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THE CENTURION

TEACHERS' COUNCIL JOURNAL

(PEER-REVIEWED MULTIDISCIPLINARY JOURNAL)

A PUBLICATION OF THE TEACHERS' COUNCIL

ASUTOSH COLLEGE

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Editorial Board

The Principal Writes...

It is my immense pleasure to present the tenth issue of *The Centurion*, the Asutosh College Teachers' Council journal, which has since turned out to be a pioneering effort in the field of journal publication in the history of our institution. We now proudly boast of two online journals with e-ISSN, but the journey had begun in 2016 with *The Centurion*, our first peer-reviewed journal with ISSN.

Every issue of *The Centurion* is special, containing articles of abiding interest written by members of faculty, with each article undergoing rigorous peer review by external subject experts, before actual publication. The entire process is coordinated by the editorial team whose efforts deserve heartfelt appreciation. Scholars and academicians who review the submitted articles deserve our gratitude for taking out time from their busy schedules for this kind of work. I also congratulate all the contributors, both past and present, for without their articles and essays this journal would not have sustainable publication venture.

Dr. Manas Kabi
Principal
&
Chairperson of the Teachers' Council
Asutosh College

From the IQAC, Asutosh College

The Centurion, the flagship journal of the Asutosh College Teachers' Council, is now in its tenth year of publication, which calls for a well-deserved congratulatory nod for all those associated with the initiative. What had been launched in the centenary of the college as a tentative effort, has now matured into a significant presence in the sphere of academic journal publication in this part of the country.

The distinctiveness of the journal lies in its eclectic selection of articles, catering to different academic interests, serious and amateur. This tenth issue is no exception, as reflected in the table of contents and the following pages. A sheaf of thoughtfully penned critical writings by our faculty members on a rich variety of topics like the relationship between climate change and mental health, or how climate change is related to the issue of social inequality in a country like ours; cosmic phenomena like geomagnetic storms that affect earth; the need for libraries in an increasingly digital world of human communication and knowledge; the existential dilemma of tribal communities situated at the crossroads of cultural complexities; the socio-economic consequences of virtual learning in the aftermath of the COVID-19 pandemic; possible solutions to abiotic and biotic stress associated with traditional cultivation methods like *Jhum*; and then, to cap it all, the complexities related to Hydrodynamics, are to be found in this issue of *The Centurion*, which the Internal Quality Assurance Cell (IQAC) of Asutosh College is justifiably proud of presenting to a discerning readership.

Dr. Sraboni Roy
Coordinator, IQAC, Asutosh College

EDITORIAL

The Centurion, a multi-disciplinary journal published annually by the Teachers' Council of Asutosh College, has aimed to break the disciplinary barrier, right from its inception. True to its objective, this edition also lives up to its reputation of collating a plethora of articles touching various themes that echo with our every-day existence. Weaving together topics from physical sciences, plant sciences, social sciences, this volume is comprehensive and unique in its approach and style where the leitmotif of inter-linkage and seamless blending characterise the essays.

From the field of physics the two articles, one single authored and the second jointly-authored, touch upon issues that are relevant in our quotidian lives. Amit Kumar Bhattacharjee's attempt at charting out a roadmap in controlling the kinetics and morphology of complex fluids and soft materials, the very essential ingredients of a variety of items ranging from food products like mayonnaise and ice-cream, personal care products like soap, shampoo, toothpaste, highlight research avenues that can be pursued in studying fluctuating hydrodynamics in various subsystems that would enable, as the author points out, "wide application in materials design, fabrication and synthesis that contain sub-micron flow and extensively dominated by thermal phenomena where fluctuating hydrodynamics finds immense importance." In an age driven by technology, advanced communication and navigation systems have become an integral part of life-system. Arpita Bose and Aditi Das focus on the occurrence of geo-magnetic storm that can de-stabilise magnetosphere and ionosphere due to the interaction of the magnetic field on the Earth and intense solar wind that comes from the Sun, thereby affecting communication and navigation that might be life-threatening since such disruption can lead to accidents and crashes. They end with a note of hope that current researches, across the world, are geared towards ensuring uninterrupted satellite signals that would ease the life of mankind.

In spite of the great strides made in the field of science and technology, climate and environmental degradation is perhaps the biggest challenge faced at present. In India, where inequalities are deeply entrenched in the social fabric, climate change wreaks havoc not only on the environment, but, as Soumen Das portrays, further exacerbates social divides of class, caste, gender. As climate-induced migration grows, urban infrastructure and labour markets struggle to cope and accommodate, leading to rising social tensions. The need of the hour as the author aptly points out, "inclusive, community-driven adaptation strategies to build a more resilient and equitable future." Till a more pro-active role of the government is witnessed, climate change will continue to affect the physical and mental health of people, as pointed out by Supatra Sen. By familiriasing the readers with the concept of 'Ecological Grief', through her article, she

sounds a note of warning as how ecological grief has engulfed the lives of tribal people of the Himalayan region and outlines its impact on Indian psyche resulting in a sense of responsibility and guilt for the deterioration in environmental quality leading to ecological grief. The underlying Indian philosophy of interconnectedness, the author says, can deepen ecological loss and grief as damage to ecosystems can disrupt the divine balance and harmony. She underlines the coping mechanism and the need for vigorous implementation of the same, that should be undertaken by the government.

To overcome mental health issues, rife in the world today, therapy is the most sought-after solution. Gouranga Charan Jana adds a new lexicon to the genre of therapy—Bibliotherapy. Books, often considered as man's best friend, can be effectively used not only as a stress-reliever, but also to overcome serious mental health issues like depression. Psychologists and psychiatrists, are increasingly incorporating this new line of treatment as a therapeutic medium of healing. Books have now entered the digital world, especially after the Covid pandemic. While this has made reading more accessible, it has its serious pitfalls, as opined by Sudip Ghosh. In his article, he dwells on digital divide—the bane of written words entering the virtual world. how the various negative externalities that affect adversely EWS of Indian society. The article explores the unintended socio-economic consequences of virtual learning in a developing country, like India and emphasises on policy interventions to address these negative externalities for ensuring equitable access to education and sustainable economic development.

As man lives up to the various challenges of everyday existence, the trio of Shyamalina Haldar, Kanchan Karmakar and Ayesh Kabir enlightens the reader on means of sustainable jhum cultivation—the lifeline of the people residing in the north-eastern Himalayas. Those engaged in agriculture are adapting to new techniques of incorporating plant-growth promoting microorganisms as bioinoculants/biofertilizers, for stress management in Himalayan plants. Although, this is yet to be adopted on a large scale, the authors hope, that in the near future, such methods will find more takers amongst the Himalayan communities, whose very livelihood and consequent identity is shaped by jhum cultivation. As communities, especially the tribals, seek to preserve their identity through their profession, their culture, their distinctness, Samayita Sen journeys to Jhargram to witness the celebration of Bandna parab of the Kudmi community. Just as embracing of new techniques in jhum cultivation would ensure the sustenance and uniqueness of their livelihood, Sen's article, too, echoes Kudmis' efforts to recover, preserve, and rearticulate their cultural selfhood through language revival, ritual re-enlivening, and the invocation of oral memory.

The wide spectrum of articles in this volume, will surely appeal to readers of varied interests and resonate with them.

~ CONTENTS ~

COMPLEXITY IN THE FLUCTUATING HYDRODYNAMICAL THEORY OF SIMPLE FLUIDS

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Abstract : Complex fluids and soft materials are ubiquitous and essential in day-to-day life. Understanding their rheological property at various thermodynamic parameters and geometry is necessary to control their kinetics and morphology, albeit, not a straightforward task even for the most simple fluids, like water, due to various experimental, theoretical and numerical challenges involved. In this article, we discuss a few classic problems that display very different characteristics than their athermal variant. We conclude the discussion by highlighting a few numerical avenues for solving stochastic partial differential equations and relevant benchmarks. This study should motivate the reader to perform numerical experiments to match laboratory experimental findings where thermal fluctuation is an important parameter.

Keywords: *Simple Fluids, Nonequilibrium Thermodynamics, Computational Fluid Mechanics, Stochastic Processes, Partial Differential Equations.*

Abbreviations: Fluctuating Hydrodynamics (FHD), Computational Fluctuating Hydrodynamics (CFHD), Navier Stokes Equation (NSE), Landau Lifshitz Navier Stokes (LLNS), Fluctuating Heat Equation (FHE), Dean-Kawasaki Equation (DKE).

1. Introduction :

The study of hydrodynamic fluctuations stands as a cornerstone in the field of equilibrium and non-equilibrium statistical mechanics. For several decades it had captured the attention of scientists into the realm of mesoscale and nanoscale fluid technologies that are far away from the macroscale athermal systems. The work of Robert Brown in 1827 on the Brownian motion of the pollen grains suspended in water at room temperature led Albert Einstein to deduce the mathematical relation between equilibrium thermal fluctuation as well dissipation in the fluid [1]. Another infamous example is the blue sky that appear due to the Rayleigh scattering from the density fluctuations of the air [2,3]. These fluctuations are significant even in distant studies in Cellular Biology, where the incessant molecular motion at the microscopic level is deeply affected by the thermal fluctuations [4-5]. C.L. Navier and G.G. Stokes in 1850 popularized the equation of motion of a viscous athermal fluid in the continuum framework – the Navier-Stokes equation (NSE) [6]. The first exposition to

fluctuating hydrodynamics (FHD) was published in 1957 by L.D. Landau and E.M.Lifshitz, where fluctuating force terms with subtle properties were included in the dissipative fluxes, leading to a new set of balance laws for density, linear momentum, energy as well as the angular momentum, usually neglected due to inherent isotropy of the system, now named as Landau-Lifshitz-Navier-Stokes equation (LLNS) [6-7].

Albeit much of the computational fluid dynamics had paced up after the advent of computers in the Los Alamos National Lab in 1960, attention to fluctuating hydrodynamics is very recent due to its inherent mathematical and computational rigour. The usage of high-end computers gave birth to computational fluctuating hydrodynamics (CFHD), that eradicated various analytical complexity, yet were harder to tackle. This was due to the computational sophistication involved in dealing with the fluxes and thermally fluctuating forces to maintain physical laws intact upto machine precision [8-10]. A few popular numerical avenues include Lattice Boltzmann method (LBM), Finite Volume method (FVM), Finite Element Method (FEM), Boundary Integram Method (BIM), Fourier Spectral Collocation Method (SCM) and the Finite Difference Method (FDM) [11-13] – the later been extensively taught in an undergraduate Physics curriculum [14].

A key principle of thermodynamics is that entropy peaks at thermodynamic equilibrium. This insight led Albert Einstein to propose that a state's likelihood is directly linked to its entropy. Essentially, a system naturally evolves toward states that are more probable and have higher entropy. This connection reveals how systems progress toward maximum entropy, marking equilibrium, and sheds light on the foundational principles of statistical mechanics that govern our universe [15-16]. For instance, the probability of any thermodynamic variable x (e.g. pressure, temperature, density etc) with equilibrium value x_{eq} is $P(x) = Cexp(-\Delta S\,(x)/k_B)$ where $\Delta S(x) = S(x_{eq}) - S(x)$. Taylor expansion around equilibrium yields the deviation of the state from equilibrium to be

$$\Delta S(x) = S(x_{eq}) - S(x_{eq}) + (x - x_{eq})S'(x_{eq}) + \frac{1}{2}S''(x_{eq})(x - x_{eq})^2 = \frac{1}{2}S''(x_{eq})(x - x_{eq})^2 . (1)$$

For Normal distribution, $P(x) = Cexp\left[-(x - x_{eq})^2/2\sigma^2\right]$ with the variance $\sigma^2 = -k_B\left(S''(x_{eq})\right)^{-1}$. Starting from the thermodynamic relation $dQ = TdS$ and using the definition of heat capacity to be $C_V = \frac{dQ}{dT}$, we have $S''(T_{eq}) = -\frac{C_V}{T_{eq}^2}$ which yields the variance of temperature fluctuations to be $\sigma^2 = k_B\,T_{eq}^2/C_V$. Water with approximately 10^{10} molecules at room temperature have variance $\sigma^2 = 10^{-12}$ units that shows thermal fluctuations are small and can be neglected in continuum studies. However fluctuations become dramatically exaggerated for systems that we deal next.

2. A plethora of Fluctuating Hydrodynamical problems.

(A) Fluctuating Heat Equation (FHE): We consider the balance equation for conduction of heat through a metal rod having energy density ϵ ($\epsilon = C_V T$ where C_V is the material heat capacity) as $\partial_t \epsilon = -\nabla \cdot \mathbb{Q}$, where the heat flux $\mathbb{Q}$ consists of a deterministic part (say $\bar{\mathbb{Q}}$) and a randomly fluctuating part (say $\mathbb{Q}$). The phenomenological Fourier law connects $\bar{\mathbb{Q}}$ with the temperature gradient as $\bar{\mathbb{Q}} = -\kappa \nabla T$, where κ is the heat conductivity. $\bar{\mathbb{Q}}$ can be obtained from the Onsager-Casimir reciprocity relation that serves the constitutive relation between the heat flux and the thermodynamic force X via the Onsager coefficient $\mathcal{L}$ as $\bar{\mathbb{Q}} = \mathcal{L}X$. The deterministic part can be calculated from the entropy production of the external sources in a volume $\boldsymbol{\Omega}$ as a summation of internal entropy production and the boundary effects to heat flow rate: $\frac{d\bar{s}}{dt} = \int \frac{d\bar{s}}{dt} dx = \int X \cdot J dx - \left[\frac{\bar{\mathbb{Q}}}{T}\right]_{\partial\Omega}$,where J is the thermodynamic flux, $\bar{s}, \bar{\epsilon}$ are the specific entropy and energy which are related as $d\mathbb{Q} = T d\bar{s} = \rho d\bar{\epsilon}$. This yields $\int \frac{d\bar{s}}{dt} dx = \int \frac{\rho}{T}\frac{d\bar{\epsilon}}{dt} dx = -\int \frac{\nabla \cdot \bar{\mathbb{Q}}}{T} dx = \int \frac{\nabla \cdot (\kappa \nabla T)}{T} dx$. (2)

Using Green's first identity, we have $\int \frac{\nabla \cdot (\kappa \nabla T)}{T} dx = \int \nabla \cdot \left(\frac{\kappa \nabla T}{T}\right) dx - \int \nabla\left(\frac{1}{T}\right) \cdot (\kappa \nabla T) dx = -\int \nabla \cdot \left[\frac{\mathbb{Q}}{T}\right] dx - -\int \nabla\left(\frac{1}{T}\right) \cdot \left(\kappa T^2 \nabla\left[\frac{1}{T}\right]\right) dx = -\left[\frac{\bar{\mathbb{Q}}}{T}\right]_{\partial\Omega} + \int X \cdot J dx = -\left[\frac{\bar{\mathbb{Q}}}{T}\right]_{\partial\Omega} + \int X \cdot (\mathcal{L}X) dx$ (3)

giving the thermodynamic force, flux and Onsager coefficient as $X = \nabla\left(\frac{1}{T}\right), J = \kappa T^2 \nabla\left(\frac{1}{T}\right) = \bar{\mathbb{Q}}$, $\mathcal{L} = \kappa T^2$. This results into the balance equation (FHE) $\rho C_V \partial_t T = \nabla \cdot \left(\kappa \nabla T + \sqrt{2 k_B \kappa T^2}\, \mathbb{\Xi}\right)$ (4)

where $\mathbb{\Xi}$ is a spatiotemporally uncorrelated white noise with the property $\langle \mathbb{\Xi}(x,t) \rangle = 0, \langle \mathbb{\Xi}(x,t) \mathbb{\Xi}(x',t') \rangle = \delta(x-x')\delta(t-t')$. This is because the fluctuating heat flux $\mathbb{Q}$ has identical property with fluctuating mass diffusion flux in Fick's law for Brownian motion in ideal solutions. The Dean-Kawasaki equation (DKE) reads

$\partial_t n = \nabla \cdot \left(D \nabla n + \sqrt{2Dn}\, \mathbb{\Xi}\right)$ (5)

with the difference being the diffusion constant is replaced with the thermal conductivity in deterministic part and Onsager coefficient in the fluctuating part, $\langle \mathbb{Q}(x,t) \rangle = 0$, $\langle \mathbb{Q}(x,t) \mathbb{Q}(x',t') \rangle = 2 k_B T \mathcal{L} \delta(x-x')\delta(t-t')$. Due to identical structure of the deterministic part, both DKE and FHE yield identical solutions. However, differences arise due to the difference in amplitude of the fluctuating force, namely $\sqrt{2Dn}$ in DKE and $\sqrt{2 k_B \kappa T^2}$ in FHE.

