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Perception of climate change from the Himalayan 'cold desert' Ladakh, India

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ABSTRACT

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Climate change perception survey is a method designed to gain insights on people's perspectives of the changing climate and recognizing important factors, complexities, and limitations towards a climate-conscious conduct. Such surveys are particularly important in ecologically sensitive transitional climatic zones but logistically difficult terrains, where meteorological data is scarce and minor changes in climatic parameters can have unanticipated consequences for the local ecosystem. The current research is focused on one of such climate-sensitive areas, in the northwestern Himalaya. A binary question-based survey (interview) was conducted in the high-altitude, cold desert region – Ladakh, which covered all the five subdivisions of the union territory. According to the climate perception data, the majority of respondents are aware of climate change or global warming regardless of age, gender, and background. The exponential growth in tourist inflow over the last two decades (attributed to 'war tourism') equates with the increasing number of vehicles and is well perceived by the locals. Approximately 86 percent of respondents believe that humans have had a negative impact on the environment. They appear to be quite optimistic about curbing the effects of climate change, with approximately 91 percent willing to participate in mitigation efforts. The results of this study show an overall agreement between people's perceptions of climate change and the scientific evidence of these changes. These findings are eventually intended to serve as an important parameter in developing adaptation and mitigation strategies in this ecologically sensitive and vulnerable region.

Key-words—People's perception, War tourism, Climate warming, Mitigation, Ladakh Himalaya.

INTRODUCTION

THE impacts of climate change are globally observed however, the fragile 'edge of the range' environments (Bellwood, 2013) like the Himalayas are the most vulnerable to the ongoing global warming and climate change effects (Safari, 2012). This warming has been attributed to a progressive increase in the atmospheric concentration of greenhouse gases (anthropogenic factors) since the mid of the 20th Century (IPCC, 2014, Allen *et al.,* 2019-IPCC). The rapid climate change is expected to have a significant impact on the freshwater resources, biodiversity, ecosystems and human well-being in the Himalayas (Myers *et al.,* 2000; Chaudhary & Bawa, 2011; Khan *et al.,* 2021). The Himalayan region is crucial as it replenishes and maintains the water budget of the major rivers originating from the entire 'third pole area' and catering almost 20% of the world's population. Outside the Polar Regions, this high-altitude glaciated region holds the key for understanding several climate uncertainties amidst the concurrent planet-warming scenario. Ladakh is a part of sensitive and fragile higher Himalayan mountainous ecosystem. Explicit reports of significant warming trends in the Himalayan region (Hamid *et al.,* 2014) leading to glacier mass loss (Bolch *et al.,* 2012; Lama *et al.,* 2015), increase in glacier lakes (number as well as area) (Scherler *et al.,* 2011; Kumar *et al.,* 2020; Pandey *et al.,* 2020), unanticipated effects on the hydrological cycle (Immerzeel *et al.,* 2010; Yang *et al.,* 2011; Singh *et al.,* 2016) of important river

systems and the consequences on downstream populations (Vedwan & Rhodes, 2001; Chaudhary *et al.,* 2011) have been the major concerns for the scientific community. These changes are mostly attributed to the ongoing climate change, hence the existence and extent of climate change is a topic of great importance to climate scientists, local people as well as policy makers to make long term strategic decisions or mitigation policies (Weber, 2010). Hence it stands true that the climate change has emerged as a global challenge and poses differential vulnerability for different communities/sectors/ regions (IPCC, 2014; Fraser *et al.,* 2011).

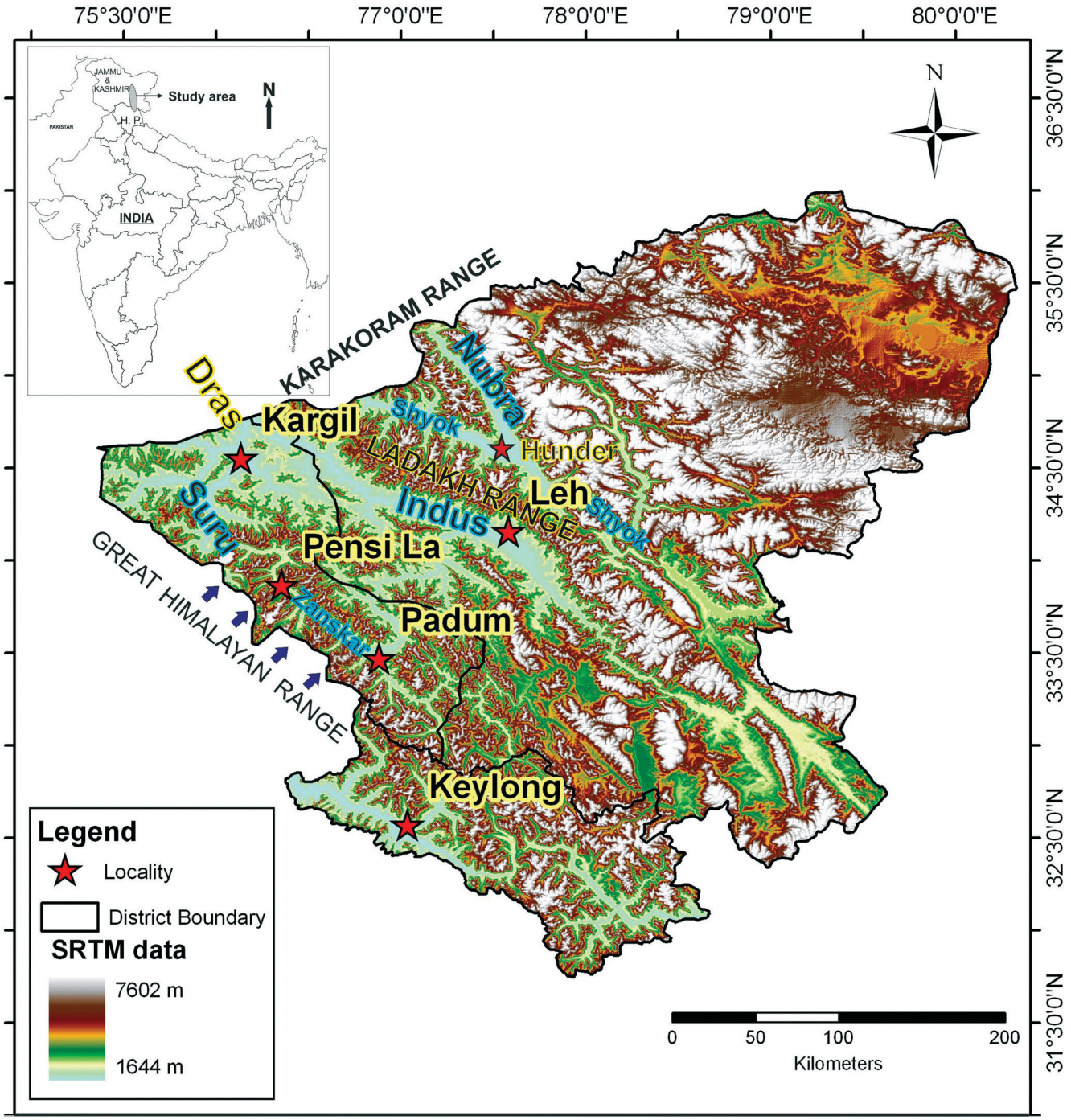

Fig. 1—Shuttle Radar Topography Mission (SRTM) digital elevation map of the Ladakh region showing the main river valleys (blue outlined text) surveyed during this study. Keylong (towards south) is the bordering locality between Himachal Pradesh and Ladakh.

The perception of climate change by the local people is one of the important pre-requisites to learn about their coping strategies to climate change by appropriate adaptive/mitigative measures (Makuvaro *et al.,* 2018; Hasan & Kumar, 2019). This perception affects the local populations dealing with climate-related risks and opportunities (Debela *et al.,* 2015; Arora *et al.,* 2021). Climate change perception of the local people not only helps in framing the climate policies but also serves a proxy, to know, whether, they are willing to change their behaviour, to lessen the adverse effects of the climate change (Niles & Mueller, 2016; Arora *et al.,*, 2021). Some scientists are of the opinion that the perception of local people on climate change will be insufficient, as it lacks rigorous scientific analyses, local awareness and vulnerabilities are suggested to be incorporated in multi-stakeholder assessments (IPCC, 2014). Climate science studies give more importance to climate models and climate impacts, adaptation and risk assessment, but relatively little attention is given to the local population's perceptions and options for adaptation, i.e. the main component of stakeholders experiencing and affected by climate change (Ayanlade *et al.,* 2017). Further, the perception of climate change by the local people is critically important to implement the appropriate adaptation measures and ensure the participation of the stakeholders (Hein *et al.,* 2019). Simultaneously, the data set should take into account the fact that people's perceptions of climate change are influenced by their ideological positions (such as climate denialism) and psychological conditions (Cook, 2019), and thus inferences drawn must be validated with additional climatic data.

