	iff $k = 1$
Eulerian	Yes

This is a *cactus* construction (no two simple cycles share more than one vertex). Let X_j denote the set of vertices introduced at layer j . A standard counting argument yields the following.

Proposition 2.2 (Size paramcters). *Let $N(k)$ be the number of new vertices at iteration k . Then*

$N(1) = p$ and $N(k) = p(p-1)^{k-1}$ for $k \geq 2$. Hence $|V(\xi_p^k)| = \sum_{j=1}^k N(j) = p \frac{(p-1)^k - 1}{(p-1) - 1}$ and $|E(\xi_p^k)| = k p$ plus the new edges from attachments.

Proposition 2.3 (Geometric and combinatorial properties). ξ_p^k is planar and outerplanar; $\text{girth}(\xi_p^k) = p$. It is bipartite iff p is even (hence $\chi(\xi_p^k) = 2$ if p even, else 3). For $k \geq 2$ there are articulation vertices, so it is not 2-connected (hence non-Hamiltonian for $k \geq 2$), but all degrees are even, so it is Eulerian. Its diameter grows linearly in k .

2.2 Automorphisms as iterated wreath products

Theorem 2.4. For $p \geq 3$ and $k \geq 1$,

$$\text{Aut}(\xi_p^k) \cong \underbrace{C_{p-1} \wr C_{p-1} \wr \cdots \wr C_{p-1}}_{k-1 \text{ times}} \wr D_p,$$

where C_{p-1} acts on the $p - 1$ non-root vertices of each attached cycle and D_p is the dihedral automorphism group of the base C_p .

Proof. Induct on k . For $k = 1$, $\text{Aut}(C_p) \cong D_p$. For $k \rightarrow k + 1$, each new $C_p(x)$ attached at $x \in X_k$ has the local symmetry group fixing x isomorphic to C_{p-1} . An automorphism of ξ_p^{k+1} induces an automorphism $\pi \in \text{Aut}(\xi_p^k)$ on the core that permutes the attachment points X_k , while coordinates a tuple of local cyclic actions across fibers $C_p(x)$. This yields $(\prod_{x \in X_k} C_{p-1}) \rtimes \text{Aut}(\xi_p^k) \simeq C_{p-1} \wr \text{Aut}(\xi_p^k)$, iterating to the stated structure. $\square$

Corollary 2.5. $\text{Aut}(\xi_p^k)$ is solvable (wreath products of solvable groups are solvable), non-abelian for $p \geq 3$, and has trivial center for $k \geq 2$.

3 WREATH CYCLES AND LOAD INVARIANTS

3.1 Wreath Cycle Decomposition

Definition 3.1 (Wreath Cycle Decomposition). Every $\phi \in \text{Aut}(\xi_p^k)$ can be written as a product of disjoint wreath cycles

$$\phi \sim \left(\prod_{i=1}^{n_1} C_i^{(1)} \right) \cdots \left(\prod_{i=1}^{n_{k-1}} C_i^{(k-1)} \right) \cdot \tau,$$

with $C_i^{(j)} \in C_{p-1}$ acting within a fiber at layer j , and $\tau \in D_p$ acting on the base. Two wreath cycles are disjoint if their supports in ξ_p^k are disjoint.

Definition 3.2 (Territory). For $\phi \in \text{Aut}(\xi_p^k)$, its *territory* is $T(\phi) = \{v \in V(\xi_p^k) : \phi(v) \neq v\}$. If $T(\phi_1) \cap T(\phi_2) = \emptyset$, then ϕ_1 and ϕ_2 commute.

Definition 3.3 (Yade-Class). For a wreath cycle C , its *Yade-Class* $Y(C)$ is the isomorphism class of the permutation representation induced by C on its support, respecting the fiber structure at that layer.

Definition 3.4 (Load). The *load* of a wreath cycle C is $\lambda(C) = (o(C), Y(C))$, the pair of its order and its Yade-Class.

Lemma 3.5 (Conjugacy invariance of load). For any $g \in \text{Aut}(\xi_p^k)$ and wreath cycle C , $\lambda(gCg^{-1}) = \lambda(C)$.

Proof. Conjugation preserves order, and the induced permutation action on the conjugated support is isomorphic to the original; hence Y is preserved. $\square$

Table 2: Hierarchy of load invariants and their roles.

Concept	Brief definition	Role
Wreath Cycle	Action on one fiber-orbit	Building block of an automorphism
Territory	Moved-vertex set	Geometric support of action
Yade-Class	Permutation-type on support	Algebraic type of action
Load	(order, Yade)	Conjugacy-invariant signature
Load-Orbit Graph	Multigraph of loads	Complete invariant of element

3.2 Load-Orbit Graph and conjugacy

Definition 3.6 (Load-Orbit Graph). Let ϕ decompose into disjoint wreath cycles $\{C_1, \dots, C_r\}$.

The *Load-Orbit Graph* $L(\phi)$ is the directed labeled multigraph whose vertices are the distinct Yade-classes $\{Y(C_i)\}$ and for each C_i a self-loop at $Y(C_i)$ labeled by $o(C_i)$.

Theorem 3.7 (Conjugacy criterion). *For $\phi, \psi \in \text{Aut}(\xi_p^k)$, ϕ and ψ are conjugate iff $L(\phi) \cong L(\psi)$ as labeled multigraphs.*

Proof. By Lemma 3.5, loads are conjugacy invariants, hence so is the multiset of loads, encoded by $L(\phi)$. Conversely, using the wreath-product normal form, one aligns the top layer via D_p and then, layer by layer, uses fiberwise conjugations inside the copies of C_{p-1} to match cycles of the same loads. This reduces conjugacy to a matching of labeled load-cycles; details parallel general treatments of conjugacy in wreath products [2, 3, 8]. $\square$

4 LOAD SPECTRAL POLYNOMIAL AND CHARACTER THEORY

4.1 The Load Spectral Polynomial

Definition 4.1 (Load Spectral Polynomial). Let $G = \text{Aut}(\xi_p^k)$, and let $T = \{\lambda_1, \dots, \lambda_m\}$ be all distinct loads occurring in G . Introduce commuting indeterminates x_λ for $\lambda \in T$ and set

$$P_G(x) = \sum_{\phi \in G} \prod_{\lambda \in \Lambda(\phi)} x_\lambda,$$

where $\Lambda(\phi)$ is the multiset of loads appearing in a wreath-cycle decomposition of ϕ .

Because $\Lambda(\phi)$ is constant on conjugacy classes (by Lemma 3.5, P_G is a class function generating series that encodes load profiles across G .

4.2 Character factorization and the Load Character Table

Irreducible characters of wreath products are classically described via Clifford theory and induction from base and top actions [12, 6]. The load stratification yields a direct factorization across wreath cycles.

Theorem 4.2 (Load character factorization). *Let $G = \text{Aut}(\xi_p^k)$. Irreducible characters of G are naturally indexed by isomorphism classes of Load-Orbit Graphs Λ . If $\chi = \chi(\Lambda)$ corresponds to Λ , then for $\phi = C_1 \cdots C_r$ we have*

$$\chi(\phi) = \prod_{i=1}^r \chi_{\lambda(C_i)}(C_i),$$

where χ_λ is an irreducible character associated to the cyclic component for load λ .