(B) Fluctuating Hydrodynamic Diffusion Equation (FHDE): Before discussing further

with FHE, let us revisit DKE in the context of a general structure of the fluctuating hydrodynamic equations in various systems of interest. We consider the balance equation for mass diffusion $\partial_t(\rho c) = -\nabla \cdot \mathcal{F}$ where ρ, c are mass density and mass fraction with the constitutive relation connecting the fluxes and forces as $\mathcal{F} = \bar{\mathcal{F}} + \mathcal{F} = \mathcal{L}X + \mathcal{F}$. Irreversible thermodynamics connects the thermodynamic force X as summation of various terms coming from the chemical potential (μ) gradient, thermal gradient leading to Soret effect, as well as pressure gradient leading to Barodiffusion by $X = -\left(\frac{\nabla\mu}{T} + \xi\frac{\nabla T}{T^2} + \psi\frac{\nabla P}{P}\right)$. In the absence of the last two, $X = -\frac{\nabla\mu}{T}$ from which for ideal solutions having mass of species m, the Onsager coefficient can be calculated from the thermodynamic relation $\mu = \mu_0(T) + \frac{k_B T}{m} lnc$ or $\nabla\mu = \frac{k_B T}{mc}\nabla c$ or $X = -\frac{k_B}{mc}\nabla c$ or $\bar{\mathcal{F}} = -\mathcal{L}\frac{k_B}{mc}\nabla c$. Comparing with Fick's law $\bar{\mathcal{F}} = -\rho D\nabla c$ yields the Onsager coefficient to be $\mathcal{L} = \frac{\rho Dmc}{k_B}$. As mentioned earlier, the Onsager coefficient enters the variance of the fluctuating force with property $\langle\mathcal{F}(x,t)\rangle = 0$, $\langle\mathcal{F}(x,t)\mathcal{F}(x',t')\rangle = 2k_B T\mathcal{L}\delta(x-x')\delta(t-t') = 2\rho Dmc\mathcal{L}\delta(x-x')\delta(t-t')$. Therefore the balance equation becomes, $\partial_t(\rho c) = \nabla\cdot\left(\rho D\nabla c + \sqrt{2\rho Dmc}\mathfrak{Z}\right)$. Readjusting the density, we have $\partial_t c = \nabla\cdot\left(D\nabla c + \sqrt{\frac{2Dmc}{\rho}}\mathfrak{Z}\right)$ (6). Defining number density as $n = \frac{\rho c}{m}$, we obtain the usual form of DKE displayed in Equation (5).

A Few More Models: Before discussing a few more intriguing examples arising in the physical sciences and engineering, a general recipe of the Balance law should be worthwhile to note. For any state variable $\wp$ having parabolic (diffusive) fluxes $\mathcal{F}^P(\wp)$, hyperbolic (convective) fluxes $\mathcal{F}^H(\wp)$ and disturbed through a fluctuating force $\Gamma(\wp)\mathfrak{Z}$ where $\Gamma(\wp)$ is the random forcing amplitude, then the general form of the balance law is [16] $\partial_t(\wp) = -\nabla\cdot[\mathcal{F}^P(\wp) + \mathcal{F}^H(\wp) + \Gamma(\wp)\mathfrak{Z}]$. (7) Einstein's fluctuation-dissipation relation relates $\mathcal{F}^P(\wp)$ with $\Gamma(\wp)$ displaying no connection with $\mathcal{F}^H(\wp)$. For example, DKE [equation (5)] can be readily obtained from the above equation (7) using the following recipe,

$\wp = n, \mathcal{F}^P(\wp) = -D\nabla n,\ \ \mathcal{F}^H(\wp) = 0, \Gamma(\wp) = \sqrt{2Dn}.$ (8)

(i) One-component Landau-Lifshitz-Navier-Stokes (LLNS) equation for compressible gas flow. The balance laws for mass ρ, momentum ρv and energy ρE (considering spatial isotropy for conserved angular momentum) for one-component compressible gases with N

$$\begin{aligned} \partial_t \rho &= -\nabla \cdot (\rho v), \\ \partial_t (\rho v) &= -\nabla \cdot (\bar{\Pi} + \bar{\mathcal{R}}) - \nabla \cdot (\rho v v^T + pI) + \rho g, \\ \partial_t (\rho E) &= -\nabla \cdot [(\rho E + p)v] - \nabla \cdot [\vartheta + (\bar{\Pi} + \bar{\mathcal{R}}) \cdot v] + \rho v \cdot g \end{aligned} \quad (9)$$

atoms under gravity is

where **v** is the fluid velocity, p is the sum of mechanical pressure (non-thermodynamic) as well as the thermodynamic pressure, **g** being the gravitational acceleration and momentum stress tensor (flux) is given by $\Pi = -\eta(\nabla + \nabla^T)v - \left(\kappa - \frac{2}{3}\eta\right) I(\nabla \cdot v) + \bar{\mathcal{R}}$, where η, κ are the Lame's coefficients and the fluctuating momentum flux is $\bar{\mathcal{R}} = \sqrt{\eta k_B T}(W + W^T) + \left(\sqrt{\frac{k_B \kappa T}{6}} - \sqrt{\frac{k_B \eta T}{3}} Tr(W + W^T)\right)$. The fluctuating force satisfies the relation for mean $\langle W(x,t) \rangle = 0$, and the variance $\langle W(x,t) W(x',t') \rangle = \delta(t - t')\delta(x - x')$. Note that in the absence of flow $v = 0$, the energy equation reduces to the FHE [equation (4)] discussed in subsection 2(A) [16-18,21].

(ii) Multi-component LLNS equation for compressible gas flow.

In this case, the balance law for mass is modified from the above as

$$\begin{aligned} \partial_t \rho_s &= -\nabla \cdot (\rho_s v) - \nabla \cdot (\bar{\mathcal{F}}_s + \bar{\mathcal{F}}_s), (s = 1,2,\dots,N_s) \\ \partial_t (\rho v) &= -\nabla \cdot (\bar{\Pi} + \bar{\mathcal{R}}) - \nabla \cdot (\rho v v^T + pI) + \rho g, \\ \partial_t (\rho E) &= -\nabla \cdot [(\rho E + p)v] - \nabla \cdot [\vartheta + (\bar{\Pi} + \bar{\mathcal{R}}) \cdot v] + \rho v \cdot g \end{aligned} \quad (10)$$

where $\rho = \sum \rho_s$ is the mass density and $\sum(\bar{\mathcal{F}}_s + \bar{\mathcal{F}}_s) = 0$. The diffusive and fluctuating mass fluxes are similar to DKE/FHDE discussed in subsection (B) [18].

(iii) Reaction-diffusion system. In a reaction-diffusion system out of N species, N_r species undergo chemical reaction with the propensity factor a_r denoting the rate of the reaction and, N_s species diffuse with diffusion constant for each species D_s. The fluctuating reaction-diffusion equation for the number density of species takes the form $\partial_t n_s = \nabla \cdot \left(D_s \nabla n_s + \sqrt{2D_s n_s}\Xi_s^D\right) + \sum \nu_{sr} \left(a_r + \sqrt{a_r}\Xi_r^R\right)$, (11) where ν_{sr} is the stoichiometric coefficient of species s in reaction r and Ξ_s^D, Ξ_r^R are the fluctuating fluxes in diffusive and reactive part. Both Log-mean equation (LMA) and chemical Langevin equation (CLE) supplemented with the law of mass action (LMA) designate the kinetic pathway of the number density for a homogeneous and well-mixed reaction-diffusion system [19].

(iv) Chemical hydrodynamical advection-reaction-diffusion system.

Supplementing the fluid flow to the above discussed reaction-diffusion system changes the mass equation to include source terms for the deterministic and fluctuating rates of reactions $\bar{\Omega}_s, \mathring{\Omega}_s$ by

$$\begin{aligned} \partial_t \rho_s &= -\nabla\cdot(\rho_s v) - \nabla\cdot(\bar{\mathcal{L}}_s + \mathring{\mathcal{L}}_s) + m_s(\bar{\Omega}_s + \mathring{\Omega}_s), (s = 1,2,\dots,N_s) \\ \partial_t(\rho v) &= -\nabla\cdot(\bar{\Pi} + \mathring{\Pi}) - \nabla\cdot(\rho v v^T + pI) + \rho g, \\ \partial_t(\rho E) &= -\nabla\cdot[(\rho E + p)v] - \nabla\cdot[\vartheta + (\bar{\Pi} + \mathring{\Pi})\cdot v] + \rho v\cdot g \end{aligned} \quad (12)$$

LME or CLE supplemented with LMA describe the numerical pathway of chemical hydrodynamics for a homogeneous and well-mixed advection-reaction-diffusion system [20].

(v) Multi-component LLNS equation for incompressible/low-Mach number liquid flow.

Our final example is for the incompressible fluid where sound waves propagate much faster than the momentum, which is the zero Mach number limit of the problem. Also the momentum diffuses extremely fast compared to the mass diffusion, which is the infinite Schmidt number limit of the problem [22-23]. In such zero or low Mach number limit of the fluctuating hydrodynamic system, the balance law takes the form,

$$\begin{aligned} \partial_t \rho_s &= -\nabla\cdot(\rho_s v) - \nabla\cdot(\bar{\mathcal{F}}_s + \mathring{\mathcal{F}}_s), (s = 1,2,\dots,N_s) \\ \partial_t(\rho v) &= -\nabla\cdot(\bar{\Pi} + \mathring{\Pi}) - \nabla\cdot(\rho v v^T + pI) + \rho g \end{aligned} \quad \text{with} \quad \nabla\cdot v = -\nabla\cdot\left(\frac{\sum \bar{\mathcal{F}}_s + \mathring{\mathcal{F}}_s}{\rho_s}\right). \quad (13)$$

Note that the right hand side of the incompressibility condition is strictly zero for single component system. For the sake of brevity, in this article we have omitted in discussing several other FHD systems, such as fluctuating Poisson-Nernst-Planck equation, fluctuating Burger's equation, fluctuating train-model equation, multiphase flow equations and will be reported elsewhere.

3. Computational methods for Fluctuating Hydrodynamic Equation (CFHD)

Computational approach to spatio-temporal partial differential equations (PDE) are, if not impossible, but are way too intricate to solve due to the inherent sophistication underlying the problem. For example, there exists multiple length and time scales which unless properly resolved lead to erroneous unphysical results that are seldom found in laboratory experiments. Any numerical avenue has to ensure that no artificial effects due to the structure of the algorithm exist, at the same time, ensuring the physical laws remain intact till machine precision [24].

The spatial part of the fluctuating incompressible flow is usually solved using FVM in a staggered grid (MAC-grid) framework (as opposed to a uniform grid) with an adaptive mesh-refinement (AMR) strategy whenever required, where scalars (density, energy etc) live on grid centres, vectors live on faces and edges of the grid to ensure discrete fluctuation-dissipation balance. The temporal integration is solved using second-order accurate explicit Predictor-Corrector scheme for scalar density and energy balance equations, whereas the momentum equations are integrated using implicit Backward difference scheme (BDS) [17, 22].

The fluctuating compressible flow equations, on the other hand, are solved on a collocative grid where scalars live at the grid nodes and vectors live at centers which are half a way between the nodes. Traditionally, implementation of fluctuating hydrodynamics in numerical routine is through the high-level languages C/C++ and Fortran 90/95, which in recent years have been written in Python for ease of implementation and application. The spatio-temporal accuracy of the stochastic PDEs is limited to second order both from the spatial part and temporal part [12].

Before performing the numerical experiments, the numerical routines are extensively benchmarked to machine precision and desirable accuracy. To this end, the static spectrum or structure factor and the autocorrelation or the dynamic correlation function of the relevant order parameter are numerically calculated and matched with the analytical results via the L-norm test. Below displayed are such correlators for a few Fourier modes for the case of incompressible low-Mach number flow on a 32X32 grid with unit grid spacing.

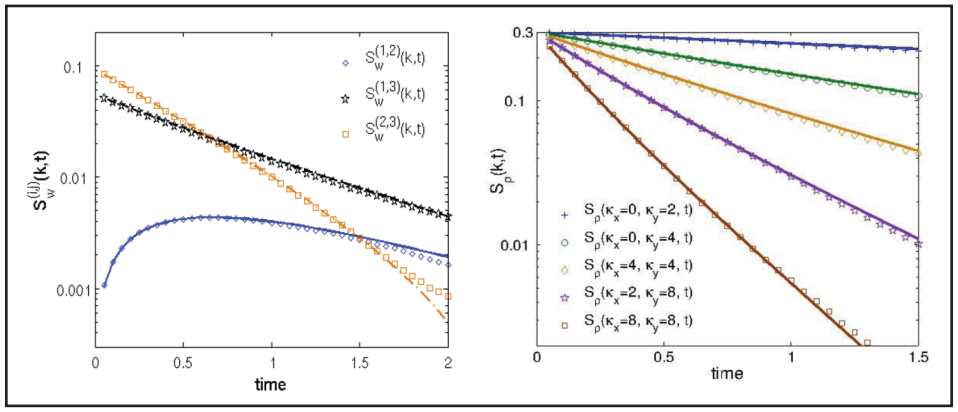

Fig.1. (a) The spectrum (static correlation function) for (1,2) (1,3) and (2,3) mode and (b) The autocorrelation function for (0,2), (0,4), (4,4), (2,8) and (8,8) mode. Both display excellent agreement between numerical and analytical result from smaller to larger Fourier modes [22].

4. Conclusions and Outlook

In this article we have briefly reviewed the existent yet unhighlighted research avenues in the studies of fluctuating hydrodynamics in various subsystems. The theoretical and numerical studies are classified within the mesoscopic coarse-grained computational method, namely, stochastic partial differential equations (SPDE) like LLNS. Various SPDEs are extensively discussed and a common structure of them in the non-equilibrium thermodynamics framework is displayed. A quantitative agreement between the numerical computation and the analytical calculation is found that guarantees a robust numerical pathway of studying LLNS through FVM. This study should find wide application in materials design, fabrication and synthesis that contain sub-micron flow and extensively dominated by thermal phenomena where FHD finds immense importance, like the giant concentration fluctuations reported in [25].

6. Disclosure statement

No potential conflict of interest was reported by the author.

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EARTH'S MAGNETOSPHERE, IONOSPHERE AND GEOMAGNETIC STORM

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Abstract : Magnetosphere and ionosphere are two important atmospheric layers of the Earth. The magnetosphere is created by magnetic field on Earth, composed of charged particles and can deflect most of the solar winds and harmful cosmic radiation, preventing them to reach earth's lower atmosphere and surface. Ionosphere is the lower and closer layer of the Earth's surface than magnetosphere. It can affect the radio wave propagation, influencing communication and navigation systems of the Earth. Geomagnetic storm is the disturbance which can temporarily affect the magnetosphere and ionosphere due to the interaction of the magnetic field on the Earth and intense solar wind that comes from the Sun. In this article, brief descriptions of magnetosphere, ionosphere and geomagnetic storm along with the corresponding impacts on the planetary atmosphere have been discussed.

Keywords: *magnetosphere, ionosphere, solar wind, magnetotail, X-rays, EUV, Van Allen Radiation Belt, magnetopause, bow shock, geomagnetic storm, CME, HSS, thermosphere, NOAA, GPS, GNSS, GIC, scintillation, Total Electron Content (TEC).*

1. Introduction :

Two most interesting layers- **magnetosphere and ionosphere**, are the regions of 'Earths atmosphere permeated by two types of electrically charged particles—named ions and electrons. The particles are large enough to affect the propagation of radio waves coming towards the Earth from the outer space. The existence of the stated layers provide sustainable environment on the Earth suitable for living things and no other planets in the vast universe till date has been discovered to have the peculiar terrestrial atmosphere and the corresponding sign of life. It is very interesting to study them and their effects on the Earth. The Geomagnetic storm, another interesting event, which depending on its severity affects the Earth's atmosphere tremendously. The RF signal transmissions from the space based navigation and communication system and satellite signal transmission as well as position fixing are severely hampered due to geomagnetic storms. In the following sections detail descriptions of the stated /phenomenon have presented with its effects on the terrestrial environment.

2. Magnetosphere and Ionosphere

2.1. Magnetosphere

Magnetosphere is the layer of the Earth that behaves like a bar magnet with its lines of force extending in space surrounding the Earth. It is a region which acts as a shields of the planet and protects the Earth from hazardous solar and cosmic radiation. This is assumed to begin from several hundred kilometres above the Earth's surface that extends thousands of kilometres into space. In this region, the behaviour of charged particles is severely affected by the magnetic fields of the Earth and the Sun. Along with that, the atmospheric erosion caused by the solar wind is also blocked by the layer. Moreover, the Earth's magnetosphere is an interesting dynamic system that responds to solar, planetary, and interstellar conditions. The magnetosphere also contains the Van Allen radiation belts (1-5 R_e), where highly energized protons and electrons travel back and forth between the north and south poles of 'Earths magnetic field. Figure 1 shows the earth's magnetosphere in detail(Picture Courtesy : Britanica).

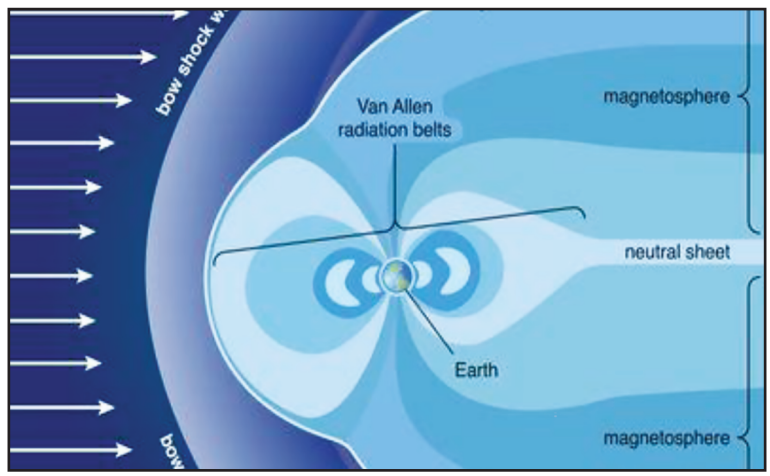

Figure 1: Earth's Magnetosphere and Van Allen Belt, Picture Courtesy : Britanica

2.1.1 Some important parts of magnetosphere :

Magnetic Cavity :

A magnetosphere is essentially a protectionbubbleof magnetic influence surrounding a planet or star.