Major climate change perception surveys from the Indian subcontinent especially the Himalayan states are limited and only eighteen such studies have been conducted from the vast region (Arora *et al.,* 2022). This may be attributed to the ecological diversity, vast geographical size, huge altitude ranges and complex topography, and harsh environments. There are studies that advocate for a link between the climate change and increasing numbers of natural disaster that are directly impacting society (Arora *et al.,* 2021). It has been reported that more than 218 million people were affected annually by natural disasters (Ara & Reazul, 2013; UNISDR; CRED, 2015), which is seven times more than those affected by conflicts (Poudel *et al.,* 2017). There is a growing concern about the effects of climate change in the Himalayan region, because the rate of increasing average temperature in this region is higher than the global average (Shreshtha *et al.,* 1999; Bhutiyani *et al.,* 2010; IPCC, 2014). The people living in the Himalayas are not only vulnerable to extreme climate events like glacial lake outburst flood, landslides, extreme rainfall events, but also to their food and drinking water security (FAO, 2008; Wang *et al.,* 2012a, b; Nagai *et al.,* 2016; Arora *et al.,* 2021). Studies show that five major flood events have occurred in the Indian part of Himalaya just in last ten years including Leh-Ladakh flood 2010 and Kedarnath flood 2013.

Ladakh is a union territory in the northwestern Indian Himalaya, sandwiched between the Tethyan and Higher Himalaya ranges in the south and the Karakoram ranges in the north. The region is known as a 'cold arid desert' because of its seasonal temperature extremes and difficult terrain, which includes a semi-arid to arid climate with little precipitation (Daultrey & Gergan, 2011; Ali *et al.,* 2018). In order to ensure the comprehensiveness of this study, we surveyed all the five sub-divisions of Ladakh, viz. Leh, Nubra, Kargil, Zanskar and Dras with a total population of around 0.29 million (2011 census). People that live in high mountains have been found to be more sensitive to climate change and, as a result, have already developed solutions to counteract climate change with little resources (Lal, 2014; Kamp *et al.,* 2011).

The growing tourism in mountain regions has a critical environmental impact (Geneletti & Dawa, 2009). Ladakh was opened for tourism in 1974 and presently the tourism industry forms an important socio-economic factor and is the major contributor to its GDP (Chatterjee *et al.,* 2005). As the number of the tourist increases, so does the problem like water pollution, vehicular pollution and traffic congestion. The ongoing warming trend in the Himalaya is exacerbating the snowmelt from already declining glacial mass and melt water that has hit the agriculture sector (Chopra *et al.,* 2018; Kumar, 2019). Hence there is a need for 'Community-based participatory methods' to understand the dissemination of climate change knowledge and people's perceptions. There is a growing concern of the policy makers and academia

Table 1—Questions that were asked and interviewed for the present study.

1.	Are you a resident of Ladakh?	2.	Are you a member of any environmental organizations?
3.	Have you heard about "climate change"?	4.	From which source you have heard about climate change?
5.	Do you feel that the pattern of weather is changing in last few years?	6.	Do you have any idea that climate is changing compared to earlier times past?
7.	Have you experienced any change in the summer temperature of your region over the past 15-20 years?	8.	Is there any change in the winter temperature of your region over the past 15-20 years?

9.	Is there any change in the rainfall pattern of your region over the past 15-20 years?	10.	Is there any change in the snowfall pattern of your region over the past 15-20 years?
11.	Is annual snowfall decreasing over the past 15-20 years?	12.	Is the rainfall increasing over the past 15-20 years?
13.	Do you think that climate change will cause natural disasters?	14.	Do you think that damages caused by snow storms, heat, and heavy rains or flooding will increase?
15.	Have you experienced rains during summers before 10-15 years?	16.	Do you think that recent cloud burst resulting into flood is linked to climate change?
17.	Do you think that the affects of climate change are going to be catastrophic?	18.	Have you noticed any seasonality changes in cultivation pattern over the years?
19.	In your village, have you noticed any change in food habits of people?	20.	Is agriculture productivity increased in last 20 years?
21.	Is there enough drinking water available during summers in your region?	22.	Based on the experience can you suggest that air pollution has affected you, your family or friend's health?
23.	Is air pollution increasing in your region?	24.	Do you believe that the affects of climate change can be mitigated?
25.	Do you believe that human contribution in global temperature increase is significant?	26.	Do you think that humans are abusing the resources of planet earth?
27.	Is there any link between energy consumption pattern and climate change?	28.	Do you believe that if people limit energy consumption then it will minimize the adverse effects of climate change?
29.	Do you believe that it is already too late to meet challenges of climate change?	30.	In your opinion, is biodiversity decreasing with increasing global warming?
31.	Do you think that the rate of global warming can be controlled or reversed?	32.	Are you afraid of the possible consequences of climate change?
33.	Do you think that adverse impact of climate change can be addressed by applying science & technology?	34.	Do you believe that human contribution in climate change is substantial?
35.	Is it possible to limit ill effects of climate change?	36.	Do you think that climate change can bring some positive change in our life?
37.	Would you like to help in some way or the other for this cause?	38.	Do you think awareness of this serious issue is important?
39.	Will you help in spreading the word of the consequences of climate change to your friend, family and village/society?	40.	Do you think the tourist coming to Ladakh is a boon (yes) or bane (no)?
41.	Should there be a number as to how many tourists should be allowed into the valley in summer season?	42.	Do you expect any help in this regard from the government?
43.	Are the private agencies helping the locals to sort out the problems related to changing weather conditions?	44.	Does the government have some schemes to combat climate change issue?
45.	Any incident you want us to know to access the severity of climate change that you or your near ones have experienced?	46.	Any mishap in the past 15-20 years in your village due to climate change?
47.	Would you think over this problem after this questionnaire is complete?	48.	Do you think this is a good exercise?
49.	Will you educate your children and family members about this issue?	50.	Any other thing that you think, we should know in this issue?

towards the climate change and its long term impact on the communities and their habitat. Hence the present research explores- (1) the nexus of ongoing climate change, (2) cultural-socio-economic change, and (3) people perceptions on this subject, that may significantly influence the vulnerability and resilience of communities living in this fragile 'edge of the range' ecosystem.

MATERIALS AND METHODS

The research was conducted in Ladakh, India's northwestern union territory. Set among the rugged peaks of the western Himalaya, the location is known for its severe mountainous environment, which has resulted in a distinctive natural beauty (Norberg-Hodge, 1991). It was a part of the Jammu and Kashmir state till 2019 and presently is the '9th Union Territory' (31st October 2019) of India. It has five subdivisions, namely Leh, Kargil, Nubra, Zanskar and Dras (Fig. 1). A survey was conducted in all these subdivisions to examine the perception of climate change among the natives and assessing the consistency of perception with meteorological and associated data. In view of providing a comprehensive record, we have conceptualized a questionnaire (50 questions) after intensive literature reviews and discussions (Table 1). The questions were specifically designed to understand the climate change and its impacts on the high mountain societies and ecosystems. To minimize any complexities, answers were required in "yes" or "no" (dichotomous; Adiyoga, 2018). Working with a dichotomous or binary scale made the interview easier and quicker for respondents, increased the number of respondents and reduced respondent fatigue; without compromising the quality of the data (Dolnicar *et al.,* 2011). Responses to the questions were obtained from direct interviews and a random sampling strategy (encounter and willingness based) was used for selection of the respondents (Arora *et al.,* 2022). Nevertheless, during the sampling we did try to be as inclusive as possible in terms of gender and age groups. Although the majority of the population in these places speak Hindi, some elderly individuals solely spoke their native tongue (Ladakhi language). Hence for language interpretation, in such cases, we enlisted a local field guide and several local acquaintances.

In total, 150 people were interviewed that include 37 interviewees from Indus Valley (Leh region), 36 from Nubra-Shyok Valley (Northern Ladakh), 47 from Suru Valley (Kargil), 18 from Zanskar Valley (Padum) and 9 from Dras Valley during August 2017. Three individuals who were working in Ladakh for over 15 years were also included in this survey. The respondents, including 98 males and 52 females, were categorized on the basis of their age into Young (Y; < 20 years), Adult (A; 20-40 years), Mature (M; 40-60 years) and Old (O; > 60 years) (Table S1). The acquired climate perception data has been subjected to cross validation with the meteorological data. Owing to the scarcity of instrumental meteorological data in the Himalayas (Shrestha *et al.,* 1999; Dimri & Dash, 2012), we have relied upon the gridded time series data of Climate Research Unit, CRU-TS 4.03 (Harris, 2019; to support the perception data) that has shown significant correlation with the instrumental data in Himalaya (Singh *et al.,* 2019). Besides this, the data obtained through the interviews have been checked for internal consistency. All the analyses were done in *Performance Analytics* (R-Package, Peterson & Carl, 2019) and R (R Core Team, 2019).