Proof. The iterated wreath product structure expresses G as successive semidirect products of fiberwise cyclic actions by C_{p-1} and a top D_p action. Induction and inflation across layers yield characters whose values multiply over independent fiber actions. Factoring along the disjoint wreath cycles gives the stated product, matching classical wreath-product character recipes but organized by loads [12]. $\square$

Definition 4.3 (Load Character Table). Form the square matrix whose rows are $\{\chi(\Lambda)\}$ and columns are conjugacy classes (equivalently, load profiles). The $(\chi(\Lambda), [\phi])$ -entry is $\chi(\Lambda)(\phi)$, computed via Theorem 4.2.

5 SPECTRAL THEORY OF CAYLEY GRAPHS ON $\text{Aut}(\xi_p^k)$

5.1 Cayley graphs and eigenvalues

Let $S \subseteq G \setminus \{e\}$ be symmetric. The Cayley graph $\text{Cay}(G, S)$ is $|S|$ -regular and vertex-transitive.

By noncommutative Fourier analysis, its eigenvalues are

$$\lambda_\chi = \frac{1}{\deg \chi} \sum_{s \in S} \chi(s),$$

ranging over irreducible characters χ .

Theorem 5.1 (Eigenvalues via loads). *With notation above, index eigenvalues by Load-Orbit Graphs Λ :*

$$\lambda_{\Lambda} = \frac{1}{d_{\Lambda}} \sum_{s \in S} \chi(\Lambda)(s),$$

where $\chi(\Lambda)(s)$ is computed by Theorem 4.2 from the load decomposition of each generator s .

5.2 Expander construction by load design

Expanders are regular graphs with a spectral gap bounded away from 0. Random small generating sets typically yield expanders for many groups [1, 4, 7, 10].

Theorem 5.2 (Explicit expander family). *For each $p \geq 3$, there exists a constant-size symmetric generating set S_p such that the family $\{\text{Cay}(\text{Aut}(\xi_p^k), S_p)\}_{k \in \mathbb{N}}$ is an expander family: there is $\varepsilon_p > 0$ with $|\lambda_2| \leq (1 - \varepsilon_p)|S_p|$ for all k .*

Proof. Choose S_p consisting of a bounded number of generators with simple, mutually *incoherent* load profiles so that nontrivial characters exhibit cancellation in the sum $\sum_{s \in S_p} \chi(s)$. The wreath-product recursion and Theorem 4.2 give uniform bounds over k . This parallels probabilistic constructions but is load-structured and explicit; compare [1, 4, 10]. $\square$

5.3 Hamiltonicity criterion

Theorem 5.3 (Hamiltonicity). *Let $G = \text{Aut}(\xi_p^k)$ (solvable). Let S be symmetric such that the projection of S generates $G/[G, G]$ and $\gcd(|G|, |S|!) = 1$. Then $\text{Cay}(G, S)$ is Hamiltonian.*

Proof. Use solvable-group criteria and lift Hamilton cycles from abelian quotients, verifying abelianization coverage and coprimality to avoid obstructions; cf. general Hamiltonicity results for Cayley graphs over solvable groups [4]. $\square$

6 GENERALIZATIONS AND FUTURE DIRECTIONS

Other recursive block families. Replace C_p by a block family $\mathcal{B}$ (cliques, trees, stars, or hybrids). The resulting automorphism groups remain iterated semidirects/wreath-like, now featuring $\text{Aut}(B)$ for $B \in \mathcal{B}$, e.g. $\mathfrak{S}_{t-1}$ for clique blocks, etc. Adapting Yade-classes and loads from cyclic to symmetric local actions suggests a path to a more general combinatorial representation theory [6, 12].

Complexity. This framework implies algorithms for (i) computing wreath-cycle decompositions, (ii) conjugacy via Load-Orbit Graph isomorphism, and (iii) building the Load Character Table. Analyzing their time/space complexity in terms of p, k and wreath depth connects to the known complexity of conjugacy in wreath products [9].

Further spectral questions. Beyond gaps: full eigenvalue distributions, random-walk mixing, higher-order Cheeger inequalities, and relations to lamplighter-type phenomena and wreath graph spectra [11].

7 CONCLUSION

The load-invariant framework for iterated wreath automorphism groups of recursive graphs is introduced. It yields complete conjugacy classification, a factorized character theory, and spectral consequences for Cayley graphs, including explicit expanders and Hamiltonicity criteria. The approach is poised to extend to richer block families with symmetric local actions, opening a broader combinatorial representation theory for self-similar symmetries.

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NEP 2020 Perspective on Integrating Indian Knowledge Systems into Contemporary Indian Education: A Conceptual Understanding

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ABSTRACT

Despite the rapid transformation of the Indian education system, it has been criticized for overtly emphasizing specialization, rote learning, and being alienated from the traditional ancient wisdom often referred to as the Indian Knowledge System (IKS) in common parlance. IKS, presumably as documented in many studies, offered complete knowledge that addressed the holistic development of learners. IKS can be understood as a wide range of ancient wisdom and knowledge that has evolved over a long period of time, covering aspects of philosophy, pedagogy, health sciences, spirituality, mathematics, etc., and is believed to address the challenges of modern times. Recognizing the potential of ancient wisdom in responding to the need of creating well-rounded individuals, the National Education Policy (NEP) 2020, which came into existence on 29th July 2020, has outlined several measures for revitalizing Indian education, including the modalities of integrating the IKS into the modern education system. Keeping this in view, this conceptual paper has reviewed secondary sources of data, particularly the National Education Policy (NEP) 2020 and its key recommendations relating to IKS, to provide a nuanced understanding of the perspectives of NEP 2020 on IKS integration into contemporary Indian education. Additionally, the paper highlights the possible challenges and discusses essential reconsiderations for accommodating IKS into the modern curriculum.

Keywords: NEP 2020, IKS, India, challenges.

INTRODUCTION

The Indian education system is ordinarily believed to have been in existence since the ancient period that hosted the Vedic education, Sutra, and epic literatures Mishra et al., (2023). Starting from the earliest times, i.e., ancient, through the British period, and in the post-independent period, Indian education has been through a lot of transformation from being completely reliant on oral traditions to modern-day written and digital modes. Despite the rapidly evolving nature of Indian education reinforced by globalisation and technological evolution, NEP (2020) recognises it as being siloed, compartmentalised, lacking relevance, holistic knowledge, rootedness, local flavour, etc. In the backdrop of this evolving nature of the Indian education system, the need for integrating the indigenous knowledge into modern education has been strongly recognised by many scholars. In this

regard, Mishra et al. (2023) maintain that the ancient learning system rested on Vedic knowledge and yogic practices contributed to calming the mind, which further facilitated learning, and during modern times have been emphasized by higher educational institutions guided by governing bodies like UGC, AICTE, etc. Moreover, many proactive policies, particularly the National Education Policy (NEP) 2020, have been catalyzing this integration by highlighting the need for reviving Indian Knowledge Systems (IKS). This integration is believed to address some of the issues in modern Indian education highlighted previously.

