Climate change resilient agricultural practices: A learning experience from indigenous communities over India

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Abstract

The impact of climate change on agricultural practices is raising question marks on future food security of billions of people in tropical and subtropical regions. Recently introduced, climate-smart agriculture (CSA) techniques encourage the practices of sustainable agriculture, increasing adaptive capacity and resilience to shocks at multiple levels. However, it is extremely difficult to develop a single framework for climate change resilient agricultural practices for different agrarian production landscape. Agriculture accounts for nearly 30% of Indian gross domestic product (GDP) and provide livelihood of nearly two-thirds of the population of the country. Due to the major dependency on rain-fed irrigation, Indian agriculture is vulnerable to rainfall anomaly, pest invasion, and extreme climate events. Due to their close relationship with environment and resources, indigenous people are considered as one of the most vulnerable community affected by the changing climate. In the milieu of the climate emergency, multiple indigenous tribes from different agroecological zones over India have been selected in the present study to explore the adaptive potential of indigenous traditional knowledge (ITK)-based agricultural practices against climate change. The selected tribes are inhabitants of Eastern Himalaya (Apatani), Western Himalaya (Lahaulas), Eastern Ghat (Dongria-Gondh), and Western Ghat (Irular) representing rainforest, cold desert, moist upland, and rain shadow landscape, respectively. The effect of climate change over the respective regions was identified using different Intergovernmental Panel on Climate Change (IPCC) scenario, and agricultural practices resilient to climate change were quantified. Primary results indicated moderate to extreme susceptibility and preparedness of the tribes against climate change due to the exceptionally adaptive ITK-based agricultural practices. A brief policy has been prepared where knowledge exchange and technology transfer among the indigenous tribes have been suggested to achieve complete climate change resiliency.

1 Introduction

Traditional agricultural systems provide sustenance and livelihood to more than 1 billion people [1–3]. They often integrate soil, water, plant, and animal management at a landscape scale,
creating mosaics of different land uses. These landscape mosaics, some of which have existed for hundreds of years, are maintained by local communities through practices based on traditional knowledge accumulated over generations [4]. Climate change threatens the livelihood of rural communities [5], often in combination with pressures coming from demographic change, insecure land tenure and resource rights, environmental degradation, market failures, inappropriate policies, and the erosion of local institutions [6–8]. Empowering local communities and combining farmers’ and external knowledge have been identified as some of the tools for meeting these challenges [9]. However, their experiences have received little attention in research and among policy makers [10].

Traditional agricultural landscapes as linked social–ecological systems (SESs), whose resilience is defined as consisting of 3 characteristics: the capacity to (i) absorb shocks and maintain function; (ii) self-organize; (iii) learn and adapt [11]. Resilience is not about an equilibrium of transformation and persistence. Instead, it explains how transformation and persistence work together, allowing living systems to assimilate disturbance, innovation, and change, while at the same time maintaining characteristic structures and processes [12]. Agriculture is one of the most sensitive systems influenced by changes in weather and climate patterns. In recent years, climate change impacts have become the greatest threats to global food security [13,14]. Climate change results in a decline in food production and consequently rising food prices [15,16]. Indigenous people are good observers of changes in weather and climate and acclimatize through several adaptive and mitigation strategies [17,18].

Traditional agroecosystems are receiving rising attention as sustainable alternatives to industrial farming [19]. They are getting increased considerations for biodiversity conservation and sustainable food production in changing climate [20]. Indigenous agriculture systems are diverse, adaptable, nature friendly, and productive [21]. Higher vegetation diversity in the form of crops and trees escalates the conversion of CO₂ to organic form and consequently reduces global warming [22]. Mixed cropping not only decreases the risk of crop failure, pest, and disease but also diversifies the food supply [23]. It is estimated that traditional multiple cropping systems provide 15% to 20% of the world’s food supply [1]. Agro-forestry, intercropping, crop rotation, cover cropping, traditional organic composting, and integrated crop-animal farming are prominent traditional agricultural practices [24,25].