RESULTS

The questions on climate change perception have been grouped and classified into ten categories (Table 2). The consistencies in the responses within these categories were tested by linear correlation and corresponding p-values. It has been observed that the responses were consistent, indicating their reliability. Correlation among categories and their correlation coefficients are shown in Fig. 2. Further, we have categorized the respondents based on gender (gM – gender

Table 2—Ten categories based on the similarity of questions.

Category No.	Question Number	Description
1	Qn. No. 5-8	Weather & temperature
2	Qn. No. 9-12	Rainfall & snowfall
3	Qn. No. 13-17	Possible causes
4	Qn. No. 18-20	Consequences
5	Qn. No. 21-23	Pollution
6	Qn. No. 24-28	Mitigation efforts
7	Qn. No. 24, 29, 31, 33, 35, 38	Action
8	Qn. No. 37, 39, 47, 49	Action – their involvement
9	Qn. No. 42-44	Govt/Pvt actions
10	Qn. No. 40, 41	Tourists

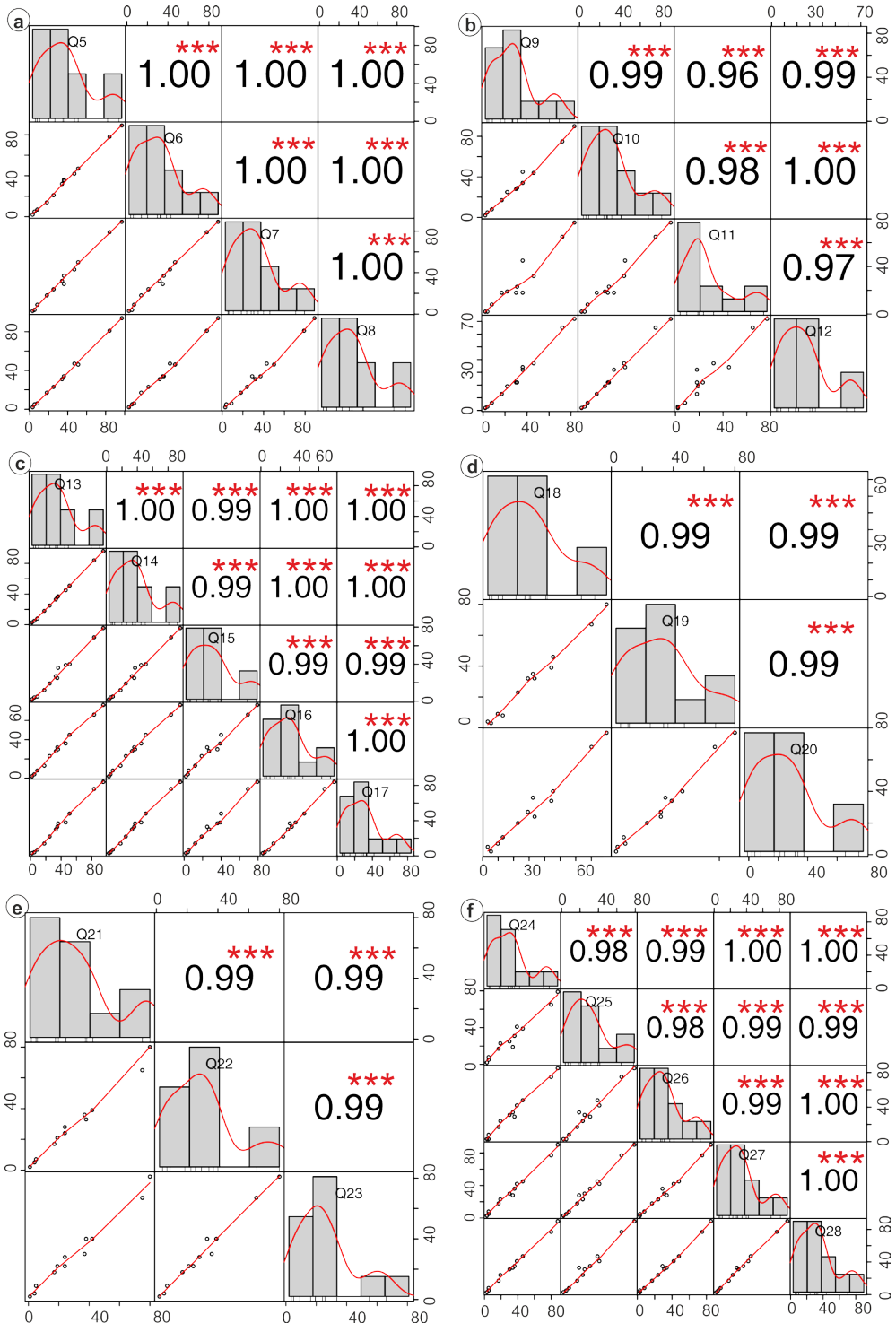

Fig. 2a-f—Correlation diagram of the responses to the ten categories provided in Table 2 (i.e. (2a) related to weather & temperature – Qn. No. 5-8; (2b) Rainfall & snowfall – Qn. No. 9-12; (2c) Possible causes – Qn. No. 13-17; (2d) Consequences – Qn. No. 18-20; (2e) Pollution – Qn. No. 21-23; (2f) Mitigation efforts – Qn. No. 24-28.

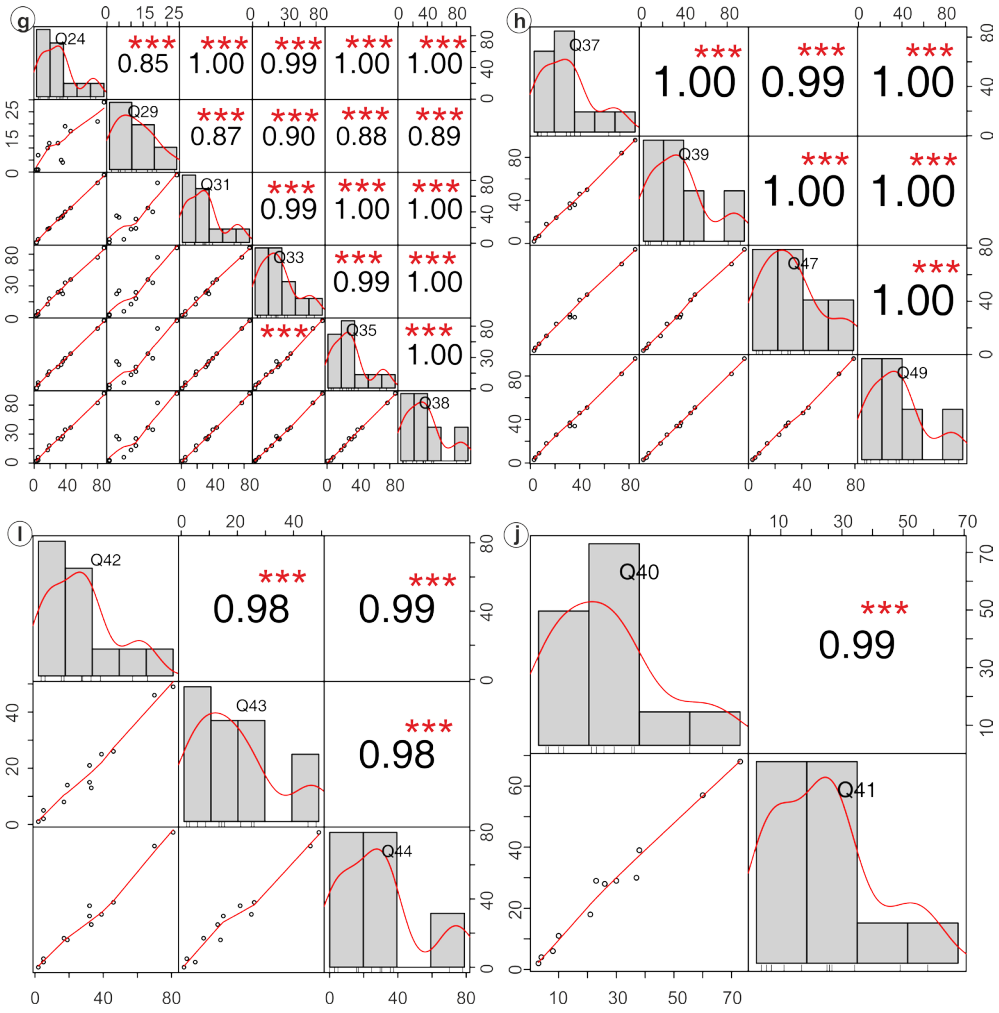

Fig. 2g-j—Correlation diagram of the responses to the ten categories provided in Table 2 (i.e. (2g) Action – Qn. No. 24, 29, 31, 35, 38; (2h) Action – their involvement – Qn. No. 9-12; (2i) Govt./Pvt. actions – Qn. No. 42-44; and (2j) Tourists – Qn. No. 40-41). Correlation coefficients (in numbers) and p-values (stars superscripted every correlation coefficients). Three stars indicate most significant correlation (p-value < 0.001) followed two stars (< 0.01) and one star (< 0.1).

male and gF – gender female), age (aY – age young, aA – age adult, aM – age mature and aO – age old) and the region they belonged to (rI – region Indus, rN – region Nubra-Shyok, rS – region Suru, rZ – region Zanskar, rD – region Dras and rNL – region non-local), and hence there are 12 categories. The regions are shown in Fig. 1 and all the responses are graphically shown in Fig. S1.