SIGNIFICANCE OF THE PAPER

The purpose of this conceptual paper is to offer a detailed understanding of the vision of the NEP 2020 on the integration of IKS into the modern education system. Additionally, the paper provides a brief overview of IKS and introduces the readers to the conceptual understanding of IKS. This paper is significant, particularly because it highlights the importance of integrating IKS into modern education and therefore enhances our understanding of the possibilities and merits of this integration. Additionally, by attempting to analyse the policy intent and discussing the implementational hurdles, the paper makes a solid contribution to the ongoing discussion on transforming the Indian education system. Further, for designing curriculum and pedagogy in tune with the vision of the policy and offering practical solutions for bridging the intent and the actual implementation of the policy, the paper is conceptually sound and significant.

METHODOLOGY

Being a conceptual study, this paper does dwell on empirical data. Therefore, it follows the method of reviewing secondary sources of data, particularly the National Education Policy (NEP) 2020 and its key recommendations relating to IKS. Additionally, the paper also analysed other academic writings to gain an understanding of the rationale of integrating IKS into modern education. As a conceptual study, the paper highlights certain challenges and possibilities to be considered for proper integration.

INDIAN KNOWLEDGE SYSTEMS (IKS)

Indian Knowledge Systems (IKS) encompasses a wide range of ancient wisdom and knowledge evolved over a long period of time, covering aspects of philosophy, pedagogy, health sciences, mathematics, etc. Kumari et al. (2025). Further, Kumari et al. (2025) also define IKS as a term that connotes a wide range of indigenous traditions covering intellectual, spiritual, philosophical, scientific, and cultural traditions evolved over time that have indirectly contributed to expanding the knowledge base of India. Therefore, it can be argued that IKS does not represent the singularity of ideas or wisdom but an all-encompassing integration of many domains that eventually presents a holistic corpus of knowledge. In this regard, Khan et al. (2024) maintain that the IKS is firmly founded on the three major components, mainly Knowledge or *Jnan*, Science or *Vigyan*, and Philosophy or *Darshan*. IKS is also understood as everything Indian, including literature, social customs and traditions, and historical evidence that have emerged over a period of many years in several languages and dialects across the length and breadth of the country (Mahadevan, 2022). Further, the authors have also analysed the words involved in the term IKS. Accordingly, Indian

essentially means indigenous knowledge generated by Indian brains. Knowledge is described as wisdom acquired by knowledge seekers on account of several experiences and challenges faced and thereby acquired in the form of insights for solving the difficulties faced in life. Since the corpus of the indigenous knowledge system is vast, easy access requires classification and codification, and therefore, the term System implies a methodology for classification and codification of the knowledge, ensuring fine interrelation among various aspects of knowledge (Mahadevan, 2022).

PARALLELS BETWEEN NEP 2020 AND IKS

NEP 2020, announced on 29th July 2020, has been considered a hallmark in modern Indian education. The policy has been mostly appreciated in terms of initiating a major overhaul in the education system, starting from school to the higher education level. Particularly relevant in the context of the present paper is the need to end compartmentalised and siloed higher education by converting existing higher educational institutions into multidisciplinary learning environments strongly backed by the ideas of ancient Indian universities that facilitate embracing IKS (NEP, 2020). Additionally, the policy outlines that rootedness and pride in Indian culture, heritage, and knowledge systems and achievements will be a guiding factor in embracing IKS. In this regard, the policy outlines that “Indian Knowledge Systems, including tribal knowledge and indigenous and traditional ways of learning, will be covered and included in mathematics, astronomy, philosophy, yoga, architecture, medicine, agriculture, engineering, linguistics, literature, sports, games, as well as in governance, polity, conservation. Specific courses in tribal ethno-medicinal practices, forest management, traditional (organic) crop cultivation, natural farming, etc., will also be made available. Video documentaries on inspirational luminaries of India, ancient and modern, in science and beyond, will be shown at appropriate points throughout the school curriculum. Students will be encouraged to visit different States as part of cultural exchange programmes.” (para 4.27, NEP 2020). Similarly, the policy states that the entire spectrum of curriculum and pedagogy spanning from the foundational stage will be overhauled to accommodate Indian culture, customs, traditions, heritage, language, and philosophy fine fine-tuning with the idea of making it relevant and rooted in Indian ethos and values. Further, the choice of stories, sports, arts, and games will be essentially rooted in the Indian and local context. The policy foresees this integration as a potential means for reviving the glorious knowledge traditions that once India was recognised for, and at the same time, prepare a world-class education system that is second to none by 2040. The policy acknowledges the specialization of great Indian scholars in varied areas and their seminal contribution to the world's knowledge and believes that the vast reservoir of Indian knowledge must not just be preserved but enhanced and used through the modern education system (NEP, 2020). In addition, the policy proposes experiential learning as a standard mode of introducing learners to the vast ancient knowledge base.

Some of the guiding concepts of the IKS, particularly in aspects of pedagogy that have withstood the test of time, have found their clear expression in modern-day educational policies and approaches. Given the fundamental premise on which the IKS rests, i.e., the idea of providing holistic education through experiential mode, many parallels have been identified between NEP 2020 and IKS. For instance, as outlined by Kumari et al. (2025), central to the IKS pedagogy is the emphasis on learning

by doing, localised and contextual knowledge that corresponds to the idea of experiential learning and the idea of rootedness emphasised by NEP 2020. Aligning with the multidisciplinary aspect of IKS that caters to the growth of well-rounded individuals, NEP 2020 has also proposed multidisciplinary education with a fine blend of science, arts, humanities, and sports intended to prepare students for a multidisciplinary world and to ensure the unity of knowledge. Moreover, the pedagogical strategy outlined by the policy, especially experiential learning, aligns with the ancient Indian system of learning, where much was acquired through experience-based learning. Likewise, NEP 2020 envisions imparting multidisciplinary, holistic knowledge instead of siloed and compartmentalised knowledge, which is founded very well on the IKS, which is integrative in nature. Aligning with many ideas of IKS and for smooth integration of IKS, the policy has outlined several mechanisms at the institutional level. In this regard, the policy proposes the need for establishing the Indian Knowledge Systems Division in educational institutions charged with the duty of conducting research and promoting IKS (Kumari et al. 2025). Additionally, pedagogical reform, a curriculum rooted in Indian ethos, may be considered as another area where policy has announced appropriate changes to accommodate the essentials of IKS.

RATIONALE FOR INTEGRATION OF IKS INTO THE MODERN EDUCATION SYSTEM

Evidently, IKS is a vast and reliable source of knowledge that has evolved in response to challenges and needs of life and society, and therefore goes beyond the mere passing of ancestral knowledge. Considered accordingly, IKS offers a solid knowledge ground and is based on the firm foundations of the ancient Vedic literature, including the Vedas and the Upanishads. IKS is poised to ensure sustainability in education by blending the indigenous knowledge system into the modern education system marked by rapid digitalization and rising trends of artificial intelligence. Since the IKS has gradually evolved over a long period of time, it serves as a reliable source of knowledge. As maintained by Khan et al. (2024), the influence of IKS will continue to shape the various cultural, social, and intellectual landscapes of Indian society. Given the foundations of IKS on ancient Vedic literatures, science, philosophy, and spirituality, it holds a lot of significance in contemporary times that are challenged by stress experienced on account of so many factors. Likewise, in the context of the contemporary educational landscape that is influenced by forces of globalisation and Western epistemologies, a strong urge has been felt to revive the indigenous knowledge systems (Kumari et al. 2025). Moreover, as maintained by Kumari et al. (2025), IKS integration is contemporarily relevant as it offers sustainability and human welfare at a time when the world has become increasingly complex. Likewise, IKS integration promises to ensure not just all-around development but also to develop a sense of identity and belongingness among learners (Khan et al. 2025).