Traditional agricultural landscapes refer to the landscapes with preserved traditional sustainable agricultural practices and conserved biodiversity [26,27]. They are appreciated for their aesthetic, natural, cultural, historical, and socioeconomic values [28]. Since the beginning of agriculture, peasants have been continually adjusting their agriculture practices with change in climatic conditions [29]. Indigenous farmers have a long history of climate change adaptation through making changes in agriculture practices [30]. Indigenous farmers use several techniques to reduce climate-driven crop failure such as use of drought-tolerant local varieties, polyculture, agro-forestry, water harvesting, and conserving soil [31–33]. Indigenous peasants use various natural indicators to forecast the weather patterns such as changes in the behavior of local flora and fauna [34,35].

The climate-smart agriculture (CSA) approach [36] has 3 objectives: (i) sustainably enhancing agricultural productivity to support equitable increase in income, food security, and development; (ii) increasing adaptive capacity and resilience to shocks at multiple levels, from farm to national; and (iii) reducing Green House Gases (GHG) emissions and increasing carbon sequestration where possible. Indigenous peoples, whose livelihood activities are most respectful of nature and the environment, suffer immediately, directly, and disproportionately from climate change and its consequences. Indigenous livelihood systems, which are closely linked to access to land and natural resources, are often vulnerable to environmental degradation and climate change, especially as many inhabit economically and politically marginal areas in
fragile ecosystems in the countries likely to be worst affected by climate change [25]. The livelihood of many indigenous and local communities, in particular, will be adversely affected if climate and associated land-use change lead to losses in biodiversity. Indigenous peoples in Asia are particularly vulnerable to changing weather conditions resulting from climate change, including unprecedented strength of typhoons and cyclones and long droughts and prolonged floods [15]. Communities report worsening food and water insecurity, increases in water- and vector-borne diseases, pest invasion, destruction of traditional livelihoods of indigenous peoples, and cultural ethnocide or destruction of indigenous cultures that are linked with nature and agricultural cycles [37].

The Indian region is one of the world’s 8 centres of crop plant origin and diversity with 166 food/crop species and 320 wild relatives of crops have originated here (Dr R.S. Rana, personal communication). India has 700 recorded tribal groups with population of 104 million as per 2011 census [38] and many of them practicing diverse indigenous farming techniques to suit the needs of various respective ecoclimatic zones. The present study has been designed as a literature-based analytical review of such practices among 4 different ethnic groups in 4 different agroclimatic and geographical zones of India, viz, the Apatanis of Arunachal Pradesh, the Dongria Kondh of Niamgiri hills of Odisha, the Irular in the Nilgiris, and the Lahaulas of Himachal Pradesh to evaluating the following objectives: (i) exploring comparatively the various indigenous traditional knowledge (ITK)-based farming practices in the different agroclimatic regions; (ii) climate resiliency of those practices; and (iii) recommending policy guidelines.

2 Methodology

2.1 Systematic review of literature

An inventory of various publications in the last 30 years on the agro biodiversity, ethno botany, traditional knowledge, indigenous farming practices, and land use techniques of 4 different tribes of India in 4 different agroclimatic and geographical zones viz, the Apatanis of Arunachal Pradesh, the Dongria Kondh of Niamgiri hills of Odisha, the Irular in the Nilgiris, and the Lahaulas of Himachal Pradesh has been done based on key word topic searches in journal repositories like Google Scholar. A small but significant pool of led and pioneering works has been identified, category, or subtopics are developed most striking observations noted.

2.2 Understanding traditional practices and climate resiliency

The most striking traditional agricultural practices of the 4 major tribes were noted. A comparative analysis of different climate resilient traditional practices of the 4 types were made based on existing information available via literature survey. Effects of imminent dangers of possible extreme events and impact of climate change on these 4 tribes were estimated based on existing facts and figures. A heat map representing climate change resiliency of these indigenous tribes has been developed using R-programming language, and finally, a reshaping policy framework for technology transfers and knowledge sharing among the tribes for successfully helping them to achieve climate resiliency has been suggested.