Gender, age and location-based correlations for 'yes' and their coherence are shown in Fig. 3. The responses from male and female populations are observed to be coherent (r = 0.95), and a similar coherency is observed among different age groups (adult = 0.86, middle = 0.87 and old = 0.54) as well. Although the correlation coefficient between young and old is low (0.54), considering the lower number of old respondents this number is significant (p-value < 0.001). In the locality-based consistency test, except for the Dras (r = 0.30), respondents from other regions (Nubra-Shyok = 0.74, Suru = 0.62, Zanskar = 0.52) provided consistent replies similar to those of Indus (Leh), the capital city of Ladakh.

The data has revealed that irrespective of the gender, age and locality, majority (> 85%) of the respondents are aware of climate change (Qn. 3; Fig. S1). Precipitation and temperature are the two main meteorological parameters that have a direct impact on people's lives and thus can be easily perceived. The perception of local people about the temperature (Qn. 7) and rainfall (Qns. 9, 12 and 15) are in agreement with

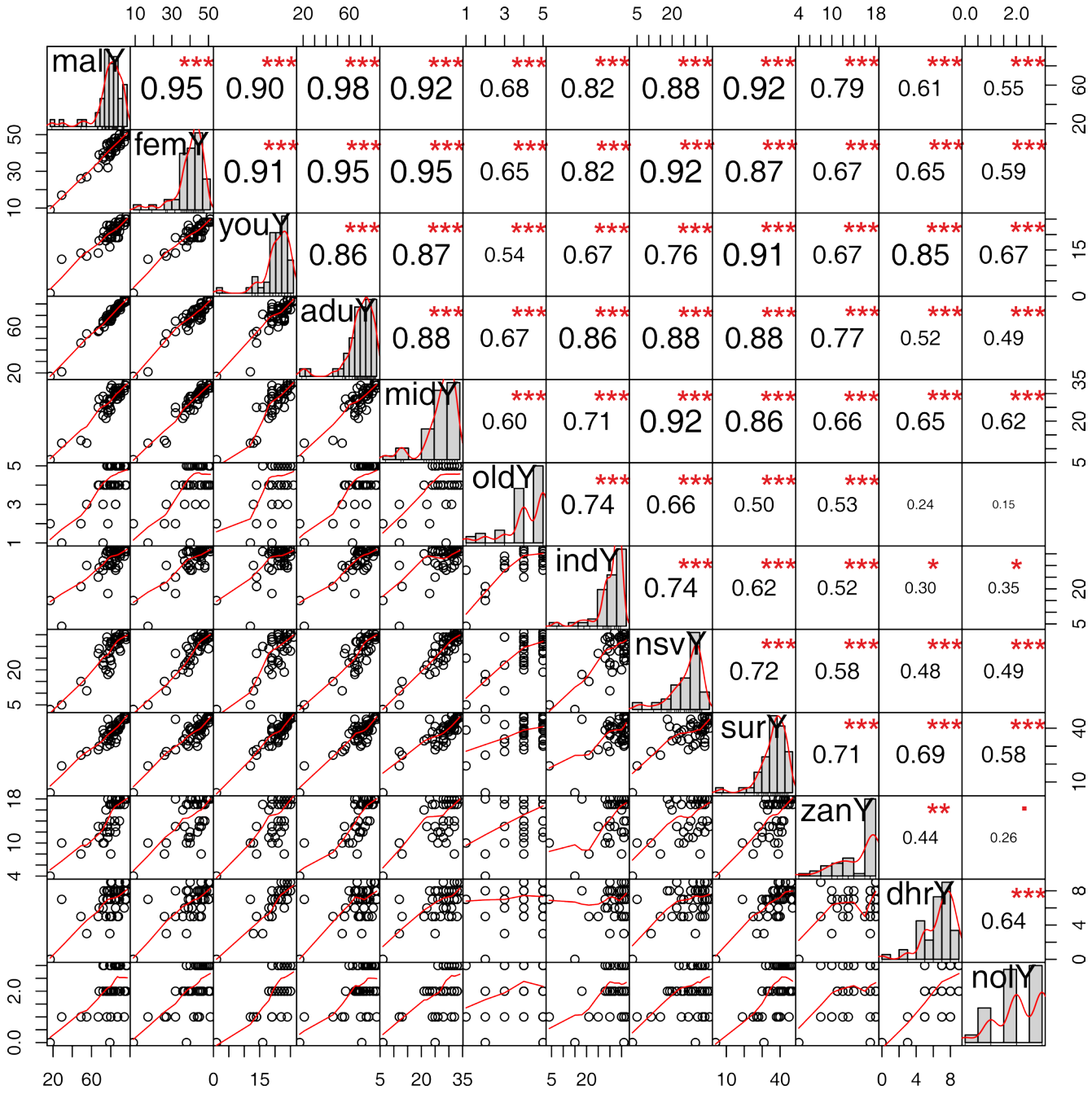

Fig. 3—Correlations among the responses (yes only) from each category that is mentioned along the diagonal. Numbers and stars are the correlation coefficients and p-values (please see Fig. 2 caption) respectively.

meteorological data (Climate Research Unit, CRU-TS 4.03). It has been observed that the Mean Annual Precipitation (MAP, mm) and Mean Annual Temperature (MAT, ºC) (from 1947-2018 CE) of Dras, Padam, Leh, Kargil and Nubra regions are showing a progressive increasing trend and has a significant correlation with the perception data (Fig. 4). While the rate of increase in the MAP between pre- and post-1998 CE (0.4 mm/year and 1.2 mm/year) is small, the pre-1998 CE MAT was markedly different than that of post-1998 CE. The rate of change in MAT (pre and post 1998 CE) is observed to be -0.005 ºC/year and 0.013 ºC/year with the average values of–0.1 ºC and 0.7 ºC respectively. Thus the climate change is significantly perceived and this accuracy of the local peoples' perception is critically important for planning and implementation of appropriate adaptation measures (Hein *et al.,* 2019). A significant increase in temperature is observed in

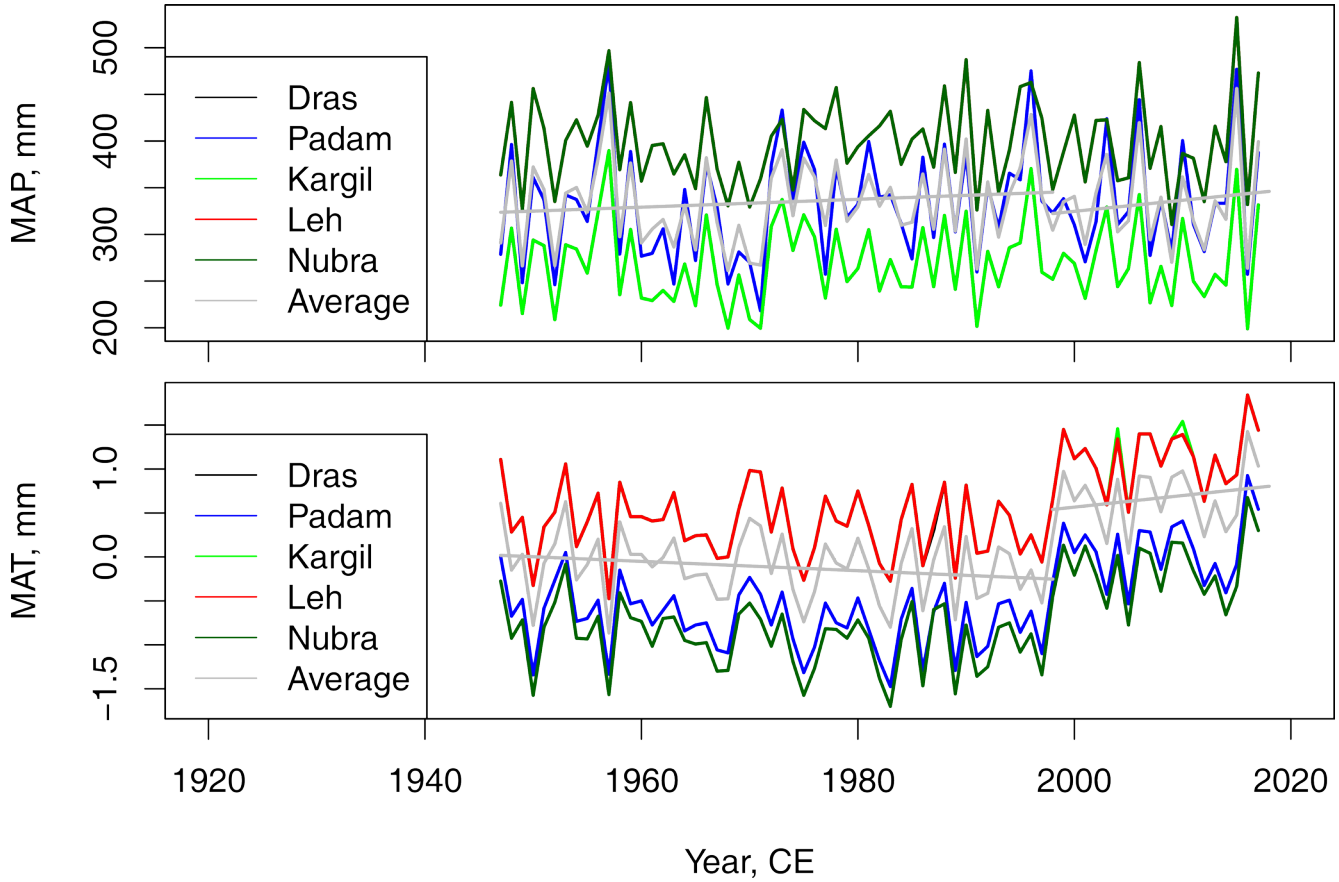

Fig. 4—Mean Annual Precipitation (MAP, mm) and Mean Annual Temperature (MAT, ºC) from 5 regions in the Independent India, as extracted from CRU TS 4.03 (see the text for more details).