Magnetopause :

The magnetosphere boundary on the sunward side (day side), called the magnetopause at several Earth's radii (~8-10R_e, where $R_e$is Earth's equatorial radius ~6378 Km). It is created

due to pressure balance of the interplanetary solar wind ,terrestrial magnetic pressure and acts as a layer between solar wind and magnetosphere. The boundary also resembles a dynamic feature with variable extent dictated by the solar events.

Van Allen Radiation Belts : Two regions of trapped charged particles located within the magnetosphere. These belts(1-5 R_e) contain highly energized protons and electrons travel back and forth between the north and south poles of 'Earths magnetic field.

Magnetotail : This part in the magnetosphere which lies on the night side of the Earth and it is the region where the magnetosphere is stretched out.

Plasma Sheet : Plasma sheet is the thick sheet of particles where the magnetic field is drawn out into a long tail consisting of two lobes separated by a $14R_e$ observed at the night side.

Neutral Sheet :

The neutral sheet is a part of magnetotail (Fig 1) which is characterized by weak magnetic field close to the neutral points ,strong cross tail current, and a reversal of the magnetic field direction across it. The development of the sheet appears to begin near the magnetic equatorial plane at a geocentric distance of $10 \pm 3R_e$. The sheet thickness seems to be larger close to the Earth. At its thinnest region the sheet is about 500 km thick and about 5000 km in the thickest part. The value of the field minimum is not found to be identically zero, so the neutral sheet is not ideally "neutral". According to some model the neutral sheet is relatively narrow region of field reversal found within the plasma-sheet (Speiser and Ness 1966).

Magnetic field is drawn out into a long tail consisting of two lobes separated by a $14R_e$-

Bow Shock : Beyond magnetopause, it is the outermost boundary of the magnetospher where the solar wind is deflected (Fig1).

Magneto sheath : It is the layer of compressed plasma between the bow shock and magnetopause.

2.1.2 Importance of magnetosphere :

Protection from Radiation : It behaves as a protecting shield, deviating most of the solar and cosmic radiation that would otherwise harm the living organisms on the Earth.

Protection from Atmospheric Erosion : It prevents the solar wind to enter and restrict from eroding Earth's atmosphere.

Influence on Climate and Life : The magnetosphere plays a role in forming Earth's climate and is important for the progression of life on the planet. The planets without magnetosphere are devoid of any atmospheric constituents and hence sign of life.

2.2 Ionosphere :

The lower part of the magnetosphere where the spectacular displays of the aurora borealis and aurora australis in the two hemisphere respectively take place.. The **ionosphere** extends from ~50-1000 km above earth's surface, composed of ionised gases and charged particles. There is no distinct layer like the others, but actually it is a region where ionization occurs and maximum. These are created by the action of extraterrestrial radiation, mainly due to X-rays and EUV (Extreme Ultra Violet) rays coming from the Sun, on neutral atoms and molecules of air. It acts like a blanket over the Earth's surface to restrict harmful UV radiations. This region plays very interesting role in radio communication, as it can reflect and modify radio waves. It also influences satellite orbit, involved in atmospheric electricity mechanism and in propagation of radio waves.

2.2.1. Specific layers within the ionosphere :

D-layer :

The lowest layer of the Ionosphere's is the D layer, which use to present during the day time and disappears at night. It absorbs radio waves of those of lower frequencies and normally extends from 50 to 70 Km in altitude.

E-layer :

The mid layer is located above the D-layer and known as the Kennelly-Heaviside layer. It reflects some radio waves, particularly at higher frequencies and shows its prominent presence during the day. It extends from ~ 70 Km to 110Km or 120 Km.

F-layer :

The upper layer is the highest and most significant layer for radio communication. It is divided into F1 and F2 layers during the day(~ 120 -300 Km), among which the F2 layer is the primary reflector of radio waves at HF band. At night these two layers combines to form a single layer. The stated altitude regions in all the layers are not fixed but changes with solar activity, day and night.

In addition to the stated regions sometimes a new layer above the F region called G layer and a new layer below the D layer called C layer are reported to appear depending on the solar geophysical conditions.

2.2.2KeyFunctions of ionosphere :

Radio Wave Propagation : The radio waves are reflected and refracted by the ionosphere, enabling long-distance radio communication and affecting navigation systems.

Atmospheric Electricity : The ionosphere is involved in atmospheric electricity and influences the distribution of electrical charges in the atmosphere.

Space Weather : The ionosphere is a key component of space weather (involving the Sun, Interplanetary space and Earth's environment), reacting to solar flares, geomagnetic storms, and other solar activity.

Satellite Orbits : Changes in the ionosphere can affect satellite orbits, particularly in low-Earth orbit (~400 Km).

Importance of ionosphere

The ionosphere is a vital part of Earth's atmosphere, affecting communication, navigation, and our understanding of space weather.

3. Geomagnetic storm

The **geomagnetic storm** is a major disturbance in Earth's atmosphere, especially to magnetosphere. As solar wind enters into the space environment of Earth, there is a transfer of energy from the said wind to the atmosphere. The geomagnetic storms result from variations in the solar wind and it produces major changes in the currents, plasmas, and fields in magnetosphere. These conditions are effective for creating geomagnetic storms (duration extending upto several hours) of high-speed wind and most importantly, a southward directed solar wind magnetic field (opposite to the direction of magnetic field of Earth) at the day side of the magnetosphere.

The most intense storms that result from these conditions are associated with solar CME (Coronal Mass Ejection)s ,where billion tons of plasma from the sun, with its embedded magnetic field, arrives at Earth. CMEs typically take several days to arrive at Earth, but sometimes for most intense storms it is observed to arrive in as short as 18 hours. On 10-11 May, 2024 a severe CME induced magnetic storm has reported to produce Aurora on Indian Ladakh region. Other type of solar wind disturbance that can create conditions favorable to geomagnetic storms is HSS (High Speed Solar) wind stream. When high speed solar wind emanating from the Sun meets the lower speed wind in the path i.e. slower solar wind in front an interaction region is formed called CIR (Co-rotating Interaction Region). These regions are also associated with geomagnetic storms which are less intense than CME storms and can deposit more energy in Earth's magnetosphere over a longer interval.

4. Impacts of Geomagnetic storm on the Earth:

Geomagnetic storms can develop intense currents in the magnetosphere. It can form changes in the radiation belts, changes in the ionosphere and also cause heating the ionosphere and upper atmosphere region (thermosphere). A ring of west wardly directed current (Ring current) around the Earth produces magnetic disturbances on the ground. The measurement of this current is Dst (Disturbance storm time) index, which can be characterized by the intensity of a geomagnetic storm. Along with that, there are

magnetospheric currents that flow along the magnetic field, called field-aligned currents. These currents are connected to the intense currents (auroral electrojets) in the auroral ionosphere. These can produce large magnetic disturbances. All of these currents, and the magnetic deviations they produce on the ground, are used to produce a planetary geomagnetic disturbance index called Kp. This Kp index is the basis for one of the three NOAA (National Oceanic and Atmospheric Administration) Space Weather Scales, the Geomagnetic Storm, or G-Scale,used to describe space weather (Figure 2).It is the weather related to space which includes solar wind, solar flare, CME etc and it can disrupt communication systems on Earth.

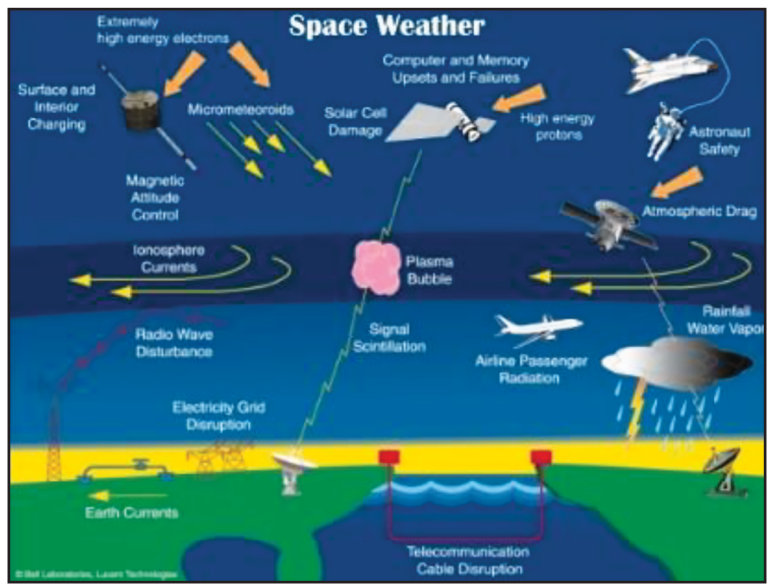

Figure 2: Different Space Weather Events, Picture courtesy: ESA

There are several effects of space weather on the mankind. Figure 2 depicts the various impacts on Earth due to Space Weather event. During storms, the ionospheric currents and the particles with huge energies that precipitate into the ionosphere generate heat energy to the atmosphere. It can, in turn, increases the number of charged particles in the upper atmosphere and can create extra drag in low-earth orbiting satellites (Zheng 2015, Khalil and Samwel 2016;Oliveira and Zesta 2019). Due to this local heating, strong horizontal density variations in the ionosphere has been developed. It can modify the trajectory of the radio signals and can develop errors in the position fixing done by the GPS(Global Positioning System). The storms can create lovely aurora in the higher latitudinal area, even when intensity of storm is high the aurora can be observed from low latitude also.

4.1. Global Navigation Satellite System (GNSS) and Geomagnetic storms:

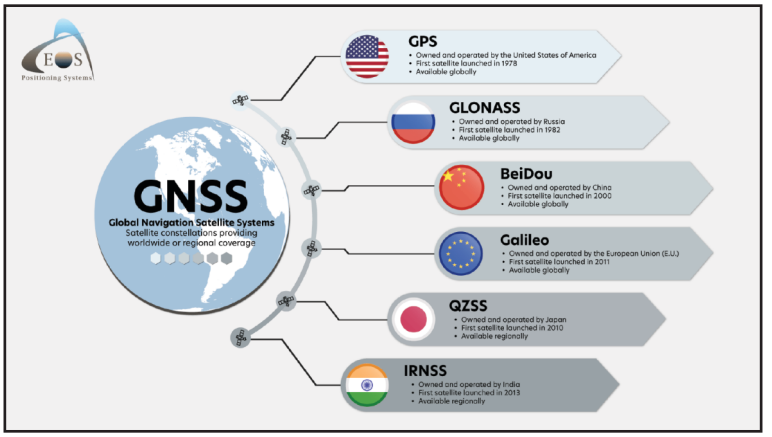

Figure 3: GNSS navigational system; Picture courtesy: EOS positioning system

The satellite navigation system, Transit, used by the United States Navy, was first successfully tested in 1960 with a constellation of five satellites. On June 26, 1993, the U.S. Air Force launched the 24 Navstar Satellite into orbit, completing a network of 24 satellites known as the Global Positioning System (GPS). In modern day, more broader navigation system, GNSS (Global Navigation Satellite System) (Figure-3) is used. Within the GNSS category the GPS was the first system designed by the US. Later on different country launched their own navigation satellites systems and collectively called GNNS (Global Navigation Satellite system). These include GPS(USA), QZSS (Japan), Galileo (Europe), GLONASS (Russia), Beidou (China) and IRNSS (India) as shown in Fig 3 The signals transmitted by the constellation of satellites, used for positional accuracy, are very much affected due to these extreme space weather events (geomagnetic storms).

With a GPS receiver, one can instantly know his location on the planet(e.g. most frequently used on car, smart mobile phones etc)- i.e. latitude, longitude, altitude--to within a few hundred feet. The GPS satellites are slow-moving Medium Earth Orbiting (MEO) satellites, which can also be used to monitor the ionosphere at a number of subionospheric points from a station, thus giving both temporal and spatial variations. The GNSS is mainly operated at two frequencies in the lower microwave band (L-band) viz. L1 (1575.42MHz) and L2 (1227.6MHz) with slight variations among the constellations. The major effects the ionosphere can create on GNSS are the following:

1) group delay of the signal change i.e. absolute range error,

2) carrier phase advance i.e. relative range error,

3) Doppler shift i.e. range-rate error,

4) refraction i.e. bending of the radio wave,

5) distortion of pulse waveforms in the signal,

6) signal amplitude fading i.e. amplitude scintillations and

7) phase scintillations of the signal.

A simple measure of ionospheric plasma is the Total Electron Content (TEC) which can be calculated with the use of group delay and phase advancement of the signals. It actually represents the state of the ionosphere.

The artificial satellites in the constellation of GNSS send radio signal which passes through ionosphere and reaches to the user for the determination of range, position etc ,experience propagation delay due to the presence of electron in the ionosphere.. By measuring the group path delay independently at the two GNSS frequencies L1 (1.57542 GHz) and L2 (1.2276 GHz) the TEC along the path from the satellite to receiver can be measure directly. A dual frequency GPS receiver measures the difference in ionospheric time delay at L2-L1 referred to as $\delta(\Delta t)$ where

$\delta(\Delta t) = (40.3/c)*TEC*[1/f_2^2 - 1/f_1^2] = \Delta t_1[(f_1^2 - f_2^2)/f_2^2 f_1^2]$,

where Δt_1 is the ionospheric time delay, f_1 and f_2 are the two GPS frequencies.

And the pseudorange from the receiver to satellite is dependent on group delay by the relation $rs = \delta(\Delta t).\ c$, where c is the velocity of light

Similarly the differential carrier phase ($\Delta\delta\varphi$) is related to TEC by,

$$\Delta\delta\varphi = \frac{40.3 * TEC(1-m)}{Cf_1}, \text{ Where, } m = f_1/f_2,$$

During Geomagnetic storm the TEC increases/decreases and as TEC is proportional to group delay, so group delay also changes resulting in degradation of positional accuracy and range determination. Rama Rao et. al., (2009) investigated geomagnetic storm of November 08-12, 2004 and found increasing range delay due to enhancement of TEC during storm. They also found phase slip of the radio signal during geomagnetic storm which results in the loss of lock of GNSS signal. Li et al., (2024) investigated geomagnetic storm during March 13-14, 2022 and they also found increase in VTEC standard deviation from March 10 to 15, 2022. Geomagnetic storm also creates harmful GICs (Geomagnetic Induced Currents) in the power grid in the higher latitude region, causing power disruption. Caraballo et al., (2025) have investigated the May 2024 storm and reported power grid disruption in Mexico during the storm.

5. Conclusion:

Modern civilisation is completely dependent on technology. We are dependent on space-based communicational and navigational systems. During solar event and geomagnetic storms, these space based navigation systems, even the power grid in the high latitude get disrupted. So early warning is very much needed to get uninterrupted satellite signals for civil aviation and position fixing and to save the electrical, electronic systems and gadgets from damage. The current space research activities throughout the globe are driven to achieve that goal.

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CLIMATE CHANGE AND SOCIAL INEQUALITY IN INDIA: A SOCIOLOGICAL INTROSPECTION

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Abstract : Climate change is not just an environmental issue—it is also a social crisis that deepens existing inequalities and disrupts livelihoods, governance, and economic stability. In India, where a large portion of the population depends on climate-sensitive sectors like agriculture, marginalized communities—including rural farmers, urban slum dwellers, Dalits, Adivasis, and women—are among the most affected. Unpredictable monsoons, prolonged droughts, rising sea levels, and extreme heatwaves increase food insecurity, force displacement, and heighten health risks. As climate-induced migration grows, urban infrastructure and labour markets are struggling to cope, leading to rising social tensions. Informal workers, who already face economic instability, experience further disruptions due to heat stress, flooding, and environmental degradation. While India has introduced climate policies such as the National Action Plan on Climate Change (NAPCC) and participates in global climate agreements, challenges like industrial lobbying, political disputes, and weak institutional implementation slow progress. To effectively address climate vulnerability, India must integrate social justice, equitable climate financing, just transition policies, and Indigenous ecological knowledge into its governance frameworks. This paper examines the connection between climate change, social inequality, and labour markets in India, highlighting the importance of inclusive, community-driven adaptation strategies to build a more resilient and equitable future.