2.3 Study area

Four different agroclimatic zones and 4 different indigenous groups were chosen for this particular study. The Apatanis live in the small plateau called Zero valley (Fig 1) surrounded by forested mountains of Eastern Himalaya in the Lower Subansiri district of Arunachal Pradesh. It is located at 27.63° N, 93.83° E at an altitude ranging between 1,688 m to 2,438 m. Rainfall is
heavy and can be up to 400 mm in monsoon months. Temperature varies from moderate in summer to very cold in the winter months. Their approximate population is around 12,806 (as per 2011 census), and Tibetan and Ahom sources indicate that they have been inhabiting the area from at least the 15th century and probably much earlier (https://whc.unesco.org/en/tentativelists/5893/).

The Lahaulas are the inhabitants of Lahaul valley (Fig 1) that is located in the western Himalayan region of Lahaul and Spiti and lies between the Pir Panjal in the south and Zanskar in the north. It is located between 76˚ 46' and 78˚ 41' east longitudes and between 31˚ 44' and 32˚ 59' north altitudes. The Lahaul valley receives scanty rainfalls, almost nil in summer, and its only source of moisture is snow during the winter. Temperature is generally cold. The combined population of Lahaul and Spiti is 31,564 (as per 2011 census).

The Dongria Kondh is one of the officially designated primitive tribal group (PTG) in the Eastern Ghat region of the state Orissa. They are the original inhabitants of Niyamgiri hilly region (Fig 1) that extends to Rayagada, Koraput, and Kalahandi districts of south Orissa. Dongria Kondhs have an estimated population of about 10,000 and are distributed in around 120 settlements, all at an altitude up to 1,500 above the sea level [39]. It is located between 190 26' to 190 43' N latitude and 830 18' to 830 28' E longitudes with a maximum elevation of 1,516 meters. The Niyamgiri hill range abounds with streams. More than 100 streams flows
from the Niyamgiri hills and 36 streams originate from Niyamgiri plateau (just below the Niyam Raja), and most of the streams are perennial. Niyamgiri hills have been receiving high rainfall since centuries and drought is unheard of in this area.

The Irular tribes inhabit the Palamalai hills and Nilgiris of Western Ghats (Fig 1). Their total population may be 200,000 (as per 2011 census). The Palamali Hills is situated in the Salem district of Tamil Nadu, lies between 11˚ 14.46' and 12˚ 53.30' north latitude and between 77˚ 32.52' to 78˚ 35.05' east longitude. It is located 1,839 m from the mean sea level (MSL) and more over the climate of the district is whole dry except north east monsoon seasons [40,41]. Nilgiri district is hilly, lying at an elevation of 1,000 to 2,600 m above MSL and divided between the Nilgiri plateau and the lower, smaller Wayanad plateau. The district lies at the juncture of the Western Ghats and the Eastern Ghats. Its latitudinal and longitudinal location is 130 km (latitude: 11˚ 12' N to 11˚ 37' N) by 185 km (longitude 76˚ 30' E to 76˚ 55' E). It has cooler and wetter climate with high average rainfall.

3 Results and discussion
3.1 Indigenous agricultural practices in 4 different agro-biodiversity hotspots

Previous literatures on the agricultural practices of indigenous people in 4 distinct agro-biodiversity hotspots did not necessarily focus on climate resilient agriculture. The authors of these studies had elaborately discussed about the agro-biodiversity, farming techniques, current scenario, and economical sustainability in past and present context of socioecological paradigm. However, no studies have been found to address direct climate change resiliency of traditional indigenous agricultural practices over Indian subcontinent to the best of our knowledge. The following section will primarily focus on the agricultural practices of indigenous tribes and how they can be applied on current eco-agricultural scenario in the milieu of climate change over different agricultural macroenvironments in the world.

3.1.1 Apatani tribes (Eastern Himalaya). The Apatanis practice both wet and terrace cultivation and paddy cum fish culture with finger millet on the bund (small dam). Due to these special attributes of sustainable farming systems and people’s traditional ecological knowledge in sustaining ecosystems, the plateau is in the process of declaring as World Heritage centre [42–44]. The Apatanis have developed age-old valley rice cultivation has often been counted to be one of the advanced tribal communities in the northeastern region of India [45]. It has been known for its rich economy for decades and has good knowledge of land, forest, and water management [46]. The wet rice fields are irrigated through well-managed canal systems [47]. It is managed by diverting numerous streams originated in the forest into single canal and through each agriculture field is connected with bamboo or pinewood pipe.