CONCERNS FOR IKS INTEGRATION

IKS integration promises to resolve some of the long-standing challenges in Indian education, yet some challenges and concerns need to be properly addressed. Some of these concerns are discussed below:

Institutional and Curricular difficulty- these may be understood as problems faced in the

institutions, mostly in the form of absence of teachers sufficiently trained in IKS, problems in switching over from traditional educational practices, and similarly, there are challenges in designing IKS-based curriculum owing to the absence of institutional autonomy. In this regard, Sancheti et al. opine that higher education, including colleges in India, is still centralised with limited autonomy. Likewise lack of sufficient funding in designing IKS courses and difficulties in conducting research on account of a lack of research centres may severely hamper the integration process. Similarly, difficulties experienced in the form of accommodating the contents of IKS into already overcrowded curricula are other challenges. Further, the lack of textbooks available in an easily understandable language complicates the integration process. Additionally, scholars like Sarita and Singh (2025) have reported insufficient teachers trained in IKS content, difficulty in switching over from traditional educational practices, resource crunch, as some challenges in integrating IKS.

Lack of Documentation- depending on the *Guru Shishya Parampara*, most of the ancient knowledge has been passed down orally from one generation to another. In this regard, authors like Khan et al. (2025) point out that such orally transferred knowledge, which is not properly documented, may be difficult to study, share, and include in formal textbooks.

Fear of Resistance- since most of ancient Indian wisdom draws its inspiration from Vedic literature, mostly available in the Sanskrit language, there clearly is a lack of a secular element in such knowledge. In this regard, Kumar (2025) maintains that since most of the IKS is available in the Sanskrit or Pali languages, translating these works without losing their essence may be challenging. Accordingly, Kumar (2025) also acknowledges that since some element of IKS is philosophical and therefore contrary to modern secular education, it might be strongly resisted. Therefore, on account of a lack of secular content, there is an underlying fear of resistance and opposition to religious-oriented knowledge. Additionally, some scholars Husain (2025), fear that ancient wisdom may not be able to respond to the demands of modern day.

Balancing Traditional Knowledge with Scientific Knowledge- balancing traditional wisdom with scientific temper may pose difficulty. While India's cultural and spiritual heritage underpins traditional wisdom and is planned in harmony with nature, modern science-backed knowledge, on the contrary, encompasses the need for reasoning, critical thinking seeking clarity. Further, scholars like Das et al. (2025) maintain that an era of artificial intelligence promises to offer holistic learning; however may not be able to provide spiritual and experiential aspects of education as easily as the traditional education system. Therefore, balancing these two extremes may be difficult and may require careful thought and planning.

WAY FORWARD

To address some of the identified challenges in IKS incorporation, certain curricular, pedagogical, and institutional modifications must be prioritised. The NEP 2020 clearly offers some guidelines for the successful merger of the rich heritage of ancient Indian wisdom with modern education. Some of the essential considerations that need to be emphasised are discussed below:

Curricular reforms- adjusting the existing curriculum to accommodate traditional knowledge must be viewed as an important measure for introducing new-age learners to the vast reservoir of ancient Indian wisdom. In this regard, as outlined by the policy, efforts should be directed towards content reduction without compromising on the essential aspects. Aligning with the vision of the policy, the curriculum should therefore be focused on presenting basic concepts, key ideas, and their real-world applications to make space for accommodating the essential elements of IKS. Additionally, making IKS available in easy languages can augment their learning and receptivity.

Pedagogical reforms- in this regard, there must be a transition from age-old practices of rote learning to experiential learning. As stated by NEP 2020, there must be an increasing emphasis on providing hands-on learning experiences for children with integration of art-integrated, storytelling-based pedagogy as an acceptable form of pedagogy. Such pedagogies can joyfully introduce learners to the vast body of ancient wisdom with less monotony.

Teacher Training- training and orienting teachers with IKS content cannot be overemphasised. Therefore, there must be a systematic way of introducing teachers to traditional knowledge. Teacher educators must acquire special training and knowledge through workshops, discussions to facilitate their acquisition of traditional knowledge. Sufficiently trained teacher educators can further impart this knowledge to prospective teachers to maintain the tradition of *Guru Shishya Parampara* – a core idea of the ancient Indian education system. Further, as delineated by the policy, teachers should continuously engage themselves in programmes of Continuous Professional Development (CPD) that facilitate them to upgrade their pedagogical skills and be acquainted with experiential learning, art-integrated, and sport-integrated pedagogy. Moreover, the Faculty Development Programme (FDP) workshops must be regularly organised to orient teachers with IKS and to facilitate its smooth incorporation into the contemporary curriculum.

Institutional mechanisms- Additionally, aligning with the vision of NEP 2020, each institution must maintain an IKS cell actively engaged in teaching, undertaking research in areas like philosophy, Ayurveda, etc., to preserve and disseminate IKS. Further, institutional funds may be generated for organising IKS-based programs in educational institutions. Additionally, institutions must collaborate with local knowledge practitioners for conducting research and for sharing their insights and understanding of IKS. Curriculum development committees must emphasize proper integration of IKS into the existing curriculum.

CONCLUSION

NEP 2020 has taken a transformative step by outlining the modalities of integrating IKS into the mainstream curriculum, recognising its potential in removing some of the ills of the modern education system. Rooted in a vast reservoir of ancient and traditional knowledge and wisdom, integrating IKS into the modern curriculum could possibly lead to a paradigm shift in the Indian education system, given the understanding that previous policies failed to consider this possibility. By considering ways of connecting IKS with contemporary education, NEP 2020 foresees the possibility of bridging the gap between traditional wisdom and modern knowledge and therefore envisions offering holistic knowledge to students. However, successful incorporation requires

many adjustments at the institutional level. Curricular modification, teacher training, and pedagogical reforms are crucial areas that cannot be overlooked. Likewise, technological innovations and their subtle influence in all areas, including teaching and learning, must be equally acknowledged. Therefore, balancing modern science-backed ideas with ancient wisdom requires committed efforts and a robust institutional machinery in the form of well-established IKS centres, trained teachers, coordination among various stakeholders, effective policy, and funding. Blending innovation with tradition must be prioritized for translating the vision of the NEP 2020 to convert India into a global knowledge superpower and to instill among learners a deep sense of respect and pride in being Indian (NEP, 2020).

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Estimation of Curie Temperature in Dilute Magnetic Semiconductors : A Theoretical Study

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ABSTRACT

We investigate the temperature dependence of magnetic order in oxides doped with p-block elements and transition metals to create dilute magnetic semiconductors. This helps us determine the existence of room temperature ferromagnetism and thus feasibility in spintronic applications of similar systems. From ab-initio studies in existing literature, we obtain the energy difference between magnetic configurations at 0 K to create the Heisenberg spin model for the system. By treating this system atomistically, we evolve it in temperature using the Monte Carlo metropolis method. The transition temperature from ferromagnetic to paramagnetic state that is the Curie temperature is thus obtained giving information about the temperature up to which ferromagnetism exists. For the current study we focus on two oxides viz. TiO_2 and SnO_2 as the base materials.