the post 1998 CE years, from all the locations. The following questions become inevitable, (1) what could be the cause of that?, (2) was it natural or anthropogenic?, (3) could that be because of the progressively increasing number of tourists to that region?, (4) could that be because of an increasing number of motor vehicles in that region?, (5) Or could that be linked with the new economic policy that was implemented in India from 1991? The possible answers to these questions are discussed in the discussion section.

Regardless of gender, the majority of respondents believe that air pollution in the region has increased, with significant contributions from anthropogenic activities (Qn. 23, 25, 34). Almost all agreed to the point that the substantial climate change has been anthropogenic (67% is the lowest percentage of agreements and that is from Zanskar). Except for non-Ladakhi respondents, more than 54% have witnessed the adverse effects of climate change on their loved ones, as well as mishaps in their villages. However, many people believe and hope that it is still possible to overcome the challenges posed by climate change (Qn. 29). When it comes to the region's biodiversity, many people believe that biodiversity has decreased as a result of rising temperatures (Qn. 30). Almost all respondents are concerned about climate change's potential negative consequences (Qn. 32), believing that it will increase the frequency of natural disasters (Qn. 13), water scarcity (Qn. 21), and lower agricultural productivity (Qn. 20). Question 36 is particularly intriguing because it necessitates more thought before answering. Except for non-residents of Ladakh (20%), respondents from Dras (33%), and Nubra (31%), more than half of respondents from the rest of the region deny that climate change is having a positive impact. With the exception of the middle-aged (35%), all other age groups have denied any positive outcome of climate change. Although a large number of respondents believe that increased tourism benefits their livelihoods, the majority of them advocate for more controlled tourism in this region (Qn. 40, 41). The data from tourists is in line with the rise in temperature (Fig. 5). Despite the fact that foreign visitors were allowed into Ladakh after 1974, the number of tourists increased significantly after the Kargil war, with a dip in 2002 that could be attributed to the renewed warlike situation in the region. Although motor vehicle data for Ladakh is unavailable for the past 15 years, data from the rest of Jammu and Kashmir corroborate with tourist and temperature data.

According to one data source for vehicle registration in Leh, 16,703 vehicles (both commercial and non-commercial) were registered between 2000 and 2016 (Chumikchan, 2016; Assistant Regional Transport Officer, Leh), indicating an increase in vehicles.

Most of the respondents expressed that this questionnaire based survey is a good exercise and almost all of them expressed their willingness to know more about climate change issues. Results are reliable and testable hypotheses can be devised (Fig. S1).

DISCUSSIONS

Perception of climate change in Ladakh

The impacts of climate change are more pronounced in ecologically fragile mountain areas like Himalaya, where the trends of temperature are more than the global averages (Shreshtha *et al.,* 1999; Bhutiyani *et al.,* 2010; Barua *et al.,* 2014; IPCC, 2014; Ghosh & Ghosal, 2021; Arora *et al.,* 2021). This rising trend of temperature is resulting into the shrinking of glaciers, increasing number of glacier lakes and changes in river discharge that have adverse consequences on

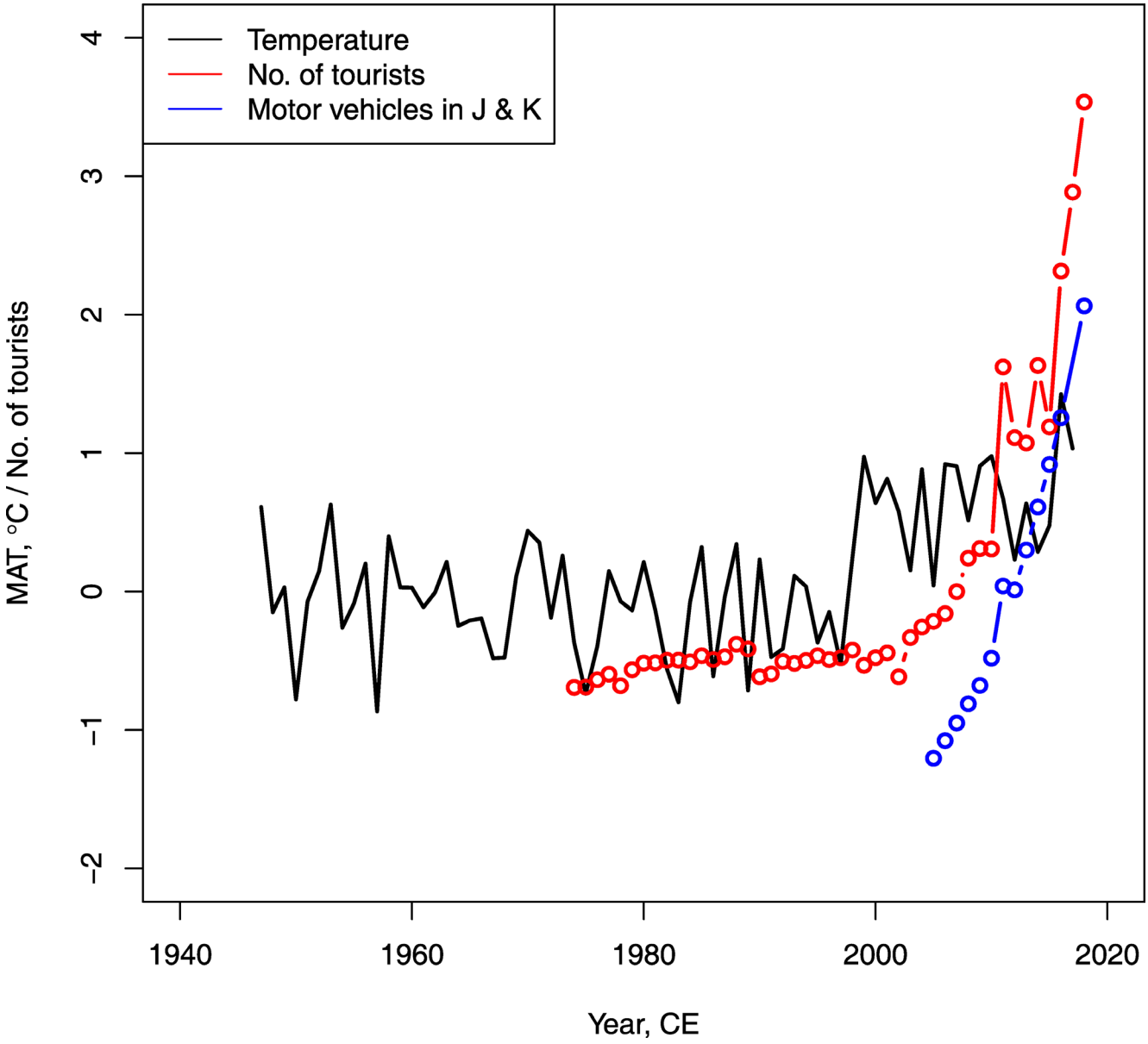

Fig. 5—Average (of 5 regions) Mean Annual Temperature (MAT, ºC) and its comparison with the number of tourists (red) and number of inferred vehicles (blue) in Ladakh, from the then State of Jammu & Kashmir.

downstream populations (Kumar *et al.,* 2020 and references therein). The majority (~80%) of the respondents in the survey claimed that they have heard about the climate change from social media and over 98% said that they have experienced the weather pattern is changing over the past few years. It is also evident from the survey that the conditions are becoming warmer over the past two decades (Fig. 5). The majority of the respondents considered drastic changes in overall weather patterns in recent years (more specifically the temperature) which are in conformity with other studies in the Himalayan region (Negi *et al.,* 2017; Pandey *et al.,* 2018; Gupta *et al.,* 2019; Arora *et al.,* 2021). The findings are consistent with climate data, and they back up the findings of recent climate change studies around the world (Chen *et al.,* 2013; Bhatta *et al.,* 205; Hussain *et al.,* 2016; Gupta *et al.,* 2019). It has also been observed that even the most illiterate elders believe that climate change is occurring at an alarming rate. People were also concerned about temperature, rainfall and snowfall changes.