Keywords: *Climate change, social inequality, climate-induced migration, environmental justice, sustainable development.*

One of the most important challenges of the 21st century is climate change, with consequences that go beyond environmental concerns to deeply affect social structures, economic stability, and governance. In India, where people's livelihoods are closely linked to climate conditions, the growing climate crisis brings unprecedented challenges, especially for marginalized communities (Roy, Kumar and Rahaman; 2024). Rural farmers, urban slum dwellers, Dalits, Adivasis, and women face increased risks due to unpredictable monsoons, prolonged droughts, rising sea levels, and extreme heatwaves. These disruptions make existing socio-economic inequalities worse, leading to displacement, food shortages,

and worsening health conditions. Additionally, climate-related disasters like floods and cyclones put immense pressure on infrastructure and social systems, disproportionately impacting those with limited financial resources and fewer options for adaptation (Mukhopadhyay; 2016). Looking at climate change through a sociological lens is crucial to understanding how different social groups experience and respond to these challenges—whether through policies, adaptation strategies, or grassroots activism. As India works through climate governance, integrating social justice, community involvement, and sustainable development into policies will be key to building resilience and ensuring a fair approach to climate adaptation and mitigation. This research paper explores the complex ways climate change affects Indian society, analysing its impact on migration, labour markets, governance, and social inequalities while highlighting the urgent need for inclusive and just climate policies.

Climate change is making existing social and economic inequalities in India even worse, hitting marginalized communities the hardest (Islam and Winkel; 2017). While wealthy individuals and urban elites have access to financial resources, advanced technology, and infrastructure that helps them adapt, economically disadvantaged groups—such as rural farmers, urban slum dwellers, and indigenous communities—struggle to cope with worsening environmental crises. India's vast rural population, which largely depends on agriculture, faces severe risks from unpredictable monsoons, prolonged droughts, and extreme heatwaves. Small and marginal farmers, who lack irrigation facilities and financial security, are the most affected, often suffering crop losses, food shortages, and deepening agrarian distress (Datta, Behera and Rahut; 2022). Many are forced to migrate to cities in search of work, only to end up in overcrowded slums with poor sanitation, where they are highly vulnerable to floods, extreme heat, and diseases like malaria and dengue. The 2020 floods in Bihar and Assam, as well as the destruction caused by Cyclone Amphan in West Bengal and Odisha, are stark reminders that the most vulnerable communities bear the brunt of climate disasters. Infrastructure gaps further widen these inequalities. Affluent neighbourhoods in metro cities like Mumbai, Delhi, and Bangalore have well-developed drainage systems, air conditioning, and emergency response services, while low-income settlements lack basic housing, clean drinking water, and healthcare facilities. The impact of climate change is especially severe for women, Dalits, Adivasis, and other historically marginalized groups, who face systemic discrimination that limits their access to disaster relief, land ownership, and financial support for rebuilding their lives (Asia Dalit Rights Forum; 2024). However, the effects of climate change in India go beyond geography. Political and economic inequalities prevent vulnerable communities from having a say in climate policies. Decisions related to industrial expansion, urban development, and mining often prioritize economic growth over environmental justice, leading to large-scale displacement of indigenous populations

in states like Jharkhand, Chhattisgarh, and Odisha (Meher; 2003). Environmental racism is also evident, as polluting industries, toxic waste sites, and coal power plants are disproportionately placed near Dalit and Adivasi communities, exposing them to long-term health risks (Sweeden; 2021-2022).

As climate change worsens, India is seeing a sharp rise in climate-driven migration, with people forced to leave their homes due to rising sea levels, expanding deserts, unpredictable monsoons, and extreme weather events. Coastal areas like the Sundarbans in West Bengal, Odisha, and Tamil Nadu are facing increasing land erosion and saltwater intrusion, making it difficult for fishing and farming communities to survive, pushing them to move inland (Mukhopadhyay; 2016). Similarly, drought-prone regions in Maharashtra, Rajasthan, and Bundelkhand (which spans Uttar Pradesh and Madhya Pradesh) are becoming less habitable as groundwater levels drop and desertification spreads, forcing rural populations to seek better conditions in cities (Raghu and Lall; 2016). This migration creates a range of socio-economic challenges. Most climate migrants come from economically disadvantaged backgrounds, including small-scale farmers, landless labourers, and marginalized groups such as Dalits and Adivasis. When they move to cities, they face legal and bureaucratic obstacles, often lacking the official identification needed to access housing, government welfare programs, and stable jobs. On top of that, they frequently encounter social discrimination and exploitation, ending up in low-paying, insecure jobs with harsh working conditions in the informal sector (Roychoudhuri; n.d.).

Unlike economic migrants who move voluntarily in search of better opportunities, climate refugees are forced to leave their homes due to environmental destruction. However, India's legal and policy framework does not yet recognize climate-induced displacement as a separate issue, leaving these migrants without proper support systems (Mukhopadhyay; 2016). The lack of comprehensive policies addressing environmental displacement makes it even harder for them to access basic rights and social protection. Most climate migration in India happens within the country, with rural communities moving to major cities like Delhi, Mumbai, Kolkata, Chennai, and Bangalore in search of work (Nadimpalli; 2023). This large-scale migration puts immense pressure on urban infrastructure, worsening problems like poor housing, water shortages, sanitation crises, and traffic congestion. Many of these migrants end up in informal settlements or slums—the only housing they can afford—which are especially vulnerable to climate threats such as flooding, heatwaves, and air pollution. Additionally, climate migration can create social tensions in host cities, especially when local populations see migrants as competition for limited resources like jobs, land, and public services. Political narratives in some areas have fuelled anti-migrant sentiments, leading to social conflicts. For instance, in states like Maharashtra and Assam, there have been cases of hostility toward migrant labourers, pushing climate migrants even further to the margins of society (Ashok and Thomas; 2014).

Climate change is transforming India's labour market, particularly in agriculture, manufacturing, and the informal sector, where workers rely heavily on stable environmental conditions (Lui, Shamdasani and Taraz; 2021). With over 90% of the country's workforce employed in the informal economy, many workers are especially vulnerable to climate disruptions. Construction workers, street vendors, and daily-wage labourers often endure extreme heat without any social protections like health insurance or paid leave. Urban floods— common in cities like Mumbai, Chennai, and Kolkata—disrupt small businesses, while rising temperatures and pollution put workers' health at risk (De, Singh and Rase; 2013). Small farmers, fishermen, and artisans are also facing growing economic uncertainty due to climate change. In coastal areas like the Sundarbans in West Bengal and parts of Andhra Pradesh, rising sea levels and saltwater intrusion are damaging fisheries and rice farming, forcing many people to abandon their traditional livelihoods (Mukhopadhyay; 2016). Similarly, unpredictable rainfall and droughts have led to an increase in farmer suicides in Maharashtra and Telangana, highlighting the devastating financial toll of climate change on rural communities. Women, especially in rural areas, are disproportionately affected. They are often responsible for collecting water, gathering firewood, and ensuring food security for their families. In states like Rajasthan and Gujarat, water scarcity forces women to travel long distances in extreme heat, increasing their risk of heat stress while also limiting their opportunities for education and paid work (Shiva; 1989). To address these challenges, gender-sensitive climate policies are crucial to ensuring that women are not left behind in efforts to adapt to climate change.

India's approach to climate governance is shaped by a complex mix of national policies, global commitments, economic needs, and environmental goals. As a developing nation with a population of over 1.4 billion, the country faces the tough challenge of boosting economic growth while also protecting the environment. Striking this balance often leads to political and industrial disputes, as strict environmental regulations are sometimes seen as barriers to economic expansion and industrialization. To address climate challenges, the Indian government has introduced several policies, including the National Action Plan on Climate Change (NAPCC) and its eight missions focused on renewable energy, sustainable agriculture, and water conservation (Ministry of Environment, Forest and Climate Change; 2021). However, implementing these initiatives is not always easy, as industrial lobbies and business groups often push back, prioritizing profits over environmental concerns. For example, the coal and mining industries—key pillars of India's energy and economic system—frequently resist tougher environmental regulations, arguing that they could lead to job losses and economic instability. The ongoing debate over phasing out coal in states like Jharkhand and Chhattisgarh highlights the constant struggle between economic interests and climate commitments (Sharma; 2023).

The success of India's climate policies largely depends on political commitment and the ability of institutions at both national and local levels to implement them effectively. While India's pledge to reach net-zero emissions by 2070 showcases its commitment to tackling climate change, state and local governments often struggle with limited financial and administrative resources needed to put green policies into action (BBC News; 2021). Delays caused by infrastructure challenges, bureaucratic inefficiencies, and a lack of coordination between the central and state governments further slow-down progress. For instance, even though India is investing heavily in solar and wind energy through the International Solar Alliance (ISA), states like Rajasthan and Gujarat face land acquisition disputes and regulatory challenges, making it difficult to transition to clean energy quickly. International organizations like the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) play a major role in shaping India's climate policies. However, like other developing countries, India argues that it should not be held to the same emission reduction standards as historically industrialized nations. India currently contributes about 7% of global CO emissions, but its per capita emissions remain far lower than those of the United States and China (DTE Staff; 2024). This argument is based on the principle of "Common but Differentiated Responsibilities" (CBDR), which India strongly advocates in climate negotiations (ibid). The idea is that developed countries, having contributed the most to historical greenhouse gas emissions, should take greater responsibility by providing financial and technological support to developing nations for their green transition. However, the lack of sufficient climate finance and technology transfers remains a key point of contention in global discussions, as many developed countries have yet to fulfil their commitments under initiatives like the Green Climate Fund (GCF).

India's Indigenous communities—Adivasis, forest dwellers, and traditional farming societies—have a deep understanding of the environment and valuable ecological knowledge that can strengthen climate adaptation efforts. For centuries, many Indigenous groups have practiced sustainable land management, water conservation, and agroforestry, offering insights that modern conservation policies can learn from. For example, the Dongria Kondh tribe in Odisha has preserved sacred forests through traditional conservation methods, helping protect biodiversity (Rout and Misra; 2022). In Nagaland, the Zabo farming system combines water conservation, livestock rearing, and organic farming, showcasing a successful model for climate resilience in hilly regions (Singh, Singh, Rajkhowa, & Deka, 2012). Similarly, the Baiga and Bhil tribes in Madhya Pradesh and Chhattisgarh have developed forest-based livelihood strategies that support reforestation and soil conservation (Arjjumend & Barrera, 2006). Despite their contributions, mainstream development policies often overlook Indigenous practices in favour of large-scale commercial projects like hydroelectric dams, mining, and

monoculture plantations. These projects not only damage ecosystems but also displace local communities. Recognizing Indigenous land rights and incorporating their traditional ecological knowledge into India's climate policies could play a crucial role in building sustainable and effective environmental solutions.

For India to effectively tackle climate challenges, it needs to strengthen its regulatory frameworks to balance economic growth with environmental protection. At the same time, building institutional capacity at the state and local levels is crucial to ensure policies are implemented effectively. Securing climate finance and technology transfers from developed nations is also essential for helping India transition to a greener economy and make large-scale investments in clean energy and sustainable infrastructure (Chakravarty et al., 2024). Additionally, supporting workers in fossil fuel industries through just transition policies—such as reskilling programs and alternative employment opportunities in the renewable energy sector—will be key to ensuring a fair shift to clean energy (ILO; 2023). Recognizing and incorporating Indigenous knowledge and community-led conservation efforts into national climate strategies can further strengthen sustainability by utilizing traditional ecological practices for adaptation and resilience (Dorji et al, 2024). A well-rounded and inclusive approach—one that combines strong governance, financial backing, labour protections, and grassroots participation—will be essential for ensuring India's long-term climate resilience and equitable development.

Conclusion:

Climate change will have a profound impact on human society in the coming century, worsening social and economic inequalities, displacing vulnerable communities, and transforming labour markets and governance systems. In India, marginalized groups—such as rural farmers, urban slum dwellers, and Indigenous communities—are already facing the harshest consequences, from unpredictable monsoons to rising sea levels and extreme heatwaves. While national policies and global climate agreements aim to address these challenges, political disputes, corporate influence, and infrastructure limitations often slow down meaningful action. A fair and sustainable response must include integrating Indigenous ecological knowledge, strengthening labour protections, securing climate finance, and promoting community-led adaptation efforts. By striking a balance between economic development and environmental responsibility, India has the potential to lead in climate resilience and equitable governance, ensuring a future that prioritizes both sustainability and social justice.

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ECOLOGICAL GRIEF : CLIMATE CHANGE AND MENTAL HEALTH

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Abstract : Anthropocene is witnessing major upheavals in climate and hence major shifts in people's lives, livelihoods, physical and mental states. Damages and disasters brought about by climate change are the cause for ecological grief in humans, an outcome for which he can only blame himself. Solastalgia and eco-anxiety are also common and in the Indian scenario they are widely prevalent. While eco-anxiety can sometimes cause pro-environmental behaviour, there are also means and mechanisms of coping with ecological grief and efforts to find the way forward.

Keywords: *eco-anxiety, solastalgia, biophilia, urgent biophilia, environmental hazards.*

Introduction :

The term 'environmental grief' was introduced by thanatologist Kriss Kevorkian in 2004 while the parallel term 'ecological grief' was introduced by social scientists Ashlee Cunsolo and Neville Ellis in an article in Nature in 2018. 'Eco-anxiety' came into vogue as a public response to the rising threat of pollution (Leff, 1990). Psychiatrists in Sweden spoke of 'climate anxiety' (Lagerblad, 2010).

Ecological Grief :

Ecological grief, eco-grief or climate grief is distress and mourning as a result of destruction of environment and/or climate change. It may include the grieving of loss of species, ecosystems specific landscapes, patterns of lives and livelihoods. Natural disasters and catastrophes as also changes in weather or season patterns could trigger such feelings of loss and grief. This can lead to severe deterioration of mental health including anger, hopelessness and desperation.

Cunsolo and Ellis recognized three types of ecological grief in their qualitative work. First, grief associated with loss of species or landscape *i.e.* physical loss, second - grief associated with doubt about environmental information as for instance unpredictability of seasons and loss of identity, and finally grief associated with probable future ecological damage and destruction.

Solastalgia :

Solastalgia on the other hand is a sense of anguish, impassiveness and mourning as a result of losing a significant place or landscape resembling homesickness when they are still a part of it (*Albrecht et al*. 2007). It originates from a deep-rooted attachment to particular landscapes. In fact attachment to a particular place is a prominent feature of solastalgia (Galway *et al*. 2019). Research on solastalgia is thereby restricted to qualitative interviews or its use as a subscale on the Environmental Distress Scale (Higginbotham *et al.* 2006) to population groups experiencing change in their native environments like people who survived natural calamities and those impacted by drastic industrial developments. The solastalgia subscale characterizes longing, craving and distress but also includes an anxiety for changed patterns of lives and livelihoods. The subscale therefore assesses not only the currently existing actual loss but also anticipated future loss.

Eco-Anxiety :

Eco anxiety or climate change anxiety will occur in response to approaching environmental threats like melting of polar caps and consequent rise of sea level, desertification etc. The slow but steady climate-induced changes can cause worry, anxiety and apprehension for the future. Eco-anxiety is taken as an adaptive response to climate change and can be associated with pro-environmental behaviour. Research on eco-anxiety is usually dependent on qualitative interviews or informal items.

The Trio in Comparison :

Ecological grief and solastalgia may largely overlap but in fact solastalgia is a subset or sub concept of ecological grief. On the other hand eco-anxiety is always future-based. Ecological grief, solastalgia and eco-anxiety are all distinct grades of pain or anguish caused due to global environmental change or climate change. While solastalgia is suffering due to change in habitat environment of which the person is a part, ecological grief is for the degradation of the natural world including species and ecosystems. Eco-anxiety is apprehension or fear of environmental crises which includes climate change on one hand and various ecological hazards on the other.

Biophilia and Ecological Grief :

The emergence of ecological grief can be explained partly by Biophilia, a term associated with E.O. Wilson which emphasizes the fact that human beings have an inherent tendency to connect with nature and all forms of life which determine their well-being (Sen, 2022a). Ecological grief can also be partly explained by place attachment theory. Both the Biophilia and place attachment theories agree on the core concept of the relationship between humans and natural places. (Engstrom, 2019). Urgent Biophilia is a mindful need or urge to be in

close association with Nature during times of stress and crisis. This particular aspect in humans suggests that Urgent Biophilia is an adaptive response for strengthening resilience during a disaster or catastrophe (Sen, 2021).

The Indian Perspective :

The native tribes of India inhabiting the Himalayan or coastal regions are often subjected to ecological grief being affected by different environmental hazards due to climate change. They suffer from loss of identity and cultural legacy. The Indian traditional knowledge systems focus on the close and intricate connection between Nature and humans which is greatly impacted by the deterioration of the environment leading to profound loss and hence ecological grief. The accompanying loss of important species, landscapes and habitats can massively upset individual and collective identities resulting in existential loss and ecological grief.

People who value nature and the natural world experience ecological grief like environmental scholars, scientists, academics, researchers, activists, planners and policymakers. The Indian perspective very often highlights the emotional and spiritual aspects of ecological losses much beyond the scientific or economic. Environmental catastrophes like floods, cyclones, forest fires etc. are significant triggers of ecological mourning or grief. Indian ceremonies and rituals are generally associated with nature and natural aspects and thereby acknowledge environmental degradation and grief. The Indian concept of 'karma' and its impact has a profound effect on Indian minds and thus there is a sense of responsibility and guilt for the deterioration in environmental quality leading to ecological grief. The underlying Indian philosophy of interconnectedness can deepen ecological loss and grief as damage to ecosystems can disrupt the divine balance and harmony.

However the positive side of ecological grief is that it can elicit pro-environmental behaviour, attitude and approach. The individual can then connect with the community attempting environmental activism and various pro-environmental activities.