Keywords: Dilute Magnetic Semiconductors, Spintronics, Monte Carlo Method, Curie Temperature, Room Temperature Ferromagnetism

INTRODUCTION

The demonstration of successful spin injection and then extremely long coherent times in non-magnetic semiconductors made semiconductor spintronics a promising area (Kikkawa & Awschalom, 1999; Y. Ohno et al., 1999). Further, it was demonstrated by H. Ohno et al. (2000) that ferromagnetism in semiconductors can be manipulated by electric fields.

Dietl's seminal paper in the same year described ferromagnetism in dilute magnetic semiconductors using the Zener model. The origin of magnetism in these materials was considered to be the Zener exchange model for ferromagnetism. Thus, a range of predictions about DMS materials with high Curie temperatures were made (Dietl et al., 2000). The main drawback was that the theory was based on long range interaction just like the mean field theory. However,

DFT which has since then been used to model these systems gives values much more in agreement with experiment, shows a short range order. The interaction energy falls off rapidly with distance

especially for low concentrations. Therefore, the ordering temperature due to the earlier theory was in most cases strongly overestimated (Sato et al., 2010).

A flurry of research kicked in after Dietl's work where researchers tried to induce magnetism with high Curie temperature by doping semiconductors with magnetic ions (Matsumoto et al., 2001; Punnoose & Hays, 2005). It was seen that when doped with transition metals, not only the concentration of the doped metal but the configuration of the dopants and the sites of doping played a major role in magnetization characteristics (Iuşan et al., 2006). Iuşan et al. (2006) also suggested a modified mean field theory that agreed with their experimental results.

The search for good DMS materials is aided by Density Functional Theory. Density Functional Theory provides the ground state information like the interaction energy, anisotropy constant, magnetic moment, etc. It is widely used to calculate these properties of novel materials (Luitel et al., 2016, 2018; Roy et al., 2019a, 2019b). However, the critical temperature is not a ground state property and hence cannot be given by it. Therefore, a variety of other methods has to be used to find the magnetic ordering with respect to temperature. The mean field expression was widely used in the literature to get an approximation of the Curie temperature (Dietl et al., 2000; Sato et al., 2003). The problems therein as discussed above lead to modified version of mean field theory. Monte Carlo simulations fill this gap as they are numerically exact and can be performed once the ground state parameters from DFT are known (Evans et al., 2014). The critical temperature as obtained from MC simulations have been found to match very well with experimental results even in disordered systems (Evans et al., 2015). Therefore, we use this method of simulating the system using the Monte Carlo algorithm to find the susceptibility and magnetization of our system. This evolves the ground state parameters as obtained in DFT atomistically through

temperature and provides an accurate determination of the Curie temperature.

In the present work we analyze the temperature dependent magnetization characteristics of ten systems formed by doping different elements in TiO_2 and SnO_2 . The interest in TiO_2 developed after Matsumoto et al. (2001) developed a room temperature ferromagnetic transparent semiconductor by doping cobalt in anatase TiO_2 . This makes it a potential candidate for DMS applications. The ability of TiO_2 to work well as a magnetic semiconductor in electronic devices was also emphasized by Ohno, especially for combining the storage, logic and user interface into a single component due to it being a transparent, ferromagnetic semiconductor (H. Ohno et al., 2000). TiO_2 is diamagnetic but inducing defects or oxygen vacancies by creating a thin film of it induces ferromagnetic order without any doping (Yang et al., 2010). It may also be doped to get ferromagnetic ordering. Experimentation on C doped TiO_2 found the ferromagnetic ordering to exist at 300 K (Luitel et al., 2019). Magnetic moments of $2\mu_B$ and $1\mu_B$ per atoms was also found in anatase TiO_2 by Yang et al. (2010) when doped with Carbon and Boron respectively

. Thus, it was clear that TiO_2 showed ferromagnetism without doping any magnetic ions or d^0

ferromagnetism. Though all of these properties of TiO_2 makes it a good candidate for DMS, the cause of magnetism in TiO_2 is still unclear. Room temperature ferromagnetism in TiO_2 based materials have been found experimentally (Hou et al., 2008; Sanyal et al., 2014). Hou et al. (2008) reported ferromagnetism in thin films of Cu doped TiO_2 at 350 K which was dependent on O vacancy and nearest neighbor distance. A similar observation was made by Wang et al. (2006) in Cr-doped TiO_2 thin film, where they found ferromagnetic ordering at 390 K through Hysteresis loop measurements. While, most room temperature ordering reports have been made experimentally, theoretical calculations through ab-initio approach can give complete information about the magnetic moments and alignment in these materials in their ground state (Luitel et al., 2018; Roy et al., 2019a; Yang et al., 2010). SnO_2 is an n-type semiconductor with a band gap of 3.8 eV (Luitel et al., 2018). This wide bandgap and semiconducting property makes it a good candidate for Dilute magnetic semicon- ductor. Pristine SnO_2 is diamagnetic in nature, but it shows ferromagnetism when defects are induced; Since, these defects need not necessarily be of magnetic nature (Luitel et al., 2018), it is d^0 ferromagnetism (Coey, 2005). The actual mechanism that causes this magnetism still has

not got any consensus. Studies by Espinosa et al. (2011) attribute it to the Sn vacancy.

Either way, there has been a consistent stream of reports on experimental observations of room temperature ferromagnetism in SnO_2 systems. Punnoose and Hays (2005) investigated iron and cobalt doped samples to get a Curie temperature of 440 K in $\text{Sn}_{0.99}\text{Co}_{0.01}\text{O}_2$ and 850 K in $\text{Sn}_{0.99}\text{Fe}_{0.01}\text{O}_2$. Theoretical or computational methods to find out the temperature dependent magnetization characteristic of these systems can vastly speed up the process of not only finding materials that work but also of understanding these systems. To that end we look at studies on SnO_2 doped with transition metals. It has been found from ground state ab-initio approach that p-block dopants (P and As) can induce magnetism with ferromagnetic ordering stability as high as 404.4 meV and 277.5 meV respectively and a magnetic moment $\sim 1\mu_B$ per dopant (Luitel et al., 2018).

In the present work, we have performed calculations through the Monte Carlo algorithm using Heisenberg spin interaction model to find out the magnetization and susceptibility of TiO_2 based DMS at incremental points in temperature. Through this we have determined the Curie Temperature (T_c) of the material and thus its feasibility for practical purposes.