Temperature and precipitation trends

People's perception of temperature change was in line with fact. The majority of respondents have noticed a rising trend in temperature in both the summer and winter seasons. To validate this, we have used the CRU 4.03 TS data, since the satellite data analysis showed a significant correlation with station data (Singh *et al.,* 2019). It is observed that the perceptions are supported by the CRU temperature data that shows an increasing trend all over the five surveyed areas since 1974 and subsequently a significantly higher jump at around year 2000 (Fig. 5). The ongoing glacial retreat in the Himalayas is more worrisome because data (17 years) has shown a two-fold increase in the mean annual maximum temperature and the winter temperature is also rising (Shrestha *et al.,* 1999; Bhutiyani *et al.,* 2010). Although this increasing trend in the temperature is attributed to the increasing green house gases, like carbon dioxide, methane and nitrous oxide which lead to global warming (The Royal Society, 2014; Tomizuka, 2015), some respondents (Qn. no. 40, 41) also think that it is because of the many fold increase in tourism that has led to increased vehicular pollution and so on (Fig. 6, S1). As per our understanding, the respondents rank temperature as the most important climatic parameter that has shown a significant change (Qn. No. 8; Fig. S1). It is also important that not only the summer, but the long-term (1991 to 2015) winter temperature trends in the north-western Himalaya are also increasing (Negi *et al.,* 2018). These findings should concern the public since the rising trend is expected to accelerate glacier and permafrost melting and CO_2 and CH_4 out-gassing from thermokarst lakes, possibly disrupting the global carbon cycle (Rabatel *et al.,* 2013; Cole *et al.,* 1994; Pandey *et al.,* 2020).

Similarly, people in Ladakh seem to be consistent with their experience and response on precipitation change. The majority of the respondents have noticed a change in both rainfalls (Qn. No. 9; 86%) as well as snowfall (Qn. No. 10; 89%) patterns. As the NW Himalaya (Ladakh) is located at the boundary of Indian Summer Monsoon influence, hence it gets very less precipitation during the summer in the form of rainfall. However, the trend has changed over the years (Bhutiyani *et al.,* 2007, 2010) and respondents have experienced an increase in the summer rainfall (Qn. No. 15; 79%). The limited meteorological station data from the NW Himalaya also suggest an increase in pre-monsoon (March-May) precipitation during 1901–2003 (Guhathakurta & Rajeevan, 2008). The overall precipitation data of CRU 4.03 TS also show an increasing trend and is in agreement with the respondents (Fig. 4). However, the survey has suggested that the rainfall over the years has increased with a complimentary decrease in snowfall. This is coherent with fact that, (1) the mid-latitude governed winter snowfall has decreased over the years (Sharma *et al.,* 2012, 2014; Kour *et al.,* 2016) and, (2) a significantly decreasing winter precipitation between December and February in the region during the period 1975–2006 is also reported, amid lack of spatially coherent phases among stations (Dimri & Dash, 2012). Besides this, significant numbers (Qn. No. 12; 73%) of respondents feel that there is an increase in the intense rainfall events. These people's perceptions are in accordance with the recent scientific studies (Joshi & Kumar, 2006; Nandargi & Dhar, 2011; Sarkar, 2020). Dimri and Dash (2012) have also reported an increasing number of warm days and a decreasing number of cold days in the NW Himalaya. Hence the temperature data and the people's perceptions go together and people seem to think that their actions (increased vehicles) have these reactions.

Tourism Industry

Opened for tourists in 1974, the Ladakh region also known as little Tibet, attracted foreign as well as domestic tourists for its peaceful, happy and carefree mountain community, cultural highlights and an impressive high altitude desert landscapes (Dame & Nusser, 2008; Fig. 5). The tourism industry has evolved at its full pace since 1974 and the trend of tourist arrivals shows exponential growth (Fig. 5). With just 750 tourists in 1974 the number reached to 21,996 in 1998, suggesting a gradual increase in the tourist arrivals. From 1999 to 2002 the tourist influx decreased because of the war that happened in 1999 and the tense situation after that. There is an exponential increase in the tourist influx to Ladakh post Kargil war and hence it is attributed to 'war tourism'. War tourism is defined as travelling to active or former war zones (O'Rourke, 1988, Wikipedia). The tourist coming to Ladakh in 2003 was 28,393 and reached to 3, 27,366 in 2018. It is also reported that ~100% of the tourists both international and domestic

came by air or road. This exponential growth of the tourism industry is unprecedented and the region is suggested to facing plethora of environmental issues (Kumar, 2019), and the toll of which falls on the natives/locals (Goeury, 2010; Clouse *et al.,* 2017). The results of the survey had mixed views regarding the increasing number of tourists; some people are of the view that tourism has generated a lot of revenue and job opportunities while a significant number (26%) of respondents feel that these climatic changes are somehow related to the increased tourism industry. According to some natives, with tourism the number of vehicles has also increased and responsible for air pollution. Interestingly, when we plotted the tourist/vehicle data along with the temperature data, a highly positive correlation was observed. The data also show that there is a sudden increase in the number of tourists and the temperature also show an increasing trend after 2002. Although the exact reason for the prominent temperature increase after 2002 is yet to be understood properly, the higher level of vehicular pollution seems to be one of the important factors (Alam & Khan, 2020).

Possible causes and consequences

The considerable comprehensive effects on the local ecosystems are also well noted by the extant individuals of various communities from all the area of the Himalayan cold desert 'Ladakh'. Regarding the causes and consequences people seem to be in dilemma, some are of the view that the warmer temperature and increase in the tourism industry has revolutionized their life by giving more jobs and enhancing the GDP of this region, while others (26%) seem to have contradictory views. Due to the warming the glacier ice and the seasonal snow are melting faster and have led to water shortage in some parts. The most affected are the rural areas,

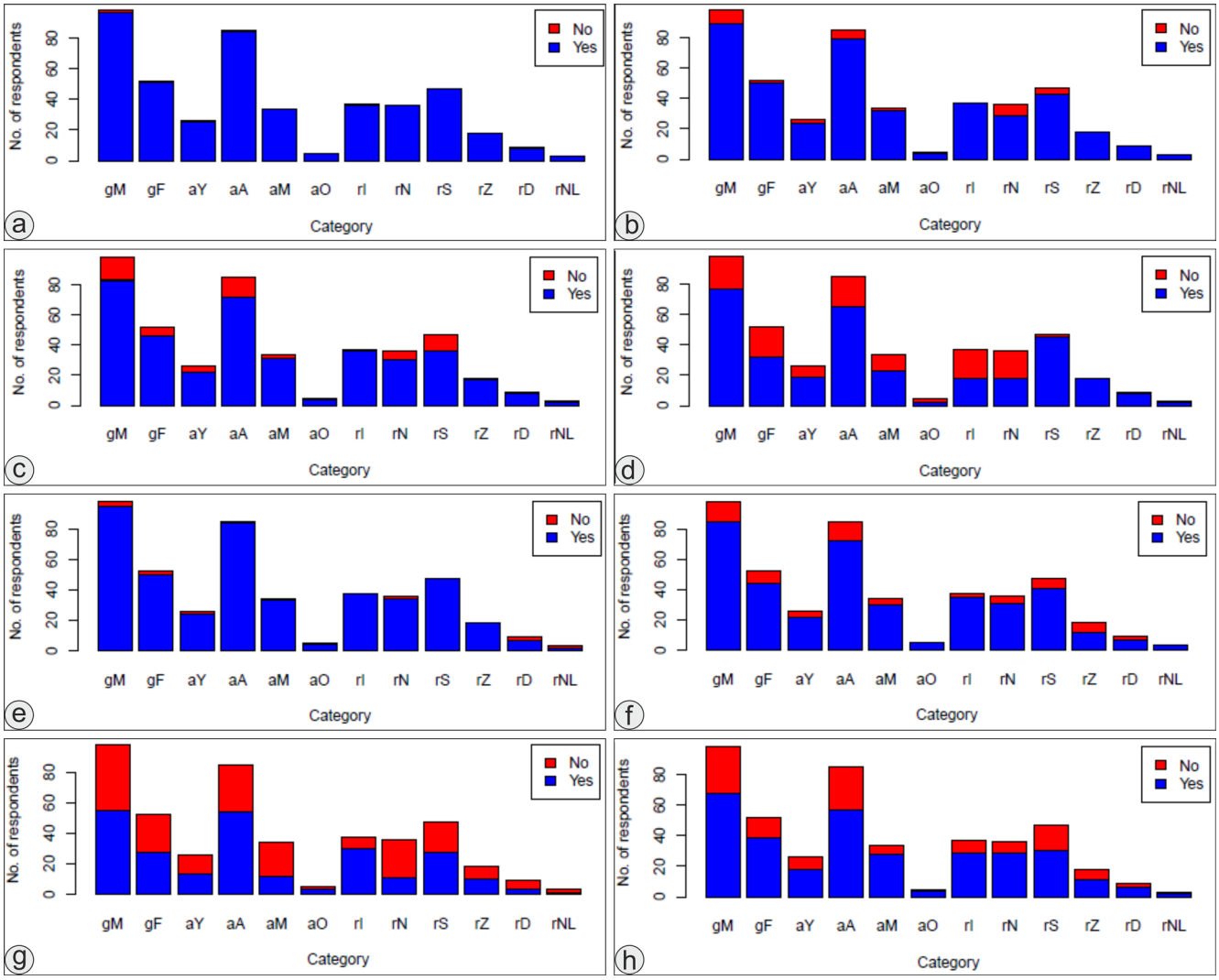

Fig. 6—Responses (Yes or No) to a few selected questions. (a) Qn. 5, (b) Qn. 7, (c) Qn. 9, (d) Qn. 11, (e) Qn. 32, (f) Qn. 34, (g) Qn. 36 and (h) Qn. 41.