Coping with Ecological Grief :

i. Association with a larger community- There may be positive outcomes for positive environment action by associating with a larger community (Sen 2022b, 2023a)

ii. Incorporating ritual and practice-These are age-old traditions and might be continued through generations

iii. Finding solace in natural spaces – Mental health may be restored by associating with open green spaces. At the same time such open green spaces must be taken good care of and maintained (Sen 2023b, 2024a). This will partly ease the guilt of lost landscapes and habitats.

iv. Focusing on what can be controlled – meaningful pro-environment initiatives may be taken such as sustainable use of resources, controlling consumption by reducing carbon footprint .

v. Engaging in positive environmental change initiatives – This has important implications and outcomes as this may bring about significant changes in outlook, perspectives and approaches thus leading to improvement or even abatement of certain of anti-environment practices.

vi. Channeling grief into creativity – Finding creative outlets through writings, poetry, paintings, stories and various other visual art forms not only heals the grief but raises awareness among millions. A local environmental issue can gain global stature and significance and caution masses against committing such grave environmental damage and devastation in future.

vii. Educating the Masses – this must start in the classroom and gradually spread among the common man. The educated student must also be involved in such major environmental movements (Sen, 2019) so that instances of ecological grief too not recur often and development as a whole is Sustainable.

vii. Finding different ways of reconnecting with Nature – This will contribute in a big way to both physical and mental well-being (Sen 2023c, 2024b).

The Way Forward :

To conclude environment has a significant impact on physical and mental health of humans. The hazards of climate change continues to accelerate manifold due to anthropogenic activities and interventions and then loss of species, habitats, landscapes result in ecological grief and cause further deterioration of mental health. Thus if pro-environmental approaches and attitude with a sustainability pledge is not ascertained and ensured the vicious chain of damage-loss-grief-poor mental health will continue. The chain must be broken at some point to restore the ecological balance and sustainable existence.

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BIBLIOTHERAPY: JUSTIFICATION FOR THE LIBRARIES IN THE ERA OF GROWING DIGITAL MEDIA INDULGENCE

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1. Introduction :

In the simplest "Bibliotherapy is the use of books to help people solve problems" (Jackson, 2006). It is basically a guidance in the solution of personal problems through direct reading. Bibliotherapy is not only the use of books but also use of selected reading materials as therapeutic adjuvant in medicine and psychiatry. Samuel MacChord Crothers used the word bibliotherapy (Crothers, 1916) in a famous article in the *Atlantic Monthly*. Reading as a joy and library's recreational role is long-standing. In the past, Aristotle's several writings were treated by many as soul-healing medication. Bibliotherapy was introduced in the academic scenario during 1960s mainly by educational psychologists Zaccaria and Moses (Jack & Ronan, 2008).

"A process of dynamic interaction between the reader's personality and literature under the leadership of a qualified assistant" is how Caroline Shrodes defined bibliotherapy (Shrodes, 2019). Bibliotherapy is the practice of using books to heal and treat problems. Without a doubt, words are with the capacity to both help and hurt. We all are aware that reading has therapeutic benefits.

For every situation in life, there will be a book that resonates with its reader, understands their situation, and provides guidance, inspiration, support, healing, and aspiration while promoting change. In libraries, bibliotherapists offer tailored reading services and book recommendations. Bibliotherapy is useful in several contexts and can be used to treat minor to moderate situation of mental health conditions. Because, it may assist to maintain a positive environment for the library customers and improve the quality library services and the institution as a whole. the researcher thinks that it may be beneficial in both formal and informal academic settings. In many nations today, bibliotherapy is certainly a developing field of research.

This fast-paced lifestyle has an impact on schooling and causes a number of health issues. It is pertinent to do comprehensive research in this domain where bibliotherapy can assist people to manage their difficulties more effectively and where literature can afford

them with vital inspiration. For many, it is of more cost-effective choice when compared to drugs and other therapies. Obtaining primary healthcare benefits and services is still viewed as a sole privilege rather than a basic right in numerous developing nations. There are manifold uses for bibliotherapy. Professionals working in the sectors of social work, education, mental health, and library services can make use of it. People's spirits are lifted by bibliotherapy, which affects their lifestyle and level of productivity at work. Bibliotherapy comes in a variety of forms, from developmental to creative to clinical, and so on (Pardeck, 2013). Thus, bibliotherapy uses reading materials for psychotherapy and shares concepts with other creative art therapies (Rottenberg, 2021).

2. Problem Statement

Reading as therapy or reading as recreation has wide and long-standing acceptance. But there is limited research into the benefits of therapeutic reading. Bibliotherapy in the present context remains unexplored, especially in the field of library science, amidst the present growing information media indulgence. Therefore, the paper tries to explore into the process and types of bibliotherapy in the context of library science. The paper also explores the impact of modern form of reading materials as aid to bibliotherapy.

3. Indulgence in digital media

Screen time, and especially the access and use of social media, has increased since the middle of 2000s. The digital platforms and social media have paved the way for an environment where information is accessed and availed 24/7. Individuals have been consuming or rather to say are compelled to consume excessive content to stay informed or connected causing information overload. Such consumption of huge amount of digital content is mainly motivated by emotional and entertaining rewards than actual need for information which contribute largely to indulgence in digital content.

At the same time, the mental health of teenagers has worsened and is today one of the leading causes of illness among adolescents (WHO, 2021). In the public debate, many argue that exposure to social media is one of the major contributing factors to the increase of mental health issues among numerous teenagers, as social media are addictive and harmful and fuel an experience of inadequacy about your personal life or appearance (Abrahamsson, 2024). In 2023, UNESCO called for a global smartphone ban in schools to tackle disruption by smartphones in classroom and protect children from cyberbullying (UNESCO, 2023).

Of particular concern is whether screen-based activities are harmful to children and adolescents learning and well-being (Kardefelt-Winther, 2017). In reply to this here it is worthy to quote from an article in India Today “Numerous studies have shown link between high levels of screen time and reduced attention spans, disrupted sleep patterns, and increased anxiety. In classroom settings, research has consistently shown that frequent

phone use can interfere with ability of students to concentrate, retain information, and engage with peers" (Bhati, 2025).

4. Types of Bibliotherapy

According to Jack & Ronan (2006), and Cook, Earles-Vollrath, & Ganz (2006) bibliotherapy is of three broad types – institutional, clinical and developmental. In case of institutionalized clients' treatment institutional bibliotherapy is used. Mental-hygiene texts are recommended as priority. Clinical bibliotherapy is conducted by therapist, psychiatrist, counselor and psychologists in case of dealing with behavioural and emotional disorders. Developmental bibliotherapy is best suited in academic media setting. For students this type is helpful to interact and connect with literature. There are different approaches to bibliotherapy also. It is something which is tailored to specific individuals along with their certain socio-psychological health conditions and needs. The types of bibliotherapy majorly include:

4.1 Clinical Bibliotherapy (it is restricted to the clinical settings and diseases):

4.1.1 Prescriptive Bibliotherapy: This approach involves therapists prescribing explicit books or genres based on the individual's needs and challenges. This will cater to certain issues concerned with the individual. The books concerned here are mostly non-fictional and can be carried out at home as a self-help mechanism or with professional care.

4.1.2 Therapeutic Bibliotherapy: Used ith other therapeutic interventions for the treatment and management of various psychological or mental health issues.

4.2 Creative Bibliotherapy:

4.2.1 Creative Bibliotherapy: It is mainly based on fiction, storytelling, poetic sessions, and journalism, etc. This approach most often happens in a group setting. This involves reading stories, poems, and fictional readings as discussed by the group. This all together involves both the utilization of literature and expressive writing as a means to explore and communicate the emotions the individual has been going through.

4.2.2 Biblio-poetry: Concerned with poetic works of literature for self-discovery and healing. The therapist might also encourage the individuals to write poetry as a form of processing emotions.

4.3 Developmental Bibliotherapy:

It includes the well-being and personality growth of an individual This approach is for the younger audience, especially children and adolescents. This methodology will provide age-

appropriate book or literature to help with the social, emotional, and developmental problems or issues concerned with children. This mainly involves fictional reads where storytelling helps the children alleviate challenges or issues concerned. Also involved in developing resilience.

4.4 Digital bibliotherapy:

This involves the exploration and use of audiobooks, digital media, or any other online platform as a means of therapeutic intervention.

From among these, Clinical bibliotherapy is mostly used by the therapists and mental health practitioners where they address emotional and behavioural issues while Developmental Bibliotherapy is used widely among educators, and literary workers, which would facilitate proper developmental transitions among students.

5. Importance and benefits

Books are used for multiple reasons – to connect with others emotionally, to escape reality, to taste adventures, to visit places someone unable to, to have fun and joy, and so on. Thus, books help us solve problems and reduce emotional burden. Books can be of immense help to increase self-esteem, self-knowledge, understand other people and society at large. Books help to gain relief from pain, conflicts and clarify personal values (Jackson, 2006). Thus, the famous quote of Margret Atwood, "A word after a word after a word is a power," encouraged many across globe to think about immense role of literature and bibliotherapy. Thus, by reading books, people can experience cognitive, affective, and psychomotor benefits (James & Römhild, 2023).

To cope up with emotional and social difficulties (Abidin et al., 2021);

To cope with stress, fears of death, and depression (Hamdan et al., 2020);

To reduce various personality disorders, suicidal tendency, depression, and other associated mental health issues (Lidini et al., 2023);

To mirror positive behaviour and values and personal development (Kim, 2010), (Lee, 2009);

To develop a positive mindset and confront the challenges of life.

Thus, bibliotherapy as reading books from the therapeutic purpose is crucial in the present scenario (Stamp, 2003).

6. Process

Bibliotherapy is a technique used in group guidance services to help with individual development in social life and usually involves identification, catharsis, and insight (James

& Römhild, 2023). It is one kind of therapy undergoes a step-by-step process. So is Bibliotherapy, which might differ from therapist to therapist, while the core remains the same. It mainly has several key steps which include:

- **Identification of involvement:** The beginning stage involves identifying if the individual would get through Bibliotherapy by analyzing their problem and interest. After discussion the therapist recommends certain books. The therapist would ask them about the characters in the case of fictional reads while talking about the turning points in the case of non-fictional reads (Yuvasri, 2024).
- **Reading** Individuals are engaged with reading to the selected text (James & Römhild, 2023).
- **Discussion:** Discussions are facilitated to help participants explore their reactions to the prescribed material (Brewster, 2009)[6] . These discussions help a therapist to have a deeper understanding of an individual and the impact of the text on him/her. (Marković, 2015).
- **Catharsis:** This step involves the crucial part as the release of tension or emotion happens and the impact of text is looked into or evaluated on the individual. The subject gets more awareness of what an individual has gone through.
- **Insight:** the final stage is whether the individual can puts together everything into positive action. They gain insight by analyzing their problem with a problem similar to fiction or non-fiction. This would certainly assist them gain strategies and make them easy to proceed and perform.
- **Application:** Application of newer findings to familiarize and relate with real life situation. The individual applies the insights gained to their own life, making positive changes or developing coping mechanisms based on their reading experience.

7. The Role of Libraries

- **Creation of Therapeutic Spaces:**

Libraries can develop and transform its space into a welcoming and supportive ambience, and thus offering comfortable reading spaces, providing access to relevant resources, and creating dedicated areas for bibliotherapy sessions.

- **Development of Specialized Collections:**

Librarians can develop collections of study materials like classics, self-help books, soulful books, human psychology, fiction, and poetry that align with certain therapeutic objectives.

- **Guidance and Support:**

Librarians can guide individuals towards relevant reading materials, facilitating face-to-face or group discussions, and assisting them to connect with other appropriate resources.

- **Collaboration with Therapists and Professionals:**

Libraries can collaborate with psychologists, mental health professionals, counselors, and educators to enhance effective bibliotherapy programs and ensure appropriate support for individuals.

By embracing bibliotherapy, libraries can evolve into dynamic centers that promote mental health, foster personal growth, and strengthen community well-being (Odiri, 2023).

8. Bibliotherapy in the Era of Technology

Bibliotherapy, the purposive and therapeutic use of books and reading materials, had been traditionally relied largely on printed books and through face-to-face sessions. However, the advent of modern digital information and communication technology has enhanced the access to bibliotherapy by-

- Podcast: A podcast is a digital audio file or content mainly original interviews that may be available as a series or streamed through episodes.
- Audio Book: An audiobook is a recording of an oral reading of a book,(Collins, 2025) or a recording, on a CD or made available on the internet, of a book being read aloud (Cambridge, 2025).
- E-Books: An e-book or book in digital form or "electronic book," that can be accessed or read on a computer or other digital devices.
- Video Conferencing: Video conferencing that simulates a face-to-face meeting is a visual and live connection between two or more parties remotely in the digital mode. It connects people remotely who normally are unable to have a face-to-face meet.
- Social Media Platforms: Social media provides the interactive digital platforms for creating, sharing and aggregation of content among virtual communities. Messenger apps like Facebook, WhatsApp, etc.
- Chatbots: Various Artificial Intelligence (AI) tools including Chatbots like Woebot, Xiaoice, ChatGPT, etc.

9. Conclusion

Reading books is regarded as a potential way of standing by an individual to deal with his/her certain concerns. Again, it offers multiple strategies to acquire specific developmental avenues of a human being. Thus, bibliotherapy is an organized approach to

find proper book for proper reader or user. This match is overly beneficial as it helps to mould an individual's behaviour, relieves emotional stress, and creates well-rounded positive minds. Bibliotherapy encompasses a larger framework of several disciplines like psychology, counselling, medicine and librarianship. During the era of growing indulgence in digital media, application of bibliotherapy to promote reading and development of positive minds in libraries is essential, and it may be effectively accomplished through sufficient training of library staff and users' education.

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NEGATIVE ECONOMIC EXTERNALITIES IN RESPECT TO TODAY'S VIRTUAL LEARNING

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Abstract : The educational landscape in India has been transformed widely by the rapid expansion of virtual learning, accelerated by the COVID-19 pandemic. Though virtual learning significantly improved access to educational opportunities, it has also caused various negative externalities that affect adversely EWS of Indian society. This article explores the unintended socio-economic consequences of virtual learning in a developing country, like India. It focuses on policy interventions to address these negative externalities for ensuring equitable access to education and sustainable economic development.

Keywords: Negative externalities, Virtual learning, Digital divide, Socio-economic impact, COVID-19 and education, EWS (Economically Weaker Sections), Online education , Government intervention.

Introduction :

Externality, as an economic occurrence, deals with cost-benefit analysis. Externalities are caused by divergence between private and social costs and benefits. Due to externalities allocation of resources in the economy is not optimal. Negative economic externalities emerges when individuals, not directly involved in the transaction process, have to bear costs of production or consumption of goods and services. It causes harm to third parties and generate inefficiencies in market mechanism. Taxation and other public policy measures of the government are needed to reduce the external costs. Government interventions backed by consumer awareness are necessary for minimizing the negative externalities.

Objectives :

In this article it is intended to assess the negative economic externalities involved with today's virtual learning with reference to India's current socio-economic environment. It is also aimed to explore how digital divide has created educational inequalities between the affluent and EWS of the society.

Virtual Learning :

Virtual learning plays a crucial role in today's society. It is an ultramodern form of learning where education is delivered from a remote location by using the Internet and web-based

platforms. In general, Google Classroom, Zoom (Zoom Communications, Inc. for live lectures), Moodle (Modular Object-Oriented Dynamic Learning Environment), Khan Academy etc. are regarded as popular platforms for virtual learning. Virtual learning in both India and abroad is evolving rapidly. While India is expanding access through government initiatives and affordable platforms, developed nations offer high-quality infrastructure and diverse courses. India has a diverse range of virtual learning platforms, catering to different educational needs. Government-backed platforms like SWAYAM provide free learning, while private platforms like Byju's, Unacademy, and UpGrad focus on school education, competitive exams, and professional upskilling.

Transformation of education during COVID-19 :

The COVID-19 pandemic transformed education globally, making virtual learning an essential component of the academic and professional landscape. Obviously, virtual learning in India has spread remarkably after the onset of COVID-19 pandemic. But it is important to note that virtual learning can be effective, if and only if, it is accessible and cost-effective.

Virtual Learning: Post COVID-19 :

After the onset of COVID, virtual learning becomes very popular at both upper and lower level of education. Infrastructural cost of virtual learning is quite high and it needs to be borne both by the sender and receiver. Indeed, telecom sectors, computer-manufacturers and government earn sizable revenue due to emergence of virtual learning. Consequently, the cost burden of the receiver is quite high.

In India after COVID, economic condition of the masses has deteriorated significantly. It becomes quite difficult for many families even to earn their livelihood. Unprivileged and underprivileged students belonging to EWS category cannot access virtual platform because either of their poor financial condition or inaccessibility of network issues and in some cases due to both of the factors.