We use an interpolation of the Curie-Bloch law that rescales the Curie-Bloch law to assimilate quantum fluctuations (Evans et al., 2014). The magnetization M as a function of temperature

$\tau = T/T_c$ is given by:

$$M(\tau) = [1 - \tau^p]^b$$

Where, p is the scaling parameter and b is the critical exponent. However, inferring the Curie temperature from the magnetization curve is rather heuristic as it shows the phase transition through a small range of temperature. Susceptibility on the other hand has a peak at the Curie Temperature due to divergence. Statistically, the zero field isothermal susceptibility is calculated as:

$$\chi = \frac{1}{K_B T} (\langle M^2 \rangle - \langle M \rangle^2)$$

The peak in the susceptibility can be justified as the divergence as seen in Curie-Weiss law when T approaches T_c i.e. $\chi = \frac{C}{T - T_c}$ where C is the Curie constant and T_c is the Curie temperature. We compare our result with the results obtained from the Mean Field theory using the relation:

$$T_c = \frac{J_{ij} \epsilon z}{3k}$$

where J_{ij} is the exchange energy, z the number of nearest neighbors and k_B is the Boltzmann constant. The term ϵ is a correction factor based on molecular field fluctuations and can be approximated close to ~ 0.86 (Evans et al., 2015).

3 COMPUTATIONAL METHODOLOGY

The Heisenberg spin interaction model has been employed in the Monte Carlo algorithm for theoretical calculations using VAMPIRE software package (Evans et al., 2014). A supercell of $2 \times 2 \times 3$ tetragonal unit cells of TiO_2 has been taken. Luitel and Sanyal (2017) have reported the optimized lattice constants for TiO_2 to be $a=b=4.59 \text{ \AA}$ and $c=2.96 \text{ \AA}$. Periodic boundary condition is introduced along all the lattice basis axes. In the pristine supercell two atoms of O have been substituted with $X=\text{B, C, Si, N, P}$ to get $\text{Ti}_{24}\text{O}_{46}\text{X}_2$. Two different configurations have been considered for these substitutions. $X=\text{B, N, P, Si}$ have been substituted in long position as shown in Figure 1b and C has been substituted in short position as shown in Figure 1a.

In the same fashion, A supercell of $2 \times 2 \times 3$ tetragonal unit cells have been taken for SnO_2 . The optimized lattice constants for SnO_2 is reported by Roy et al. (2019b) to be $a = b = 4.736 \text{ \AA}$ and $c = 3.186 \text{ \AA}$ along with $\alpha = \beta = \gamma = 90^\circ$. Two Sn atoms in the SnO_2 supercell have been substituted by $X=\text{Fe, Cr, Co}$ such that we get $\text{Sn}_{22}\text{X}_2\text{O}_{48}$, Figure 1c. Similarly, two oxygen atoms in the supercell have been substituted by $Y=\text{P, As}$ to get $\text{Sn}_{24}\text{Y}_2\text{O}_{46}$, Figure 1d.

Since, each of these systems has a magnetic moment localized over the doped atom (Luitel et al., 2018; Roy et al., 2019b). For all calculations, the nearest neighbor spin interaction of only that atom has been considered in a system of 25,392 atoms. A numerical Heisenberg model simulation has been performed for each system using the Monte Carlo Metropolis algorithm. The system is run for

10^5 trial steps and the data is averaged for 5×10^5 steps at each point in temperature.

To analyze the data obtained we use the Curie Bloch interpolation as given in equation 1. We also analyze the susceptibility curve whose peak corresponds to the transition from ferromagnetism to paramagnetism. Finally, we calculate the T_c according to the mean field expression as given in equation 3 and compare with our simulation results.

4 RESULTS AND DISCUSSION

In the short position, the dopant atoms are positioned on two sides of two Ti adjacent atoms as in Figure 1a. Only carbon has been chosen for study in this position as it shows a significant ferromagnetic alignment preference at 0 K as found by Luitel et al. (2018) through DFT studies. The distance between two carbon atoms is 4.84 Å and a magnetic moment of $0.4\mu_B$ is induced.

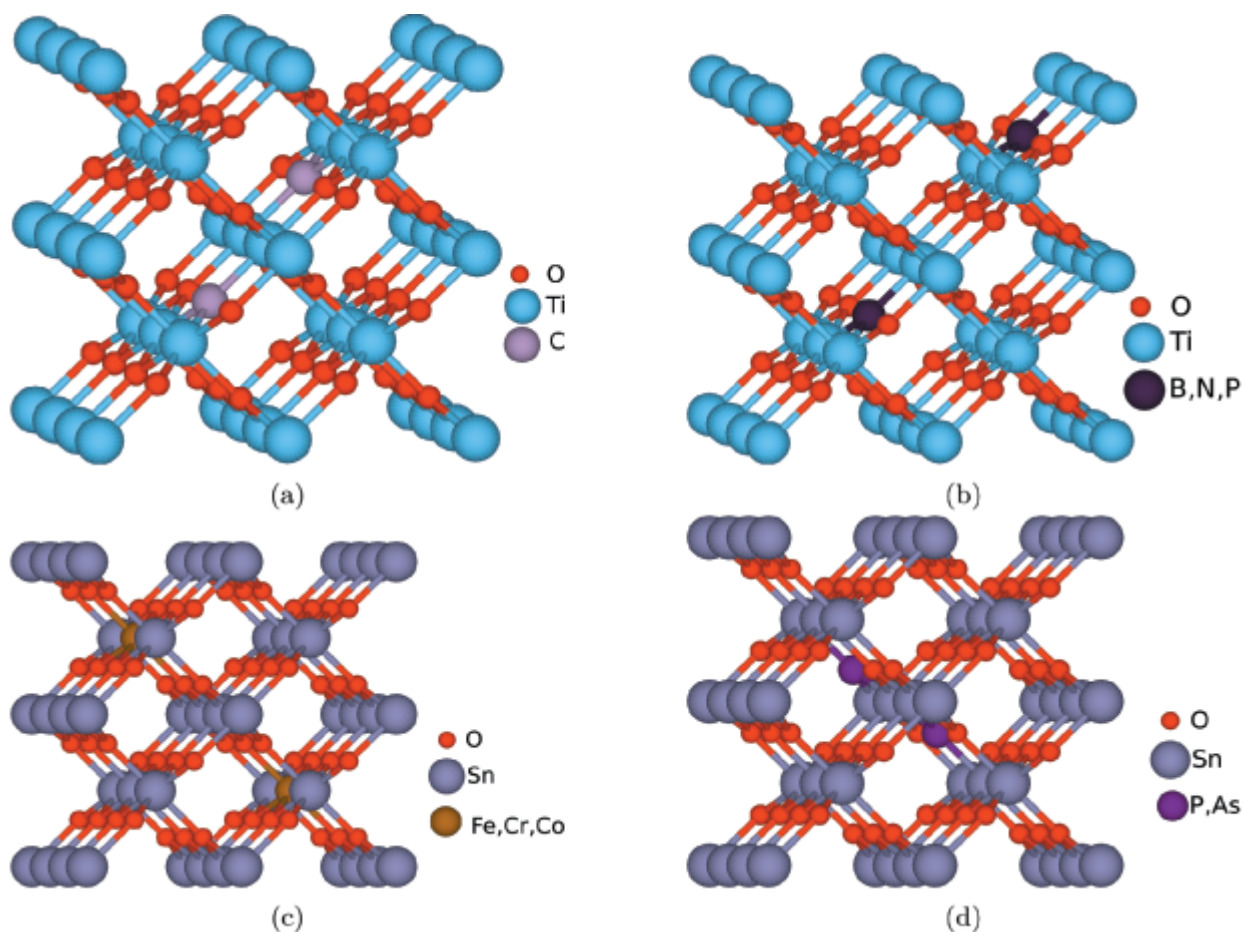


Figure 1: Structures with dopant substitutions in TiO₂ and TiO₂ lattices. Subfigures (a–b) correspond to TiO₂ substitutions, where (a) shows C substituted in the short position and (b) shows B, Si, N, and P substituted in the long position. Subfigures (c–d) correspond to SnO₂ substitutions, where (c) shows Fe, Cr, and Co doped at the Sn site and (d) shows P and As doped at the O site.