The entire cultivation procedure by the Apatani tribes are organic and devoid of artificial soil supplements. The paddy-cum-fish agroecosystem are positioned strategically to receive all the run off nutrients from the hills and in addition to that, regular appliance of livestock manure, agricultural waste, kitchen waste, and rice chaff help to maintain soil fertility [48]. Irrigation, cultivation, and harvesting of paddy-cum-fish agricultural system require cooperation, experience, contingency plans, and discipline work schedule. Apatani tribes have organized tasks like construction and maintenance of irrigation, fencing, footpath along the field, weeding, field preparation, transplantation, harvesting, and storing. They are done by the different groups of farmers and supervised by community leaders (Gaon Burha/Panchayat body).

Scientific and place-based irrigation solution using locally produced materials, innovative paddy-cum-fish aquaculture, community participation in collective farming, and maintaining
agro-biodiversity through regular usage of indigenous landraces have potentially distinguished the Apatani tribes in the context of agro-biodiversity regime on mountainous landscape.

3.1.2 Lahaula (Western Himalaya). The Lahaul tribe has maintained a considerable agro-biodiversity and livestock altogether characterizing high level of germ plasm conservation [49]. Lahaulas living in the cold desert region of Lahaul valley are facultative farmers as they able to cultivate only for 6 months (June to November) as the region remained ice covered during the other 6 months of the year. Despite of the extreme weather conditions, Lahaulas are able to maintain high level of agro-biodiversity through ice-water harvesting, combinatorial cultivation of traditional and cash crops, and mixed agriculture–livestock practices. Indigenous practices for efficient use of water resources in such cold arid environment with steep slopes are distinctive. Earthen channels (Nullah or Kuhi) for tapping melting snow water are used for irrigation. Channel length run anywhere from a few meters to more than 5 km. Ridges and furrows transverse to the slope retard water flow and soil loss [50]. Leaching of soil nutrients due to the heavy snow cover gradually turns the fertile soil into unproductive one [51]. The requirement of high quantity organic manure is met through composting livestock manure, night soil, kitchen waste, and forest leaf litter in a specially designed community composting room. On the advent of summer, compost materials are taken into the field for improving the soil quality.

Domesticated Yaks (Bos grunniens) is crossed with local cows to produce cold tolerant offspring of several intermediate species like Gari, Laru, Bree, and Gee for drought power and sources of protein. Nitrogen fixing trees like Seabuckthrone (Hippophae rhamnoides) are also cultivated along with the crops to meet the fuels and fodder requires for the long winter period. Crop rotation is a common practice among the Lahaulas. Domesticated wild crop, local variety, and cash crops are rotated to ensure the soil fertility and maintaining the agro-biodiversity. Herbs and indigenous medicinal plants are cultivated simultaneously with food crops and cash crop to maximize the farm output. A combinatorial agro-forestry and agro-livestock approach of the Lahaulas have successfully able to generate sufficient revenue and food to sustain 6 months of snow-covered winter in the lap of western Himalayan high-altitude landscape. This also helps to maintain the local agro-biodiversity of the immensely important ecoregion.

3.1.3 Dongria Kondh (Eastern Ghat). Dongria Kondh tribes, living at the semiarid hilly range of Eastern Ghats, have been applying sustainable agro-forestry techniques and a unique mixed crop system for several centuries since their establishment in the tropical dry deciduous hilly forest ecoregion. The forest is a source for 18 different non-timber forest products like mushroom, bamboo, fruits, vegetables, seeds, leaf, grass, and medicinal products. The Kondh people sustainably uses the forest natural capital such a way that maintain the natural stock and simultaneously ensure the constant flow of products. Around 70% of the resources have been consumed by the tribes, whereas 30% of the resources are being sold to generate revenue for further economic and agro-forest sustainability [52]. The tribe faces moderate to acute food grain crisis during the post-sowing monsoon period and they completely rely upon different alternative food products from the forest. The system has been running flawlessly until recent time due to the aggressive mining activity, natural resources depleted significantly, and the food security have been compromised [53].