Challenges before EWS :

In fact, both affluent and non-affluent sections of an economy contribute resources for economic development. Admittedly, benefits to be rendered by the society to EWS category should be noteworthy. But inaccessibility to virtual learning by the greater society is quite unjustified. Social cost becomes quite significant where EWS category is deprived of the opportunity of virtual learning. Apart from that, social cost in respect to Internet or mobile addiction, online safety, overloading of information, health issues, etc. cannot be neglected. As a consequence, negative externalities are created. A study by the Azim Premji Foundation showed that almost 60 per cent of school children in India cannot access online

learning opportunities. A similar study by Oxford Committee for Famine Relief (Oxfam), India found that even among students of urban private schools, half of the parents reported issues with the Internet signal and speed. Broadly, the divide between the digital haves and have-nots is nothing but a reflection of economic inequality and it strengthens the case of negative externalities of virtual learning in India.

Policy Measures :

The fact invariably fuels negative externalities with reference to virtual learning in today's age. To minimize unintended consequences, following measures can be initiated both at government and non-government level:

a) Desktop / Laptop / Mobile Phone to be offered to the students of EWS category absolutely free of cost.

b) Telecom companies must reduce their existing tariffs and government should initiate reduction of GST for EWS category.

c) Special initiatives must be taken by telecom companies to improve their network connectivity.

d) Telecom companies should offer data services free of cost for education purposes, particularly when device is logged in through educational institution ID.

e) Proper training should be given to existing and potential users belonging to EWS category for effective utilization of their devices.

f) It is virtual learning that has contributed positively to make learning more accessible, affordable, and flexible in India, but challenges like the digital divide, engagement issues, and insufficiency of practical training, etc. must be taken into consideration with utmost care. Issues relating to negative economic externalities must be given priority both by central and state government.

Conclusion :

Undoubtedly, both the affluent and non-affluent section of the society in India are regarded as taxpayers and they bear a large share of indirect taxes. But significant portion of EWS category even among urban households are deprived of the facility of virtual learning owing to socio-economic and technical issues despite sharing of their taxable amount.

Today virtual learning has ushered in adverse effects in the developing countries like India that disproportionately affect vulnerable groups by reducing economic efficiency to a large extent. Widening digital divide caused by inaccessibility to smartphone or tablet,

unstable Internet connectivity, etc. are considered as responsible factors for depriving the children as well as adolescents of proper education. Apart from that, excessive screen time and isolation for long hours in respect to virtual learning cause both physical and mental health issues among the students. As a consequence of excessive growth of virtual learning, long term economic cost associated with reduced human capital development rises substantially. In India, implementation of effective strategies in the form of robust policy interventions, aiming at digital access expansion, is not only necessary but an imperative.

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PLANT GROWTH PROMOTING MICROORGANISMS: A SOLUTION TO THE ABIOTIC AND BIOTIC STRESSES IN JHUM CULTIVATION OF THE NORTH-EASTERN HIMALAYAS

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Abstract : High altitude areas including mountains and hills are rich repositories of plant growth promoting microorganisms. However, thriving of these microorganisms in these extreme environments is really challenging. The cold-adapting capability facilitates their applications as eco-friendly bioinoculants, including biofertilizers and biocontroling agents for the agricultural crops particularly in the high-altitude areas. This review elucidates the diverse composition of plant growth promoting microorganisms identified from the Himalayas; followed by their uses as bioinoculants/biofertilizers for stress management in Himalayan plants. The review concludes with the summary of bioprospecting of this group of microorganisms towards sustainable jhum cultivation.

Keywords: *Himalayas, plant growth promoting microorganisms, bioinoculants, jhum, bioprospecting.*

1. Introduction :

Soil is the richest repository of microorganisms including bacteria, fungi, algae and nematodes; of which 95% of the bacteria form an integral part on the surface of the plant roots (rhizoplane), inside the roots (endophytes) and it's adjacent soil (rhizosphere) (Tartaglia et al., 2020). This plant-microbe collaboration leads to long-term effects benefitting the plant development as the microbes help the plants (1) to acquire nutrients from the environment which would have otherwise remained limiting for the plants to avail and (2) to inhibit the attack by the pathogenic microorganisms. These microorganisms collectively termed as plant growth promoting microorganisms (PGPM) have been of immense importance as alternative eco-friendly, cost-effective and environmentally sustainable strategies to chemical fertilizers and pesticides in the agro-ecosystems (Kulkova et al., 2023). In addition, PGPM has a potential to maintain the soil quality, soil fertility, increase of shell-life, enrichment of soil biodiversity and the maintenance of ecological balance without negative impacts on environment (Chouhan et al., 2021). This in

turn empowers the crops to overcome the environmental challenges and thereby offering a better food security to the human race (Chouhan et al., 2021).

For the last two decades, interests have developed on the mountain ecosystems, as they form an affluent repository of biodiversity and take important role in ecosystem functioning (Wang et al., 2022). The soils of mountains are depleted of nutrients, as a result of which the mountain-agriculture becomes a low-input, low-yielding and sustenance active agriculture (Tingey et al., 2024). In spite of this, the hill-cultivation is one of the sustainable agro-ecosystems in the world that takes advantage of organic farming. In this scenario, the use of PGPM as bioinoculants for the betterment of the quality and the yield of agricultural production in mountain areas will offer a great advantage. Therefore, developing knowledge on the microbial resource of the mountains, their adaptability characteristics in the extreme stressful environments, their potential role in plant growth and subsequently developing strategies to incorporate the indigenous micro-flora in the form of bioinoculants/biocontroling agents (BCA) for the hill-cultivation systems is worthwhile. Extensive literature is accumulated in the last two decades pertaining to the microbial consortia and their functional role in the mountain ecosystem and agriculture that point to the host-microbe specificity, the role of microbes in modifying the soil characteristics to make it less stressful and more suitable for the growth of pioneer plants, the variation in microbial diversity along the elevation levels and the significant efforts to design and develop bioinoculants from the native soil microbiota in these regions (Tingey et al., 2024; Ahmad et al., 2022; Shao et al., 2024).

The Indian Himalayan region comprised of 12 states including Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Sikkim, Meghalaya, Nagaland, Mizoram, Manipur, Tripura, Arunachal Pradesh, Assam and West Bengal covers approximately 18% of the country's area. This province forms the abode for more than fifty-million residents whose primary occupation is agriculture and forestry (Bishop et al., 2025). Slash or shifting cultivation and burn agriculture, popularly termed as jhum cultivation combined with exceptional traditional innovations is the most primitive form of crop cultivation system in these regions. Though hilly regions of North-Eastern India is rich in productive soils with high organic content, accounts a good amount of annual rainfall, niche for lagging far behind (Vaid, 2020). Thereby, the present review focuses on the present status of abiotic and biotic stresses faced by the North-Eastern Himalayan agro-ecosystem and the approaches of exploitation of PGPM to combat the challenges.

2. Traits in PGPM

PGPM includes plant growth promoting rhizobacteria (PGPR), N2-fixing cyanobacteria, mycorrhiza, plant disease suppressive beneficial bacteria, stress tolerance endophytes and bio-degrading microbes (Khalmuratova et al., 2020; Shaffique et al., 2022; Ngosong et al.,

2022; Toribio et al., 2022). Decomposition of organic matter, acquisition of nutrients, absorption of water, recycling of nutrients, bio-control and control of weeds are the numerous services provided by the PGPM to the agricultural crops (Blake et al., 2021). PGPM attribute additional factors also to the agricultural management practices *including* tillage preservation, crop rotation, alteration in the organic content, reprocessing of residual crops, management of the fertility of the soil and the biocontrol of pests and pathogens, all of which subsequently increase the agricultural sustainability (Chen et al., 2022; Guerrieri et al., 2020).

The mechanisms recruited by PGPM towards the plant growth and development are of two types: indirect and direct. The indirect mechanisms include the biological control of plant pathogens through antibiosis, production of lytic enzymes and biocidal volatiles and degrade the phytopathogens, synthesis of siderophores to sequester iron and thereby making it unavailable for the pathogens, quorum quenching and preventing the pathogen from becoming progressively lethal and preventing it from hindering the growth of the plants (Benchlih et al., 2023; de Andrade et al., 2023). PGPM not only provide competition for nutrients but also for binding sites on the plant-surfaces making it's proliferation difficult (de Andrade et al., 2023). In contrast, the production of phytohormones, increasing the bioavailability of nutrients (iron, phosphorus),provision of amino acids, and atmospheric nitrogen fixation and providing it to the plants are the direct mechanisms adopted by PGPM towards the maintenance of overall plant fitness (de Andrade et al., 2023). In addition, priming of induced systemic resistance (ISR) in plants through the synthesis of secondary metabolites (cell-wall degrading enzymes: chitinase, peroxidases and β-1,3-glucanases; signalling molecules: salicylic acid/jasmonic acid) and stimulating the growth and colonization of diverse beneficial microbes including mycorrhiza fungi are two other indirect mechanisms adopted by PGPM (Lee et al., 2021; Lucke et al., 2020). However, the cultivar-type, edaphic factors, climatic variations, presence of predators and competitors influence the activities of PGPM (Pacheco et al., 2022).

Gram-positive *Bacillus sp.* form the best commercial bioinoculants due to their high abilities of plant growth promotion as well as biocontrol activities by producing volatile antimicrobial metabolites along with their sporulating capabilities permitting them to grow in unfavourable environments (Wash et al., 2022). Gram-negative *Pseudomonas sp.* (eg. *P. vancouverensis*, *P. putida*, *P. fragi*, and *P. corrugata*) are the metabolically diverse groups of PGPM that can withstand wide range of temperatures and abiotic and biotic stresses (Pandey and Gupta, 2020). Mobilization of soil nutrients for easy uptake by the roots of the plants and antagonizing the pathogenic microbes by producing antimicrobial metabolites including siderophores, biosurfactants, cyclic lipopeptides, hydrolytic enzymes, hydrogen cyanide (HCN), 2,4-diacetylphloroglucinol phenazines and pyoluteorin are the two

methods used by the *Pseudomonas sp.* to aid the development of plants (Lazcano et al., 2021). Among the acquisition of nutrients, the solubilization of inorganic phosphate has been a well-known contributing factor among the PGPM including *Azotobacter sp.*, *Rhodococcus sp.*, *Arthrobacter sp.* and the *Pseudomonas sp.* (Elhaissoufi et al., 2021).The production of indole compounds, gluconic and 2-ketogluconic acids by *Burkholderia vietnamiensis* and *Enterobacter sp*. is a way to solubilise inorganic phosphate (Castillo-Texta et al., 2024). *Bacillus sp.*, *Aspergillus sp.* and *Acidothiobacillus ferooxidans* also help in the solubilization of soil potassium and make it available for various crops (Kumar et al., 2021; Muthuraja and Muthukumar, 2022).

PGPM like *Achromobacter sp.*, *Pseudomonas sp.*, *Bacillus sp.* and *Serratia sp.* have been found to inhibit the synthesis of ethylene, a negative-regulator for growth of plants, by hydrolysing it's immediate precursor 1-aminocyclopropane-1-carboxylate (ACC) to -ketobutyrate and ammonia by ACC-deaminase enzyme; thereby contributing indirectly to the growth advancement of the plants (Shahid et al., 2023). *Pseudomonas sp.* (*P. aeruginosa*, *P. putida* and *P. fluorescence*) have been found to produce salt-stress induced protein molecules and the different osmolytes that help the halophytes to overcome the high salt conditions of the soil by reducing the absorption of Na+ and enhancing the rate of uptake of K+, Ca2+and Mg2+ by the roots (Dong et al., 2024). The production of 2, 4-diacetylphloroglucinol (DAPG) and calcisol by *Bacillus polymyxa*, *Mycobacterium phlei*, *P. alcaligenes* and *P. Syringae* provide adaptability to the plants to drought and salinity. These bacterial species have been found to increase the chlorophyll content and the activities of the enzymes: glutathione peroxidase, ascorbate peroxidase and catalase in the leaves under drought conditions, thereby scavenging the free radicals (Liu et al., 2022). *Pseudomonas sp.* (*P. putida, P. fluorescence*), *Azospirillium sp.*, *Glucanacetobacter sp.* and *Phosphobacteria sp.* have been reported to protect plants from the devastating effects of heavy metals (Cadmium) through multiple metabolic processes (Huang et al., 2023).

Among the phytohormones produced by PGPM, the best studied so far is the auxin which is released by 80% of PGPM (Veselova et al., 2023). This auxin helps in phototropic and geotropic movements of the plants, differentiation of vascular tissues, establishment of apical dominance, initiation of lateral and adventitious roots, cell division and elongation of roots and stem (Li et al., 2023).

The expression of genes for cytokinin synthesis has been also found in several PGPM including *Bacillus subtilis* (Veselova et al., 2022). Through the production of cytokinins, PGPM can delay the senescence in plants, enhance chlorophyll content, stimulates cell division, initiation of stem, expansion of leaves, root-elongation and root-hair formation and modification of endogenous phytohormone levels (Moradtalab et al., 2020). *Achromobacter xylosoxidans, Acinetobacter calcoaceticus, Azotobacter sp.,*

Azospirillum sp., *Bacillus sp., Gluconobacter diazotrophicus, Herbaspirillum seropedicae* and *Rhizobia sp.* have been found to produce gibberellins stimulating the growth of the shoots (Acharya et al., 2024; Tshikhudo et al., 2023).

The synthesis of antibiotics by *Bacillus sp.* and *Pseudomonas sp.* offers a highly beneficial mechanism to combat the growth of the pathogenic microbes (Jardim et al., 2022). Tas A, bacilysin, bacillaene, chlorotetain, fengycin, iturin, sublancin, subtilin, subtilosin and surfactin are identified from *Bacillus sp*. (Ham et al., 2023; Puan et al., 2023). On other hand, from *Pseudomonas sp.* we have antibiotics like Aerugine, Azomycin, Butyrolactones, Cepaciamide A, Cepafungins, 2,4-Diacetyl Phloroglucinol (DAPG), Ecomycins, Kanosamine, Karalicin, OomycinA, Phenazine-1-carboxylic acid (PCA), Pseudomonic acid, Pyoluteorin, Pyrrolnitrin, Rhamnolipids,Viscosinamide and Zwittermycin A (Sah et al., 2023; Mehmood et al., 2023). PGPM like *Bacillus sp.*, *Pseudomonas sp.* and *Trichoderma sp.* are HCN-producers which in turn inhibits plant cytochrome c oxidase and other metalloenzymes (Khan et al., 2019; Syed et al., 2023).

The nitrogen-fixing group of PGPM include *Azotobacter sp.*,(*A. armeniacus, A. beijerinckii, A. chroococcum, A. nigricans, A.vinelandii, and A. paspali*), *Azospirillum sp.* (*A. amazonense, A. brasilense, A. halopraeferens, A. Lipoferum* and *A. irakense*), *Burkholderia sp.* and *Rhizobacter sp.* that contribute to the significant amount of nitrogen intake in plants and positively influence the plant development by increasing the height of the plants, number of leaves, radius of the stem, the dry weight of the seeds and the percentage of seed filling and changing the morphology of the roots by enhancing the quantity of lateral roots and the amount of root-hairs to increase the surface area of absorption (de Andrade et al., 2023). Additionally, synthesis of phytohormones viz. cytokinins (CK), gibberellins (GA) and indole acetic acid (IAA), and vitamins like thiamine and riboflavin are the attributes of these nitrogen-fixing PGPM. The nitrogen-fixing cyanobacteria viz. *Aulosira*, *Anabaena Nostoc*, *Plectonema*, *Scytonema*, and *Tolypothrix* have been reported to aid in plant growth by being the chief source for plant growth promoting substances including phytohormones and vitamins (Singh et al., 2024). In leguminous plants, nitrogen-fixing *Rhizobium sp.* has been found to enhance the count of pink nodules, activity of nitrate-reductase enzyme and amount of leghaemoglobin. This legume-rhizobial symbiosis is also helpful towards the development of resistance against the attacks of the soil-borne-pathogens and the herbivores (Berrabha et al., 2024).

3. Use of PGPR for Biotic and abiotic stresses in North-Eastern Himalayan agro-ecosystems

Biotic and abiotic stresses are the main restraints that affect the crop-production (Baillo et al., 2019). Among various techniques evolved to manage the stress-related agricultural losses, use of PGPM as bioprotectants has gained sufficient importance among the

biotechnologists because for their capability to augment the growth of plants and preserve plant-survival amidst several abiotic and biotic stressors (He et al., 2024). A comprehensive list of PGPM/BCA isolated from Indian Himalayan region and their uses have been summarized in Table 1.