The difference between parallel and antiparallel states is -88 meV. The p-orbital electrons of carbon are mainly responsible for the observed magnetic moment (Luitel et al., 2018).

Using, these parameters and running the Monte Carlo simulation gives us the results as shown in Figure 2a. On fitting this data with the Curie-Bloch interpolation from equation 1, we get a Curie temperature of 490 K. We can see a slight deviation from the fit near the Curie point which is caused by a finite probability of fluctuation of the spins. The susceptibility also shows a peak at the value of 490 K which corresponds to the ferromagnetic to paramagnetic transition.

Table 1: Properties of doped system of TiO_2

System	Doping Site	Dopant	Magnetic Moment (μ_B)	Exchange Energy (meV)	Obtained Tc (K)	Tc from MFT (K)
TiO_2 , (Luitel & Sanyal, 2017)	O	C	0.2	88	490	292.5
	O	Si	0.885	3	465	39.9
	O	P	1	1	460	13.3
	O	B	0.8385	1	460	13.3
	O	N	1	1	460	13.3

Table 2: Properties of doped SnO_2 .

System	Doping Site	Dopant	Magnetic Moment (μ_B)	Exchange Energy (meV)	Obtained Tc (K)	Tc from MFT (K)
SnO_2 , (Roy et al., 2019b)	Sn	Fe	2.5	15	320	199.4
		Cr	2	9	290	119.6
		Co	1	3	270	39.8
SnO_2 , (Luitel et al., 2018)	O	As	0.995	277.5	410	922.3
		P	0.99	404	460	1342.7

The magnetization curve as seen in Figure 2a has a rather sharp drop right at T_c . This behavior is a characteristic of ferromagnets with a metamagnetic origin (Punnoose & Hays, 2005). Therefore, it is likely that the magnetism has an influence of itinerant carriers. The T_c we obtain here is consistent with experiments on C doped rutile TiO_2 (Luitel et al., 2019). On comparison with Mean field Theory, considering two nearest neighbors, we found that it underestimates the Curie temperature for the carbon doped TiO_2 system by over 60% as shown in Table 1.

In the long position, the dopant atoms are positioned on alternating bonds on two sides of two Ti atoms as in Figure 1b. Boron, Nitrogen, Phosphorus and Silicon show a significant ferro-magnetic alignment preference at 0 K as found by Luitel et al. (2018) through DFT studies. The distance between the two dopant atoms varies slightly for each dopant as, distance between B was found to be 7.24 Å, for Si: 8.32 Å, N: 7.14 Å, P: 7.32 Å. The magnetic moment induced by all four dopants were above $1.5\mu_B$. Further, unlike the short position, the difference between parallel and antiparallel states are only a few meVs, as can be seen in Table 1. While the 3d electrons of TiO_2 are responsible for the magnetic moment seen in case of B and Si, it is attributed to the 2p electrons in the other three cases (Luitel et al., 2018).

Performing the simulation with these parameters gives us the results in Figure 2 and are tabulated in Table 1. On fitting this data with the Curie-Bloch interpolation from equation 1, we get a T_c of 260 K for P, B, N doped TiO_2 . We note here that these three systems have identical exchange energies. The T_c for Si doped TiO_2 is slightly higher at 265 K. The susceptibility shows a peak at the same values for T_c . The T_c value for B doped TiO_2 was experimentally found to be above room temperature (Luitel et al., 2020), our simulation results are consistent with it.

The transition metals doped at Sn site in the SnO_2 lattice in Figure 1c. Through DFT studies performed by Roy et al. (2019b) it came to light that Co, Fe, Cr show ferromagnetic alignment at 0 K. The distance between the two dopants is 6.7 Å with the d orbital electrons of these transition metals being the cause of magnetic moment.

It must be noted here that Co doped SnO_2 system forms a p-type semiconductor and would be a much-needed candidate for p-type room temperature ferromagnetic semiconductor. However, we found that its T_c is 50 K below room temperature. Moreover, The difference in Curie temperatures of the systems directly relate to the exchange energies of the systems. However, the relation is not linear in contrast to the direction shown by mean field theory.

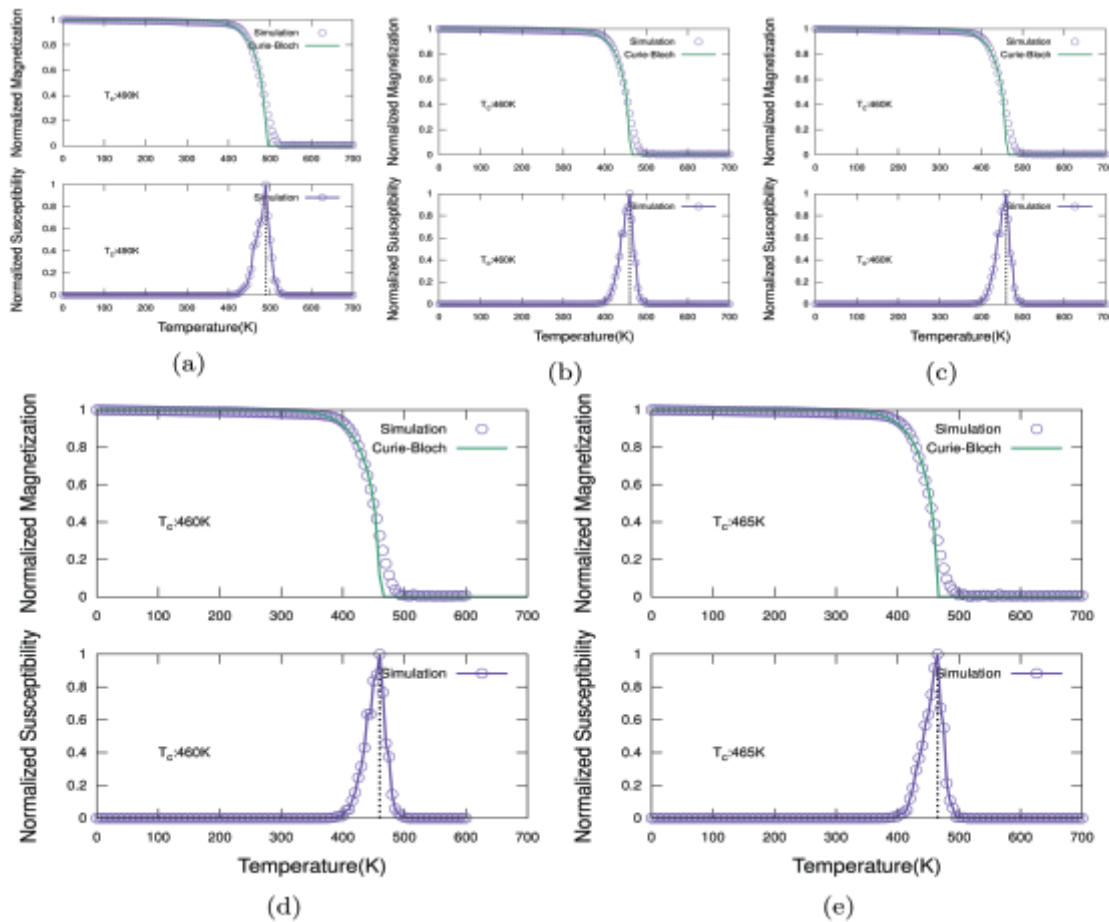


Figure 2: The dependence of magnetization on temperature as obtained from Monte Carlo simulations for TiO_2 lattice with dopants (a) Carbon (b) Boron (c) Nitrogen (d) Phosphorus (e) Silicon. In each subfigure the top panel is the normalized magnetization and the bottom panel is susceptibility which peaks at the Curie temperature.