However, the Kondh farmer have developed a very interesting agrarian technique where they simultaneously grow 80 varieties of different crops ranging from paddy, millet, leaves, pulses, tubers, vegetables, sorghum, legumes, maize, oil-seeds, etc. [54]. In order to grow so many crops in 1 dongor (the traditional farm lands of Dongria Kondhs on lower hill slopes), the sowing period and harvesting period extends up to 5 months from April till the end of August and from October to February basing upon climatic suitability, respectively.
Genomic profiling of millets like finger millet, pearl millet, and sorghum suggest that they are climate-smart grain crops ideal for environments prone to drought and extreme heat [55]. Even the traditional upland paddy varieties they use are less water consuming, so are resilient to drought-like conditions, and are harvested between 60 and 90 days of sowing. As a result, the possibility of complete failure of a staple food crop like millets and upland paddy grown in a dongor is very low even in drought-like conditions [56].

The entire agricultural method is extremely organic in nature and devoid of any chemical pesticide, which reduces the cost of farming and at the same time help to maintain environmental sustainability [57].

3.1.4 Irular tribes (Western Ghat). Irulas or Irular tribes, inhabiting at the Palamalai mountainous region of Western Ghats and also Nilgiri hills are practicing 3 crucial age-old traditional agricultural techniques, i.e., indigenous pest management, traditional seed and food storage methods, and age-old experiences and thumb rules on weather prediction. Similar to the Kondh tribes, Irular tribes also practice mixed agriculture. Due to the high humidity in the region, the tribes have developed and rigorously practices storage distinct methods for crops, vegetables, and seeds. Eleven different techniques for preserving seeds and crops by the Irular tribes are recorded till now. They store pepper seeds by sun drying for 2 to 3 days and then store in the gunny bags over the platform made of bamboo sticks to avoid termite attack. Paddy grains are stored with locally grown aromatic herbs (*Vitex negundo* and *Pongamia pin-nata*) leaves in a small mud-house. Millets are buried under the soil (painted with cow dung slurry) and can be stored up to 1 year. Their storage structure specially designed to allow aeration protect insect and rodent infestation [58]. Traditional knowledge of cross-breeding and selection helps the Irular enhancing the genetic potential of the crops and maintaining indigenous lines of drought resistant, pest tolerant, disease resistant sorghum, millet, and ragi [59,60].

Irular tribes are also good observer of nature and pass the traditional knowledge of weather phenomenon linked with biological activity or atmospheric condition. Irular use the behavioral fluctuation of dragonfly, termites, ants, and sheep to predict the possibility of rainfall. Atmospheric phenomenon like ring around the moon, rainbow in the evening, and morning cloudiness are considered as positive indicator of rainfall, whereas dense fog is considered as negative indicator. The Irular tribes also possess and practice traditional knowledge on climate, weather, forecasting, and rainfall prediction [58]. The Irular tribes also gained extensive knowledge in pest management as 16 different plant-based pesticides have been documented that are all completely biological in nature. The mode of actions of these indigenous pesticides includes anti-repellent, anti-feedent, stomach poison, growth inhibitor, and contact poisoning. All of these pesticides are prepared from common Indian plants extract like neem, chili, tobacco, babul, etc.

The weather prediction thumb rules are not being validated with real measurement till now but understanding of the effect of forecasting in regional weather and climate pattern in agricultural practices along with biological pest control practices and seed conservation have made Irular tribe unique in the context of global agro-biodiversity conservation.

3.2 Climate change risk in indigenous agricultural landscape

The effect of climate change over the argo-ecological landscape of Lahaul valley indicates high temperature stress as increment of number of warm days, 0.16 °C average temperature and 1.1 to 2.5 °C maximum temperature are observed in last decades [61,62]. Decreasing trend of rainfall during monsoon and increasing trend of consecutive dry days in last several decades strongly suggest future water stress in the abovementioned region over western Himalaya.
Studies on the western Himalayan region suggest presence of climate anomaly like retraction of glaciers, decreasing number of snowfall days, increasing incident of pest attack, and extreme events on western Himalayan region [63–65].