where the basic source of livelihood is farming and grazing (Chopra *et al.,* 2018). The early snowmelt and decreasing glaciers have created drought-like situation in some parts and people prefer to engage in tourism-related jobs. This has not only resulted into a decline in agriculture and grazing animal activities, but people are migrating towards the urban areas. If this sort of migration persist, then a 'community collapse' in the rural areas seems inevitable. Recently, Kumar (2019) argued that the alarming number of tourists visiting Ladakh, has already challenged the carrying capacity of an already fragile ecosystem. He further argues that the lower oxygen levels leave the tourists to consume three times more water than the natives and is responsible for drinking water stress/ shortage and a hike in plastic pollution. The exponential growth in tourist arrivals during the past two decades as also increased the pollution and greenhouse gases at the microclimate level and exacerbating the snowmelt from an already shrinking glacier, leading to freshwater scarcity, and lack of water for irrigation (Chopra *et al.,* 2018; Kumar, 2019).

CONCLUSIONS

The present study reveal significant percentages of respondents have experienced the effects of ongoing climate change in Ladakh and are a matter of concern for the natives, researchers and the policy makers. Irrespective of age, gender their educational level, majority of the respondents perceive that climate is changing and the temperature is increasing (leading to glacier melting) with decreasing snowfall (less water in streams during summer) is their major concern. A significant number of individuals feel that the phenomenal increase in tourism and associated vehicular pollution is responsible for the temperature increase. Our data is also in agreement with their perception and shows a significant correlation between increasing temperature, tourist and motor vehicle number. The present data further indicate that the majority of respondents (> 95%) believe that this will lead to an increase in natural disasters. Additionally, the increasing pollution has an adverse effect on the health of the natives of the region.

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Table S1—Questions that were asked and interviewed for the present study.

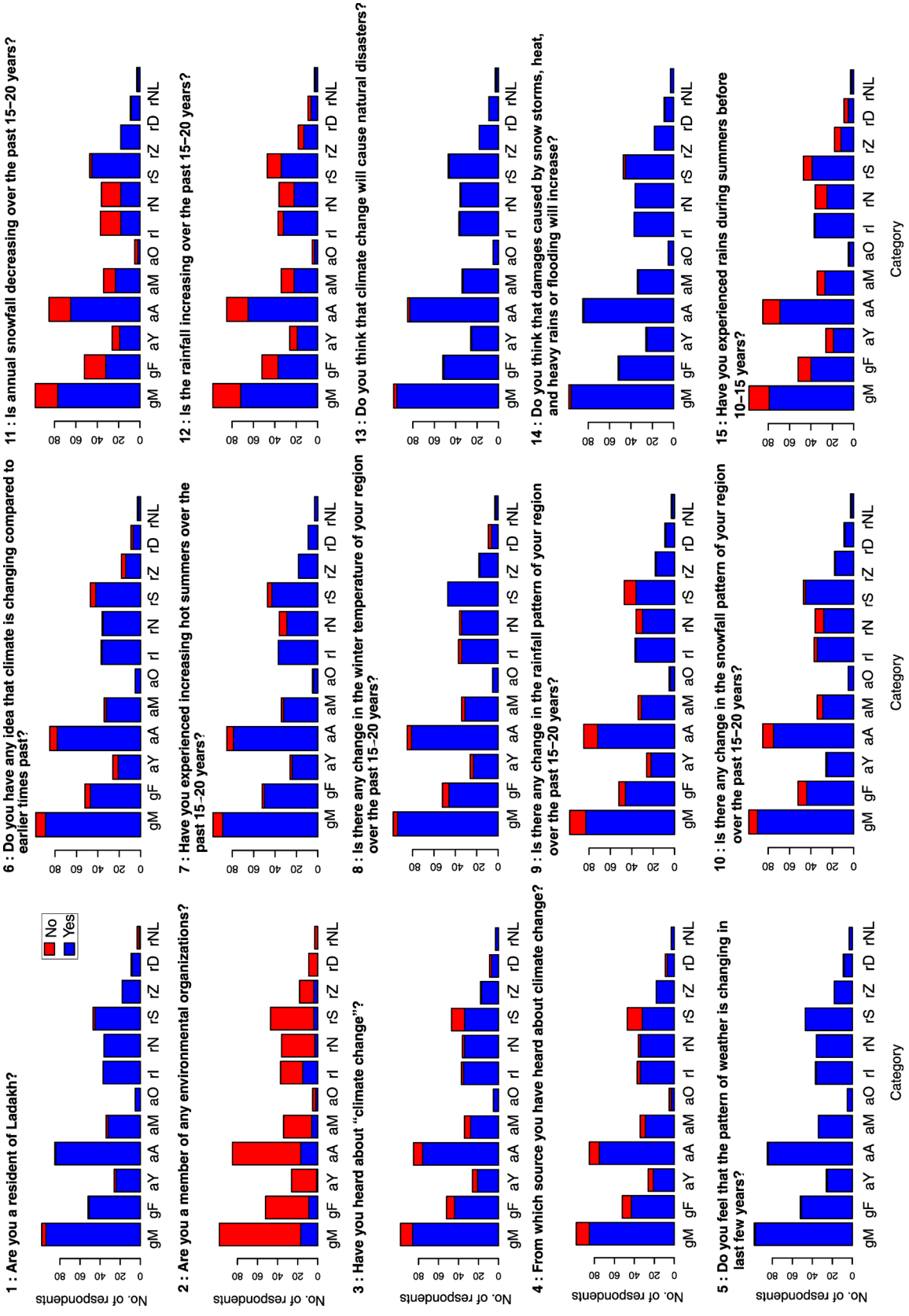
S.No.	Sex	Age category	Age (years)	Region	Locality	Date
1	M	A	20-40	Indus Valley	Leh	26-08-2017
2	F	A	20-40	Indus Valley	Choglamsar	28-08-2017
3	M	A	20-40	Indus Valley	Leh	28-08-2017
4	F	A	20-40	Indus Valley	Choglamsar	30-08-2017
5	F	A	20-40	Indus Valley	Leh	25-08-2017
6	M	A	20-40	Indus Valley	Leh	26-08-2017
7	M	A	20-40	Indus Valley	Stok Leh	25-08-2017
8	M	A	20-40	Indus Valley	Leh	26-08-2017
9	M	A	20-40	Indus Valley	Leh	26-08-2017
10	F	A	20-40	Indus Valley	Saspol	26-08-2017
11	F	Y	18	Indus Valley	Chichot	26-08-2017
12	M	A	20-40	Indus Valley	Leh	26-08-2017
13	M	A	20-40	Indus Valley	Leh	26-08-2017
14	M	A	20-40	Indus Valley	Leh Ladakh	24-08-2017
15	M	A	20-40	Indus Valley	Chengspa Zangsti (Leh)	12-08-2017
16	F	O	> 60	Indus Valley	Xansgsti (Leh)	12-08-2017
17	M	O	> 60	Indus Valley	Leh	13-08-2017
18	M	A	20-40	Indus Valley	Kocha, Ladakh	14-08-2017
19	F	A	20-40	Indus Valley	Tibetan Refugee Mkt	14-08-2017
20	M	A	20-40	Indus Valley	Leh	15-08-2017
21	M	A	20-40	Indus Valley	Leh	16-08-2017
22	F	A	20-40	Indus Valley	Mali Bridge	16-08-2017
23	M	M	40-60	Indus Valley	Mali Bridge	16-08-2017
24	F	A	20-40	Indus Valley	Mali Bridge	16-08-2017
25	F	A	20-40	Indus Valley	Leh	16-08-2017
26	M	M	40-60	Indus Valley	Hemiya	16-08-2017
27	F	M	40-60	Indus Valley	Hemiya	16-08-2017
28	M	A	20-40	Indus Valley	Leh	19-08-2017
29	M	M	40-60	Indus Valley	Leh	17-08-2017
30	M	M	40-60	Indus Valley	Leh	17-08-2017
31	M	A	20-40	Indus Valley	Leh	20-08-2017
32	F	M	40-60	Indus Valley	Leh	17-08-2017
33	F	Y	19	Indus Valley	Leh	28-08-2017
34	M	Y	< 20	Indus Valley	Leh	28-08-2017
35	F	M	40-60	Indus Valley	Leh	01-09-2017
36	M	Y	19	Indus Valley	Leh	30-08-2017
37	M	A	22	Indus Valley	Leh	31-08-2017
38	M	A	20-40	Nubra-Shyok Valley	Hunder Ladakh	25-08-2017
39	M	A	20-40	Nubra-Shyok Valley	Hunder Dock	25-08-2017