Table 1: PGPM with their PGP/BCA activities isolated from the Indian Himalayas

Genera/species of PGPM/BCA	*In-vitro* PGP traits	In-planta assessment			Reference
		Strain Name	Isolation source	BC/PGP Activity & TEST PLANT	
Exiguobacterium sibiricum	N2 fixation, IAA production, P and K solubilization	K1	Indian Himalayan regions	Increased growth and germination rate & *Amaranth-aceae* sp. (Spinach)	Kumari et al., 2024
Pezicula radicicola, Paraconiothyrium archidendri	P-solubilization and production of siderophore, IAA and ACC deaminase	GBPI_ beF1, GBPI_ beF2, GBPI_ beF4, GBPI_ beF5	Himalayan silver birch (*Betula utilis* D. Don)	Increased biomass and germination index of *Glycine max* (Soybean) and *Zea mays* L (maiz)	Dasila et al., 2024
Pseudomonas protegens, Pseudomonas atacamensis, Psychrobacter faecalis, Serratia proteamaculans, Pseudomonas mucidolens, Glutamicibacter bergerei	P and K solubilization, nitrogen fixation, IAA production, siderophore and HCN production	LPH60, LSH24, LUR13, LUR44, LUR70, LUR77	Night-soil compost of North-west Himalays	Increased biomass and germination index & *Triticum aestivum* L. (wheat), *Zea mays* L	Borker et al., 2024

Bacillus sp.	Production of IAA, HCN, siderophores, N2 fixation, P and zinc complex dissolution, s	CG2-1, CME6-1, CME6-4, CME6-5, CME6-9, CJ7-1, CMA 10-1, CI11-3, CI11-4	Seeds of citrus plants from North-East Himalayas	Growth enhancement & Citrus crops	Sinha et al., 2023
Serratia marcescens, Pseudochrobacter sp., Stonotrophomonas pavanii, Pseudomonas brassicacearum and Serratia marcescens	Antifungal activity	FS-23, GS-15, HER-9, HER-20, IS-2	Rhizos-phere of *Zingiber officinale*	Reduction in gall formation by *M. incognita* & *Zingiber officinale* (Ginger)	Kaushal et al., 2023
Pseudomonas jesenii and Pseudomonas palleroniana	Nutrient mobilization Improving soil quality	Mp1 and N26	Central Himalayas	Enhancement of grain yield & *Phaseolus vulgaris*	Khan et al., 2023
Ochrobactrum thiophenivorans	Solubilisation of phosphorus	EU-KL94	Wheat plants of Great Himalayas	*Avena sativa L.* (Oats)	Kour and Yadav, 2023
Pseudomonas monteilii	Siderophore production	MN75-9447	Western Himalays	Enhancement of yield & *Dalbergia sissoo*	Srivastava et al., 2022
Bacillus subtilis, Pseudomonas aeruginosa, Cedecea lapagei	P-solubilisation, siderophore production and antifungal activity	KU21, SI12, KU14	*Rosmarinus officinalis* in North-western Himalays	Increased growth & *Rosmarinus officinalis*	Sharma et al., 2021
Glutamicibacter arilaitensis	Germination rate	LJH-19	Night-soil compost of North-western Himalayas	Germination rate & *Pisum sativum* (Pea)	Borker et al., 2021

Bacillus sp., *Streptomyces* sp., *Pseudomonas sp.,* *Exiguobacterium* sp., *Aeromonas sp.,* *Enterobacter* sp.,	Antifungal activity	CB 80, CR 42, CE 19, SB 32, SR 36, SKB 1, SKR 6, KR 8, KE 16, CR 1, CR 14, KB 17 and 19, SB 2, SR 18, KE 15	Rice-rhizosphere from Western Himalayas	Antagonistic activity against bacterial and fungal plant pathogens & *Oryza sativa* L.	Jasrotia et al., 2021
Burkholderia sp.	Production of IAA, siderophores, ACC-deaminase, HCN, salicyclic acid and ammonia	GBPI_ TWL	Indian Himalayan Region	Growth enhancement & *Oryza sativum* (Rice) and *Glycine max*	Adhikari and Pandey, 2020
Enterobacter sp.	Production of siderophores, HCN, salicyclic acid and ammonia	GBPI_ TWr	Indian Himalayan Region	Growth enhancement & *Oryza sativum* and *Glycine max*	Adhikari and Pandey, 2020
Serratia quinivorans	Production of plant hormones	PKL:12	Rhizosphere of *Picrorhiza kurroa*	Vegetative growth and survival of micropropa-gated plantlets & *Picrorhiza kurroa* Royle ex Benth	Kumar et al., 2021

Variovorax paradoxus, Pseudomonas sp., Achromobacter sp., Ochrobactrum anthropi	Alleviation of water stress	RAA3, DPC12, DPB13, DPB15, DPB16, PSA7, PSB8, DPC9	Rhizosphere of *Triticum aestivum* L (wheat)	Decreased drought stress & *Triticum aestivum* L	Chandra et al., 2019
Pseudomonas fragi, Pseudomonas chloropaphis, Pseudomonas fluorescens, Pseudomonas proteolytica and Brevibacterium frigoritolerans	Abiotic stress alleviation		Indian Himalayan Region	Enhanced the cold tolerance of plants by decreasing freezing injury & *Phaseolus vulgaris* (Bean)	Tiryaki et al. 2019

A. Biocontrol agents

One of the major reasons for extensive cultivation with little crop-rotation in hilly regions is due to heavy pathogen attacks because of the prevalence of small and dispersed land-holding (<0.5 ha). However, use of biocontrol agents to combat the phytopathogens in these regions depend on a number of natural properties one of which being their ability to tolerate extreme cold temperatures (Jhala et al., 2020; Yarzábal, 2020). Their commercial use depends on their satisfactory field performance, toxicological properties, feasibility of mass production through fermentation, permissible property rights and marketing (ref). Eg. *Trichoderma harzianum*, *Trichoderma konengii* and *Trichoderma viride* isolated from Himalayan soil were found to be antagonistic against *Pythium afertile*, *Fusarium oxysporum. Cladosporium oxysporum*, *Alternaria alternate* and a non-sporulating dematiaceous fungi through synthesis of volatile and hence easily diffusible antifungal metabolites were found to be tolerant to low temperatures with sporulation occurring within three weeks of time at 4^0C (Katoch et al., 2019; Suyal et al., 2022).

Similarly, *Pseudomonas sp.* viz. MN759447, MP and N-26 from Indian Himalayas have been found to inhibit the growth of *Alternaria alternate*, *Phytophthora sp*., *Fusarium solani* and *Fusarium oxysporum* through either lysis or fungistasis and production of antimicrobial phenazine-1-carboxylic acid (PCA) (Khan et al., 2023; Srivastava et al., 2022; Sahgal et al., 2024). *Streptomyces*, *Rhizobium*, *Microbacterium* and *Enterobacter sp.* with antioxidant properties and antimicrobial activity against various pathogenic strains including *Staphylococcus*, *Escherichia*, *Listeria*, *Bacillus* and *Pseudomonas* species have

been isolated as endophytes from endogenous plant of Himalayas, *Viola odorata* (Salwan et al., 2023; Jain et al., 2021).

B. Mineral metabolism

The highly practiced jhum cultivation in the hilly regions of India which includes the burning of biomass has negative effects on the soil microbiome resulting in decrease of edaphic health and productivity (Temjen et al., 2022). However, symbiotic *Rhizobium sp.* and *Frankia sp.*, free-living nitrogen-fixing group including *Acetobacter sp., Azotobacter sp., Azospirillum sp., Beijerinckia sp., Burkholderia sp., Gluconacetobacter sp., Kosakonia sp., Rhodococcus sp*., phosphate solubilizing and plant-growth modulating bacterial groups *Arthrobacter sp., Bacillus sp., Enterobacter sp., Flavobacterium sp., Pseudomonas sp.* and *Serratia sp.* have been found to be effective in boosting of soil-productivity in jhum-practising highlands by being the natural renewal resources for fertilizers.

PGPM strains: *Bacillus cereus, Bacillus methylotrophicus,* and *Curtobacteriumoceano sedimentum* and the fungal strains: *Penicillium stratisporum*, *Penicillium virgatum* and *Metarhizium pinghaense* were identified from jhum cultivation sites growing paddy crops in North-East India and were applied as biofertilizers or biocontrol agents in the jhum fields of Longkhum district of Nagaland (Giri et al., 2023).

The acidic nature of the highland soil coupled with limited availability of free phosphorus in the soil and it's high reactivity with heavy metals convert the organic phosphorus to it's insoluble inorganic form which becomes inaccessible to the plants. Therefore, use of chemical fertilizers containing organic phosphorus becomes an alternative approach in hill-agriculture. But this latter also fails to provide sufficient mineral to the plants and in addition, results in decrease of soil fertility and increase of environmental pollution; thereby calling for the investigation of psychrophilic phosphate solubilizing bacteria with potential to solubilize and mineralize insoluble phosphate under low-temperature environment (Giri et al., 2020). *Pseudomonas sp., Bacillus sp., Massilia sp.* and *Paenibacillus sp.* have been used for the purpose. Cold-tolerant *Pseudomonas putida*, *Pseudomonas fragi* and *Pseudomonas lurida* proved to be proficient PGPM along with fungal species like *Aspergillus sp., Paecilomyces sp.*and *Penicillium sp.* by solubilising phosphate, producing inorganic acids and phosphatase enzymes (Diksha et al., 2023).

Nitrogen is another limiting factor for crop-production in extreme environments. Nitrogen-fixing bacterial species viz. *Azotobacter sp., Arthrobacter sp., Azoarcus sp., Bacillus sp., Serratia sp., Gluconacetobacter sp., Pseudomonas sp., Klebsiella sp., Enterobacter sp.,* and *Azospirillum sp.* withnitrogen-fixing ability under low-temperature conditions were identified (Giri et al., 2020;Khan et al., 2024).

Siderophore-production wasobserved in *Pseudomonas lurida* M2RH3 isolated from Himalayas (Giri et al., 2023). *Vigna radiata* plants inoculated with cold-tolerant *Pseudomonas fluorescens* showed 17-fold increase in the production of siderophores and positive effects on the plant's growth (Giri et al., 2020).

C. Phytohormone production

Psychrotolerant *Pseudomonas jesenii* in association with native *Cajanus cajan, Cicer arietinum, Eleusine coracana, Vigna radiate* and *Vignamungo sp.* produced IAA and enhanced plant-growth (Diksha et al., 2023). Among various IAA-producing low temperature tolerant bacterial groups discovered from Himalayas, *Pseudomonas sp.* strain PGERs17and NARs9 could enhance wheat growth promotion (Dasila et al., 2023). Besides this, *Pantoea dispersa* strain 1A with multiple plant-growth-promoting-traits (PGPT) including IAA and hydrogen cyanide production, phosphate solubilization, siderophore synthesis and high cold-tolerance levels have been reported from Indian Himalayan region (Sharma et al., 2021). Likewise, *Acinetobacter sp.* strain BIHB 72 also endowed with multiple PGP activities was found to increase the yield of barley, chickpea, maize and pea under field conditions (Gulati et al., 2024).

D. Synthesis of enzymes

A new strain of low-temperature-tolerating fungus with laccase-producing capability was isolated from the Himalayas and was documented as *Cladosporium tenuissimum* (Hafeez et al., 2023; Bashir et al., 2023). Cold-tolerant bacterial strains (*Variovorax paradoxus*, *Pseudomonas sp*., *Achromobacter sp.*and *Ochrobactrum anthropi*) with ACC-deaminase activity were identified that could alleviate the water-stress of wheat plants at low temperatures (Chandra et al., 2019).

E. Cold-stress resistance

Cold stress (CS) is one of the foremostintrusionsin uphill agriculture like Himalayas. Therefore, the use of cold-tolerant PGPM provides protection to agricultural crops in these regions by enhancing nutrition procurement, modulatingthe release of planthormones and synthesis of siderophores to stimulatetheproduction of antioxidantsatthe low temperatures (Kushwaha et al., 2020). In general, psychrophilic bacteria include*Bacillus sp., Vibrio sp.*, *Psychroflexus sp., Psychrobacter sp., Polaromonas sp., Polaribacter sp., Pseudoalteromonas sp., Pseudomonas sp., Moritella sp., Moraxella sp., Micrococcus sp., Flavobacterium sp.,* and *Arthrobacter sp.*(Kushwaha et al., 2020). Cold-adapted strains of antagonistic *Trichoderma harzianum, Trichoderma koningii, Trichoderma viride, Streptomyces* strains along with various strains of *Pseudomonas* including phosphate-solubilizing *Pseudomonas corrugate*, *Pseudomonas putida*, *Aspergillus niger*, *Paecilomyces hepialid*, siderophore-producing *Pseudomonas fluorescens*, diazotrophs

Pseudomonas palleroniana N26 and *Pseudomonas migulae S10724*, *Exiguobacterium acetylicum* strain 1P,plant-growth-promoting *Pseudomonas cedrina*, *Brevundimonas terrae*, *Acinetobacter rhizosphaerae*, *Arthrobacter nicotianae*, and multiple strains of *Arthrobacter sp.*, *Acinetobacter sp.*, *Bacillus sp.*, *Dyadobacter sp.*, *Bordetella sp.*, *Providencia sp.* and *Stenotrophomonas sp.* were isolated from Indian Himalayas (Gulati et al., 2024). From the cold desert of Arunachal Pradesh, *Pseudomonas koreensis* P2 was isolated showing PGPT very recently (Awasthi et al., 2019). These microbes have been found to offer adaptation to cold stress in plants by a number of mechanisms including synthesis of cold-shock proteins, accumulation of osmolytes, enhanced nutrient availability with drop of electrolyte leakage, improved systemic tolerance by modifying plant-physiology and metabolism, increased membrane-fluidity and up-regulation of proton pumps (Kushwaha et al., 2020).Numerous bacterial types among these are being used as biofertilizers in post-assays and field-trials for wheat, soybean, chickpea, gram, pigeon pea and *Arabidopsis thaliana* and are found to augment the plant development in the presence of stress (Gulati et al., 2024).

F. Drought-stress Resistance

Drought or recurrent phases of water-shortage is a crucial limitation to agriculture worldwide subsequently affecting the global food security. During the water-stress, plant homeostasis is maintained by ethylene resulting in reduction in root and shoot growths (Borker et al., 2024). ACC-deaminase enzyme plays an important role in this respect. ACC-utilizing bacteria that have resulted in assuaging drought-stress on various agricultural crops include *Achromobacter piechaudii* ARV8, *Variovorax paradoxus* 5C-2 and *Pseudomonas sp.* (Borker et al., 2024; Gulati et al., 2024). Chandra et al., isolated ACC deaminase producing bacteria belonging to *Proteobacteria* from fertile agricultural fields of the Kumaun region of Central Himalayas in Uttarakhand, India and gauged their PGP activities on wheat plants by using them individually as well as in consortium with other bacteria and assessed their abilities to reinforce drought-tolerance in wheat cultivars (Chandra et al., 2019).

G. Heavy-metal tolerance

The aquatic systems of Northeast India, mostly from Assam, are rich in freshwater green and blue-green algae (cyanobacteria). (Roy et al., 2022). The common strains of *Nostoc sp.* that can be used as biofertilizers include *Nostoc muscorum*, *Nostoc punctiforme* and *Anabaena azollae* and were found to produce positive effects in crop fields with acidic soil (Garalapati et al., 2019). These blue-green algae have been in use as biofertilizers for agricultural crops (eg. paddy); production of fish-feed, cosmetics, nutraceuticals like single-cell proteins and omega-3 fatty acids, biodiesel and bioethanol (Kumar et al., 2022; Arora et al., 2021; Tripathi et al., 2024). They also have potency for bioremediation of waste elements including heavy metals (Kalita and Baruah, 2024).

Summary

The yield of food grains, fruits and vegetables during post 2015 period from North East India has been found to be 2.8%, 3.7%, and5.4% respectively, and this accounts for relatively low production compared to other parts of India. However, agricultural output can be improved by increasing (1) the area of agricultural lands and/or (2) crop-productivity. The latter is achieved by adopting modern agricultural technologies explicit to hills. Therefore, use of PGPR isolated from uphill areas towards better crop production is of immense importance; particularly for the diverse jhum agricultural systems of North-East India. Though traditional organic farming practices provide successful results in different regions of North-East India, the routine use of PGPR will improve the security of foods for the agricultural communities.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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CAUGHT IN THE COMPLEX OF CULTURE: A STUDY OF THE KUDMI MAHATO COMMUNITY IN JHARGRAM, WEST BENGAL

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Introduction :

It was the autumn of October 2022. *Bandna parab* (*Bandna* meaning worship and *parab* meaning carnival/ritual), a major festival of the Kudmi Mahato community was approaching. Eager to witness the festival that I had so extensively read about in community-authored magazines and texts[1], I visited the Kudmi-majority village of Gheekalla (name anonymized) in Jhargram. While the villagers remained busy in their fields during the day, they usually indulged in long, leisurely conversations during the evening. As we connected over *Bandna,* they reminisced about bygone days, and lamented the gradual but stark decline of the celebration of community festivals within the village. From their stories, a growing gap between the practiced *Parab* and the remembered *Parab* became palpable. An appraisal of this distance is crucial because it signals the slow erosion of a distinctive mode of communitarian living among Kudmis.

If there is cultural loss, there are also attempts at its revival. Having suffered from a steady erosion of cultural consciousness over time, a section of intellectuals from within Kudmis, comprising mostly teachers and businessmen, are attempting to culturally consolidate the community. While there are disagreements over the ways of cultural revival and reform with the loyalties of the masses divided, the bid for cultural consolidation is nonetheless manifesting. This paper seeks to explore the retreat and concomitant attempts at the revival of Kudmis' communitarian culture in three sections, in addition to the introduction and conclusion. The first section provides a glimpse of the changing identity of Kudmis in the eyes of the State; the second section indicates the reasons behind experiences of cultural loss among Kudmis; while the third section, preceding the conclusion, traces the community's attempts at cultural revival with a focus on two distinct movements.

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[1]*Banda Parab* is spread across three-five days. Through its celebration, Kudmis express their gratitude to draught animals like cows, buffaloes etc. which help them in agrarian practices. Farming tools like plough, shovel, axe, and sickle are also worshipped. Rituals are performed by community priests known as Laya or the oldest male member of the household. Variety of rice-cakes and meat fritters are prepared for consumption.