Apatani tribes in eastern Himalayan landscape are also experiencing warmer weather with 0.2°C increment in maximum and minimum temperature [66]. Although no significant trend in rainfall amount has been observed, however 11% decrease in rainy day and 5% to 15% decrease in rainfall amount by 2030 was speculated using regional climate model [67]. Increasing frequency of extreme weather events like flashfloods, cloudburst, landslide, etc. and pathogen attack in agricultural field will affect the sustainable agro-forest landscape of Apatani tribes. Similar to the Apatani and Lahaulas tribes, Irular and Dongria Kondh tribes are also facing climate change effect via increase in maximum and minimum temperature and decrease in rainfall and increasing possibility of extreme weather event [68,69]. In addition, the increasing number of forest fire events in the region is also an emerging problem due to the dryer climate [70].

Higher atmospheric and soil temperature in the crop growing season have direct impact on plant physiological processes and therefore has a declining effect on crop productivity, seedling mortality, and pollen viability [71]. Anomaly in precipitation amount and pattern also affect crop development by reducing plant growth [72]. Extreme events like drought and flood could alter soil fertility, reduce water holding capacity, increase nutrient run off, and negatively impact seed and crop production [73]. Agricultural pest attack increases at higher temperature as it elevates their food consumption capability and reproduction rate [74].

3.3 Climate resiliency through indigenous agro-forestry

Three major climate-resilient and environmentally friendly approaches in all 4 tribes can broadly classified as (i) organic farming; (ii) soil and water conservation and community farming; and (iii) maintain local agro-biodiversity. The practices under these 3 regimes have been listed in Table 1.

Human and animal excreta, plant residue, ashes, decomposed straw, husk, and other by-products are used to make organic fertilizer and compost material that helps to maintain soil fertility in the extreme orographic landscape with high run-off. Community farming begins with division of labour and have produced different highly specialized skilled individual expert in different farming techniques. It needs to be remembered that studied tribes live in an area with complex topological feature and far from advance technological/logistical support. Farming in such region is extremely labour intensive, and therefore, community farming has

<table>
<thead>
<tr>
<th>Types of practices</th>
<th>Apatani</th>
<th>Irular</th>
<th>Dongria</th>
<th>Lahaulas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Indigenous methods of farming practice</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>2. Conserving agro-biodiversity/wild crops</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>3. Mixed cropping/crop rotation</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>4. Agro-forestry</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>5. Compost application</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>6. Soil conservation and management</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>7. Integrated practices (with fish/livestock)</td>
<td>✓</td>
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<tr>
<td>8. Recycling of water</td>
<td>✓</td>
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<td>9. Biopesticides</td>
<td>✓</td>
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<td>10. Weather forecasting</td>
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<td>11. Heirloom seeds</td>
<td>✓</td>
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become essential for surviving. All 4 tribes have maintained their indigenous land races of different crops, cereal, vegetables, millets, oil-seeds, etc. that give rise to very high agro-biodiversity in all 4 regions. For example, Apatanis cultivate 106 species of plants with 16 landraces of indigenous rice and 4 landraces of indigenous millet [75]. Similarly, 24 different crops, vegetables, and medicinal plants are cultivated by the Lahaulas, and 50 different indigenous landraces are cultivated by Irular and Dongria Kondh tribes.

The combination of organic firming and high indigenous agro-biodiversity create a perfect opportunity for biological control of pests. Therefore, other than Irular tribe, all 3 tribes depend upon natural predator like birds and spiders, feeding on the indigenous crop, for predation of pests. Irular tribes developed multiple organic pest management methods from extract of different common Indian plants. Apatani and Lahaulas incorporate fish and livestock into their agricultural practices, respectively, to create a circular approach to maximize the utilization of waste material produced. At a complex topographic high-altitude landscape where nutrient run-off is very high, the practices of growing plants with animals also help to maintain soil fertility. Four major stresses due to the advancement of climate change have been identified in previous section, and climate change resiliency against these stresses has been graphically presented in Fig 2.