For the SnO_2 based systems, the Curie temperatures of phosphorus and arsenic doped systems are well above room temperature while Iron doped system barely crosses the threshold. Phosphorus doped in oxygen site has Curie temperature (T_c) ~ 460 K and As doped at the same site has $T_c \sim 410$ K which are the highest Curie temperatures obtained in the system.

Further we see that the values of T_c we got for the systems with dopants in long position are proportional to the exchange energies they have and therefore the MFT values. However, MFT has a linear relationship with the exchange energy, and it is evident from Table 1 and 2 that T_c as obtained from simulation is not. This is consistent with recent studies by Li et al. (2025) on dilute magnetic semiconductors that report on the vast discrepancy between transition temperature given by mean field theory methods and MC simulations; the latter being much closer to experimental values.

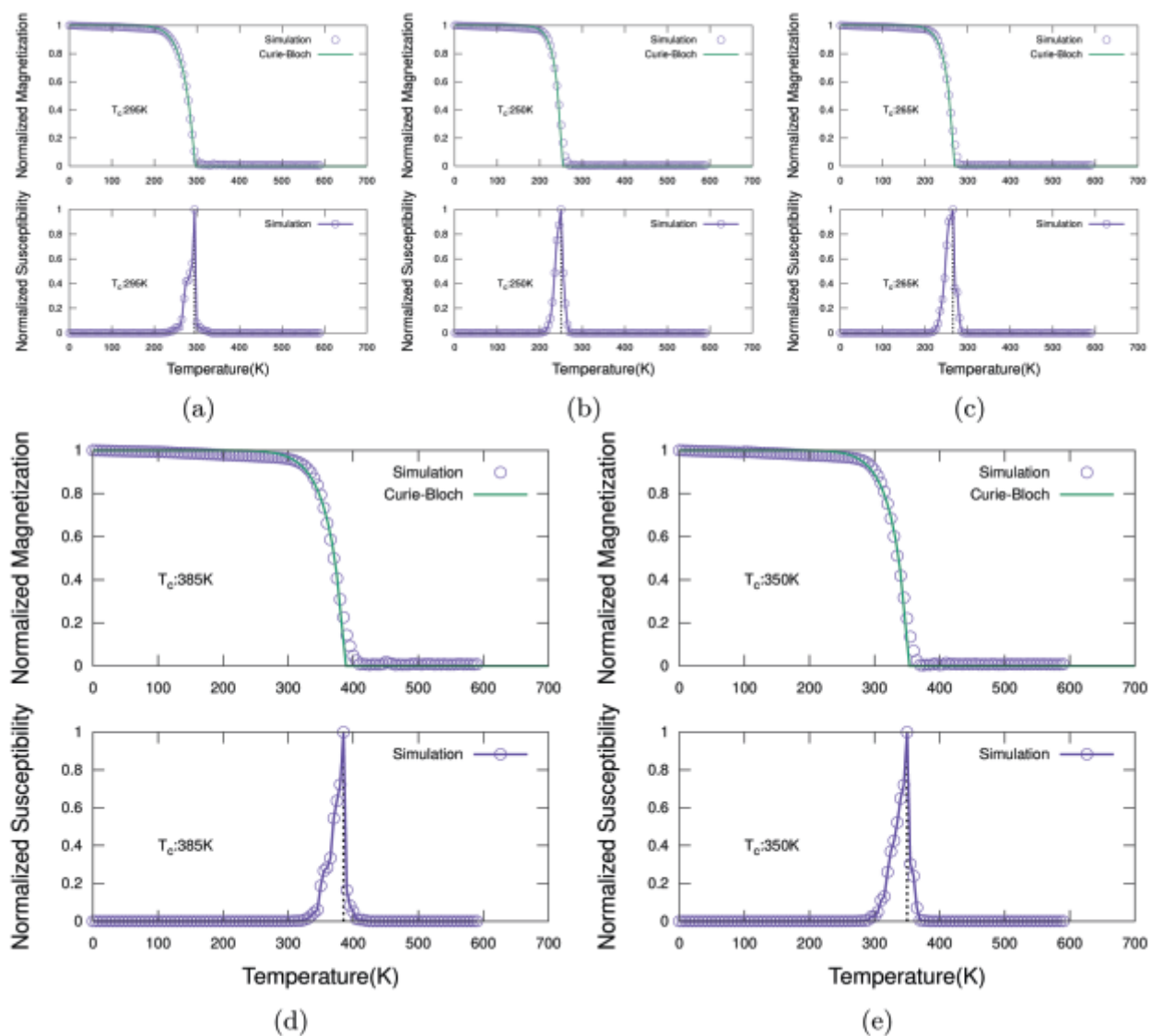


Figure 3: The dependence of magnetization on temperature as obtained from Monte Carlo simulations for SnO_2 lattice with different dopants. Subfigures (a–c) correspond to substitution at the Sn site with dopants Fe, Co, and Cr, respectively. Subfigures (d–e) correspond to substitution at the O site with dopants Phosphorus and Arsenic, respectively.

CONCLUSION

We see here that the exchange energy is the primary determiner of Curie temperature as the systems with identical exchange energies have identical T_c irrespective of the small differences in magnetic moments. The high T_c of Si, P, B, N doped systems even with a comparatively tiny exchange energy to that of C doped systems can be attributed to the fact that they are in long positions as shown in Figure 1b. This allows them to have 8 nearest neighbour interactions whereas Carbon in the short position (Figure 1a) can only have 2.

TiO₂ based systems have a Curie temperature above room temperature for all dopants tested. On comparison with Mean field Theory, we found that it underestimates the Curie temperature of doped systems of TiO₂. While, the T_c according to MFT is linear with the exchange energy T_c obtained through simulation is not and doesn't share the trends that it provides. Therefore, it provides no reliable estimate as to the Curie temperature of the systems studied here.

Carbon doped TiO₂ shows the highest $T_c \sim 490$ K from the materials studied. While P, B, N have identical $T_c \sim 460$ K and Si has $T_c \sim 465$ K. Our results are consistent with available experimental results as was seen in the case of B and C doped systems. SnO₂ based systems have a Curie temperature slightly above room temperature for all dopants tested. While transition metal doped SnO₂ show a Curie temperature right at room temperature, P and As doped SnO₂ have Curie temperatures higher than 400 K. This makes them much more suitable for DMS applications than the transition metal doped systems.

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