Who are Kudmis?

The Kudmi community inhabits parts of Eastern India, mainly Jharkhand, West Bengal (WB), Odisha, and Bihar. In WB, they are majorly present in the districts of Jhargram, Purulia, and Bankura. Interestingly, colonial census exercises failed to fix the administrative identity of Kudmis. The community was initially recorded as tribals. In 1931, following protests from a small section of community elites who mobilized along Kshatriya lines eager to record themselves as caste Hindus in the eyes of the colonial administration (Islam 2000), Kudmis were eventually dropped off from the list of tribes. Their name did not also feature in the list of Scheduled Tribes (ST) published in 1950. Consequently, Kudmis were denied the privileges of protective discrimination enjoyed by communities whose names are in the list[2]. Eventually, with the publication of the Mandal Commission Report in 1990, Kudmis were legally recognized as an Other Backward Class (OBC) for high degree of social and educational backwardness prevalent within their ranks. Notwithstanding this recognition, a large percentage of Kudmis from West Bengal, Jharkhand and Odisha are presently mobilizing for ST-status. Pro-ST Kudmis, who identify themselves as *Dhonr* (meaning stomach) *Kudmis* believe that recognition of their tribal roots will not only help them reinvigorate their decaying culture but will also signal an end to the political ploy that have for decades denied Kudmis 'legitimate' tribal past. *Dhonr* Kudmis profess an adherence to totemism/animism, also known as *Sarna dharam*, and claim a constitutional recognition of their cultural difference from the idol-worshipping Hindu Kurmis of Bihar (and Uttar Pradesh) with whom they are routinely conflated in the administrative census.

History of Cultural Loss among Kudmis

Kudmi solidarity began to face significant roadblocks during the last decades of the nineteenth century as a section of community elites pursued a movement of rank ascription. (Samaddar, 1998). This movement was conceived by the All India Kudmi Kshatriya Mahasabha, established in 1894 whose main demand of identifying Kudmis as Hindu Kshatriyas received active support from caste-Hindu organizations like Arya Samaj, Hindu Mahasabha, and Hindu Mission (Nanda & Kulke, 2015). The movement showed limited success because its orientation remained largely elitist and it had little to no appeal among

[2]There are disputes regarding the elimination of the Kudmi community from ST-list. Mehta (1982) claims 'political reasons' as the underlying cause, while Kamra (2016) and Islam (2020) identify Kudmis' aspiration for accessing a higher ritual status of Kshatriyahood as the reason behind their elimination. However, Kudmi intellectuals complain of deliberate deletion of their community name from ST-list. They hold that with Nehru government's focus on heavy industries and with protection imposed on the sale/lease/exchange/mortgage of tribal land to non-tribals, it would have been difficult for the governments to acquire industrial land in Kudmi majority areas had the community been declared ST. Although the claim remains historically unverified, but this argument remains a major plank around which the community mobilizes to achieve ST-status. A detailed discussion of Kudmis' ST claims remains beyond this paper's scope.

the masses. In fact, there were instances of active retaliation against such elitist reappraisals of Kudmi identity. For instance, in response to elitist thrust towards assimilation with caste Hindus, ordinary Kudmis launched the Gossaiyan movement in the 1930s, to protect Kudmi cultural identity from the homogenizing effects of Kshatriyization (P. Mahato, 2000).

Meanwhile, successive famines in the nineteenth century led to large-scale migration among Kudmis to the forests of North Bengal and plantations in Assam. This dispersal disrupted their shared cultural practices and contributed to a gradual erosion of communitarian life. The spread of Congress-led nationalist politics in the 1920s and 1930s also brought new cultural influences (Samaddar 1998). Bengali upper-caste/class nationalists engaged Kudmis in Gandhian mobilizations, promoting Hindu rituals, literacy campaigns, and even encouraging the adoption of Bengal as a mother tongue. These efforts sought to reshape Kudmis into 'gentle, cultured, educated, traditional Hindus' (ibid. 253), thereby displacing the indigenous cultural idioms with dominant nationalist scripts.

Vaishnavism too gained popularity among Kudmis during the twentieth century. Oppressed by Brahmins, the anti-caste, monotheistic thrust of Vaishnavism appealed to Kudmis (Bhowmik, 2014). Vaishnava rituals continue to leave a deep imprint on the cultural life of Kudmis. Ritualistic practices like the worshipping of Tulsi plants and ritual chanting of names, venerated widely in the Vaishnava order remain popular among Kudmis. These practices have undoubtedly impacted the traditional animist beliefs of a large percentage of Kudmis but a renewed awareness regarding their folk practices is slowly gaining ground again among Kudmis. A large section of the community is now eagerly participating in attempts at cultural revival aimed to reinvigorate lost cultural practices, typical to their community. The following section throws light at two contemporary efforts at reviving Kudmis' communitarian culture. These revivalist attempts are mostly led by men with women playing only a cursory role. This is important to note for such gendered attempts at communal reinvigoration point to continued stereotyping of gender roles in cultural and political life which reduces women to passive recipients and men to active superiors.

Politics of Cultural Revival: Ritualistic and Linguistic

Cohen (1993) argues that for communities who 'predicate their very identity on the culture', loss of culture is akin to 'social death' (p. 202). Culture has been the dominant, but also perhaps, the most assaulted aspect of Kudmi identity. Most texts by Kudmi intellectuals focus on their community's culture. Bankim Mahato (1983) highlights Kudmi rituals to show their affinity with broader Jharkhandi traditions. Pashupati Mahato (2014, 2000) critiques the systematic cultural memocide of Kudmis by the dominant *Bhadrolok* class. He coins the term *Nirbakization* (meaning cultural silencing) to describe this erosion and contrast it with *Sanskritization* (meaning ritual emulation of upper-caste practices) to argue

that while the latter involves voluntary caste mobility, Kudmis were made to adopt the symbolic repertoires of the dominant class against their volition. Recent publications, including little magazines like *Titki* and *Goram Thaan*, bring together articles that overwhelmingly focus on Kudmi "*chaari"* or culture. Thus, although cultural silence has affected the cultural rubric of the community, a simultaneous process of revival or 'cultural literacy' (to borrow from Samaddar's (1998) phrase) is also underway.

Hall (1990) sees cultural identity as a process influenced by the interventions of history and power, which sometimes also demands a revival of a collective sense of an 'authentic' self. This section engages with the theme of identity as recovery of such an 'authentic' self, driven by the search for a shared cultural essence, that is believed to exit beneath layers of fractured memories. The *Adivasi Negachari Kudmi Samaj* movement (*Nega* meaning left and *Chari* meaning culture), led by Anup Mahato, a contractor, seeks to revive the 'authentic' and 'essential' self of Kudmis through cultural reclamation. In conversation, Anup described that the movement aims to remove the continuing effects of Brahmanical influences from within Kudmis. In his vision, such a removal can be effectuated by resurrecting what he terms an 'unalloyed' (*nikhaad*) cultural past of Kudmis through a reinvigoration of fading rituals and collective performance of traditional folk practices. Structurally, the organization of the movement draws inspiration from the traditional five-tier Mandal system of the community with Anup serving as the *Desh Morol* (leader of the Mandals), overseeing a hierarchy modeled on customary forms of community governance.

While elaborating on the movement's principles, Anup stated, "*Amader itihaser dike dekhte hobe, somajer otiter dike dekhte hobe*" (We have to look back at our own history, we have to turn to the past of our community). This invocation of the community's *otit* (past) can be interpreted along what Hall (1990) might describe as an *essentialised* past which is a quest to recover a cultural identity that is grounded in presumed historical continuity. While the *Negachari* movement takes into cognizance the impact of shifting trends of history and power on the transient cultural life of the community, it nevertheless insists on basing the Kudmi self in what it claims to be a unique and continuous cultural lineage specific to the community. For leaders of the movement, this essentialist orientation is key to reclaiming a distinct indigenous identity. Though supportive of the demand for ST recognition, the main focus of the movement lies in rekindling the lost cultural pride of Kudmis. Anup, for instance, sees constitutional recognition as ST a necessary safeguard against cultural erosion but remains deeply skeptical of State intervention in politicizing the community's cause. His distrust toward the Bengali *Bhodrolok* class and the Kolkata-centric bureaucratic machinery that typically implements government policies runs deep. Therefore, Anup insists that the revitalization of Kudmi cultural life must be led by the community itself and should organically emerge from within it.

The *Negachari* movement has sought to reinvigorate traditional community rituals, particularly those involving collective performances as part of its attempts to resuscitate Kudmi culture. Rituals are seen as forging a sense of unity among those who come together to perform them. The movement has employed groups of people, mostly men, who visit villages, organize villagers, and lecture them on the community's traditional ritualistic practices. This is also done with the motive of minimizing the impact of Brahmanical and Vaishnavite practices on Kudmi cultural life. The movement which is almost a decade old is slowly gaining ground amongst a section of villagers. For instance, in present times, many Kudmis are hiring people associated with the movement to officiate ceremonies like marriage and cremation which were earlier presided over mostly by Brahmin priests.

In addition to reinvigoration of communitarian rituals, the movement has petitioned the WB government to declare sectional holidays on important festivals pertaining to the Kudmi community. Leaders argue that while dominant Hindu festivals have been declared as public holidays in the state, Kudmis are increasingly becoming indifferent to their *Parabs* and other communal revelries due to a shortage of celebration time. *Negachari*s opine that since the state is responsible for the protection of minority culture and folk practces, it must actively engage itself in awareness campaigns and aid the celebration of community festivals through funding. Such state-sponsored attempts *Negacharis* opine, will encourage Kudmis to participate in their traditional rites.

As part of their attempt to foreground the importance of Kudmi ritualistic exercises, the *Negacharis* frequently dwell on their scientific rigor. Although ritual is often posed as regressive, unscientific, and also 'derided as a relatively ineffectual way of engaging the world' (Stephenson 2015, 2), the leaders seeks to upturn this hierarchy. They foreground the scientific nature of ancient Kudmi ritual knowledge. By aligning traditional communitarian rituals with seasonal transitions and agricultural cycles, *Negachaaris* aim to foster a sense of cultural pride rooted in the community's long association with the environment, specifically land. They also contest the colonial and postcolonial construction of indigenous rituals as primitive and irrational. They relegate to the realm of the mythic the practices associated with Brahminism and through the claim to scientificity, aim to reclaim a respect for their folk practices in a world where science tops knowledge hierarchy.

Tusu Parab and the practices associated with it are often cited as a key example of ritual scientificity. Celebrated over five days, the *Parab* coincides with the winter solstice, when the sun is farthest from the earth. The fifth day, *Makar*, marks the shift toward longer days and the return of the light. Therefore, the day of the *Makar* marks the beginning of the Kudmali agrarian calendar. *Tusu Parab* is therefore also known popularly as *Makar Parab* among Kudmis. Anup highlights that the festival's alignment with the rhythms of nature underscores the scientific consciousness embedded in Kudmi ritual practices. Through such

claims, *Negacharis* seek to reclaim an indigenous epistemology that has long been invalidated by dominant narratives of modernity.

Aligned with its aim of reviving the cultural ethos of Kudmis, the movement actively encourages Kudmi traditional performing arts, with a particular focus on *Jhumur* songs. Youths are being trained in folk songs and dance forms. Folk songs have long served as vehicles of the community's cultural expressions. Through songs, Kudmis have both orally and aurally conveyed tales of their economic hardship, political resistance, social marginalization, and collective defiance. For instance, *Tusu* songs played a key role in mobilizing Kudmis of Manbhum district against linguistic oppression perpetrated by a section of Bihari elites during the Manbhum movement (an agitation that eventually led to the inclusion of Purulia in Bengal) in 1956. However, with the death of elders and limited youth engagement the collapse of traditional folk edifice has undoubtedly deepened. Anup therefore lamented, "*sikkhya amader osikhyito kore dilo"* (Education has made us illiterate), underscoring his belief that true education lies in cultural literacy, where Kudmi identity is most powerfully rooted.

Another movement, the *Kudmali Chisoi Chari* movement is looking for a linguistic revival of the community. It started in the 1980s under the leadership of Jayanta Mahato, a primary school teacher, and Narayan Mahato, an Ayurveda practitioner. In multiple interviews conducted by the author between 2022-2024, both leaders confessed that the *Chisoi Chari* movement was triggered by the anxiety over the possible death of Kudmali, the language of Kudmis. Jayanta Mahato opined that language constitutes the very 'core of culture'. He felt that the movement was catalyzed by a steady erosion of Kudmali linguistic repertoire. Jayanta expressed particular concern about Kudmis living in and around Jhargram. Unlike those in Purulia district that lie closer to the Jharkhand border where Kudmali is still pervasively spoken, Kudmis in Jhargram have increasingly lost touch with their vernacular mostly because of the spread of Bengali-medium education among them. Also, Jhargram is near to and intimately connected with cosmopolitan urban centers like Kharagpur and Kolkata which Jayanta conveys has escalated its assimilation with the mainstream. The linguistic movement's primary aim has been to develop Kudmali as a literary and educational language.

Kudmali historically lacked a standardized script. In its attempt to institutionalize the language, the *Chisoi Chari* movement under the aegis of Jayanta Mahato has developed a script, called *Chisoi,* in 1986. The script has, after much deliberation among Kudmali linguists, found acceptance among a large majority. While other scripts are used mostly by community writers locally, *Chisoi* is popular because it draws on symbols best associated with Kudmali culture (Mondal 2022). For instance, some of its letters resemble motifs that popularly appear in the community's traditional art, locally known as *alpona,* a kind of wall

and floor painting very specific to Bengal. According to Jayanta, the uniqueness of Kudmali grammar and phonetics necessitated the need for a unique script as mainstream Bengali fails to capture the essence of the language. While Bengali is an Indo-Aryan language, Kudmali, Jayanta believes is a Dravidian language. While he lauded the WB government's efforts in introducing courses in Kudmali across colleges in Jhargram, he remained sceptic about its impact on linguistic survival. He highlighted that in these colleges, Kudmali is being taught in Bengali which he added is grammatically and syntactically so different than Kudmali that culture-specific aspects of the latter will get lost if written in the Bengali script.

Narayan Mahato, his comrade, also pitched a similar concern, albeit in a more tacitly critical way. He argued that while the spread of Bengali-medium education among Kudmis may give them an edge in competitive examinations and job market, it will eventually expedite Kudmali's extinction as a language and its replacement by a more regionalized variant of Bengali, akin to the ones used by the dominant linguistic elite. Both leaders repeatedly underscored the need for a standardized script. In their interpretation, script is not merely a technical medium but a fountain of cultural memory and identity.

With the aim to bring about the community's linguistic revival, the *Kudmali Chisoi Chaari* Foundation, which leads the language movement, runs diploma courses in Kudmali. These courses have seen substantial participation in recent years. Since 2009, elementary schools and adult education centers have also been initiated by the Foundation. Although the leaders of this movement support the demands for ST status, their primary aim is the linguistic reinvigoration of Kudmali. The movement is currently mobilizing for Kudmali to be recognized under the Eighth Schedule of the Indian Constitution. The leaders opine that Kudmali's recognition as a minority linguistic community is key in preserving the language.

This attempt at linguistic rebuilding also has a larger political basis. Kudmis live scattered across states of Odisha, Jharkhand, and Bengal. Divided geographically, they speak in different dialects. This movement aims to strike a linguistic unity among the members of the dispersed community by standardizing script and grammar. In simpler terms, this movement aims to unify a geographically dispersed community having similar historical trajectory linguistically. For the leaders of this movement, linguistic consolidation and not ritual reinvigoration remains key for cementing internal cohesion of an orally organized community like Kudmis. They opine that the history of the community has been aurally passed across generations, and with the decay of language, the entire gamut of aural tradition runs the risk of disappearance. This reflects that linguistic revival is not merely a cultural act. More crucially, it is an attempt to transcend forced political fragmentation through rebuilding of shared semiotic networks. In this sense, the revitalization of Kudmali clearly goes more than its restoration as a medium of

communication. The movement recognizes Kudmali as a site of memory with *Chisoi* as a tool to document the oral culture's memories and amnesias.

Conclusion

Kudmis offer a compelling glimpse into how a community actively rehearses its culture and seeks to revive it in the face of both historical fragmentation and contemporary political erasure. At a time when there is a flattening of dissent and subsumption of cultural plurality globally, Kudmis' efforts to recover, preserve, and rearticulate their cultural selfhood mark a powerful act of resistance. Through language revival, ritual re-enlivening, and the invocation of oral memory, Kudmis are not merely asserting their difference. They are also searching for a consciousness that has long been denied recognition. As with many subaltern groups, identity here is not a fixed process; it is fragile and contested in the face of uncertainty. When the oppressed speak, their voice may be hesitant, fragmented, or encoded but it demands to be heard. This paper has attempted, however partially, to listen to that voice and trace its unfolding contours.

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Asutosh College, formerly known as South Suburban College, was established in 1916 by Sir Asutosh Mookerjee, the renowned mathematician, educationist, jurist, and the second Indian Vice Chancellor of the University of Calcutta, whose life's mission was to open the doors of modern education in the western tradition to students of his motherland.

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