Retraction of the glaciers and direct physiological impact on the livestock due to the temperature stress have made the agricultural practices of the Lahaula’s vulnerable to climate change. However, Irular and Dongria Kondh tribes are resilient to the temperature stress due to their heat-resistant local agricultural landraces, and Apatanis will remain unaffected due to their temperate climate and vast forest cover. Dongria Kondh tribe will successfully tackle the water stress due to their low-water farming techniques and simultaneous cultivation of multiple crops that help to retain the soil moisture by reducing evaporation. Hundreds of perennial
streams of Nyamgiri hills are also sustainably maintained and utilised by the Dongria Kondhs along with the forests, which gives them enough subsistence in form of non-timber forest products (NTFPs). However, although Apatani and Lahuala tribe extensively reuse and recirculate water in their field but due to the higher water requirement of paddy-cum-fish and paddy-cum-livestock agriculture, resiliency would be little less compared to Dongria Kondh.

Presence of vast forest cover, very well-structured irrigation system, contour agriculture and layered agricultural field have provided resiliency to the Apatani’s from extreme events like flash flood, landslides, and cloud burst. Due to their seed protection practices and weather prediction abilities, Irular tribe also show resiliency to the extreme events. However, forest fire and flash flood risk in both Eastern Ghat and Western Ghat have been increased and vegetation has significantly decreased in recent past. High risk of flash flood, land slide, avalanches, and very low vegetation coverage have made the Lahaulas extremely vulnerable to extreme events. Robust pest control methods of Irular tribe and age-old practices of intercropping, mixed cropping, and sequence cropping of the Dongria Kondh tribe will resist pest attack in near future.

3.4 Reshaping policy

Temperature stress, water stress, alien pest attack, and increasing risk of extreme events are pointed out as the major risks in the above described 4 indigenous tribes. However, every tribe has shown their own climate resiliency in their traditional agrarian practices, and therefore, a technology transfers and knowledge sharing among the tribes would successfully help to achieve the climate resilient closure. The policy outcome may be summarizing as follows:

a. Designing, structuring and monitoring of infrastructural network of Apatani and Lahaul tribes (made by bamboo in case of Apatanis and Pine wood and stones in case of Lahaulas) for waster harvesting should be more rugged and durable to resilient against increasing risk of flash flood and cloud burst events.

b. Water recycling techniques like bunds, ridges, and furrow used by Apatani and Lahaul tribes could be adopted by Irular and Dongria Kondh tribes as Nilgiri and Koraput region will face extreme water stress in coming decades.

c. Simultaneous cultivation of multiple crops by the Dongria Kondh tribe could be acclimated by the other 3 tribes as this practice is not only drought resistance but also able to maximize the food security of the population.

d. Germplasm storage and organic pest management knowledge by the Irular tribes could be transferred to the other 3 tribes to tackle the post-extreme event situations and alien pest attack, respectively.

e. Overall, it is strongly recommended that the indigenous knowledge of agricultural practices needs to be conserved. Government and educational institutions need to focus on harvesting the traditional knowledge by the indigenous community.

3.5 Limitation

One of the major limitations of the study is lack of significant number of quantifiable literature/research articles about indigenous agricultural practices over Indian subcontinent. No direct study assessing risk of climate change among the targeted agroecological landscapes has been found to the best of our knowledge. Therefore, the current study integrates
socioeconomic status of indigenous agrarian sustainability and probable climate change risk in the present milieu of climate emergency of 21st century. Uncertainty in the current climate models and the spatiotemporal resolution of its output is also a minor limitation as the study theoretically correlate and proposed reshaped policy by using the current and future modeled agro-meteorological parameters.

4. Conclusions
In the present study, an in-depth analysis of CSA practices among the 4 indigenous tribes spanning across different agro-biodiversity hotspots over India was done, and it was observed that every indigenous community is more or less resilient to the adverse effect of climate change on agriculture. Thousands years of traditional knowledge has helped to develop a unique resistance against climate change among the tribes. However, the practices are not well explored through the eyes of modern scientific perspective, and therefore, might goes extinct through the course of time. A country-wide study on the existing indigenous CSA practices is extremely important to produce a database and implementation framework that will successfully help to resist the climate change effect on agrarian economy of tropical countries. Perhaps the most relevant aspect of the study is the realization that economically and socially backward farmers cope with and even prepare for climate change by minimizing crop failure through increased use of drought tolerant local varieties, water harvesting, mixed cropping, agro-forestry, soil conservation practices, and a series of other traditional techniques.

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