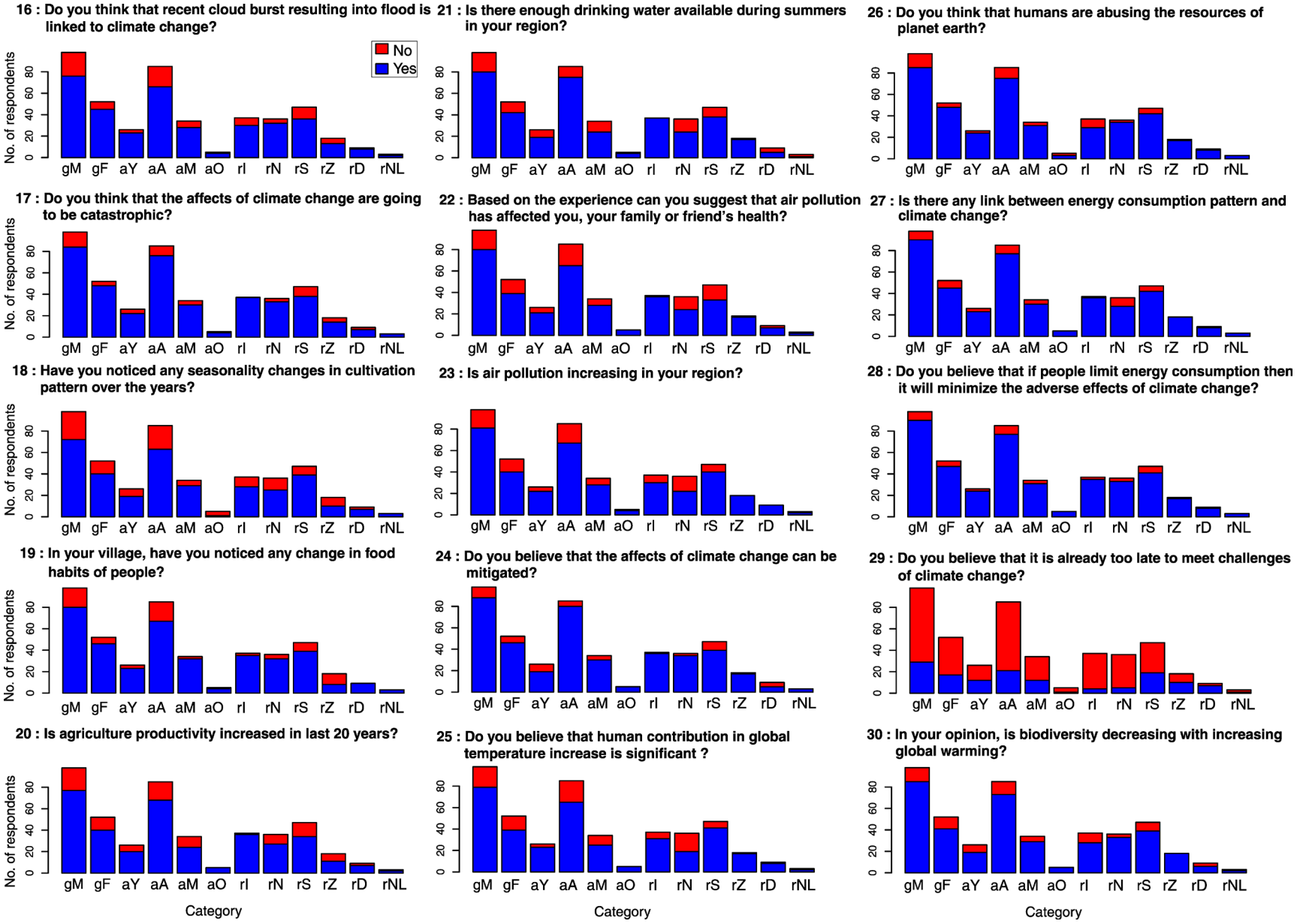
40	F	A	20-40	Nubra-Shyok Valley	Hunder Rubha	25-08-2017
41	M	M	40-60	Nubra-Shyok Valley	Hundar	25-08-2017
42	M	M	40-60	Nubra-Shyok Valley	Hunder	25-08-2017
43	F	A	20-40	Nubra-Shyok Valley	Hunder	25-08-2017
44	M	A	20-40	Nubra-Shyok Valley	Ladakh Hunder	24-08-2017
45	F	A	20-40	Nubra-Shyok Valley	Diskit	25-08-2017
46	F	A	20-40	Nubra-Shyok Valley	Hunder Hubba	24-08-2017
47	F	M	40-60	Nubra-Shyok Valley	Hunder	25-08-2017
48	F	Y	20-40	Nubra-Shyok Valley	Hunder Dock	24-08-2017
49	M	M	40-60	Nubra-Shyok Valley	Hunder	25-08-2017
50	F	A	20-40	Nubra-Shyok Valley	Hunder Hubba	24-08-2017
51	M	O	60-80	Nubra-Shyok Valley	Diskit	25-08-2017
52	M	A	20-40	Nubra-Shyok Valley	Hunder	24-08-2017
53	F	A	20-40	Nubra-Shyok Valley	Hunder Rubba	24-08-2017
54	M	A	20-40	Nubra-Shyok Valley	Skampuk	25-08-2017
55	F	A	20-40	Nubra-Shyok Valley	Hunder	25-08-2017
56	F	A	20-40	Nubra-Shyok Valley	Hunder	25-08-2017
57	F	A	20-40	Nubra-Shyok Valley	Hunder	25-08-2017
58	M	M	40-60	Nubra-Shyok Valley	Tunkic	25-08-2017
59	M	A	20-40	Nubra-Shyok Valley	Tuttuk (Shyok)	25-08-2017
60	M	A	20-40	Nubra-Shyok Valley	Tuttuk (Shyok)	25-08-2017
61	M	A	20-40	Nubra-Shyok Valley	Tuttuk (Shyok)	25-08-2017
62	F	A	20-40	Nubra-Shyok Valley	Diskit	25-08-2017
63	M	M	40	Nubra-Shyok Valley	Hundar	25-08-2017
64	F	Y	18	Nubra-Shyok Valley	Shyok	28-08-2017
65	F	Y	20	Nubra-Shyok Valley	Shyok	28-08-2017
66	F	M	57	Nubra-Shyok Valley	Shyok	28-08-2017
67	M	M	55	Nubra-Shyok Valley	Shyok	28-08-2017
68	F	Y	17	Nubra-Shyok Valley	Shyok	28-08-2017
69	F	M	48	Nubra-Shyok Valley	Shyok	28-08-2017
70	F	A	30	Nubra-Shyok Valley	Shyok	28-08-2017
71	M	A	26	Nubra-Shyok Valley	Shyok	28-08-2017
72	F	M	42	Nubra-Shyok Valley	Shyok	28-08-2017
73	F	A	26	Nubra-Shyok Valley	Shyok	28-08-2017
74	M	Y	20	Suru Valley	Skalzangling	28-08-2017
75	M	A	20-40	Suru Valley	Kargil	29-08-2017
76	F	A	21	Suru Valley	Stakmo	31-08-2017
77	M	Y	19	Suru Valley	Stok	31-08-2017
78	M	M	40-60	Suru Valley	Sankoo	23-08-2017
79	M	A	20-40	Suru Valley	Kargil	23-08-2017
80	M	A	20-40	Suru Valley	Kargil	23-08-2017
81	M	A	20-40	Suru Valley	Kargil	23-08-2017

82	M	A	20-40	Suru Valley	Kargil	23-08-2017
83	M	M	40-60	Suru Valley	Sankoo	26-08-2017
84	M	M	40-60	Suru Valley	Sankoo	21-08-2017
85	M	A	20-40	Suru Valley	G.M. Pere Kargil	22-08-2017
86	M	M	40-60	Suru Valley	Kargil	22-08-2017
87	M	M	40-60	Suru Valley	Sankoo	24-08-2017
88	M	A	20-40	Suru Valley	Sankoo	25-08-2017
89	M	A	20-40	Suru Valley	Kargil	28-08-2017
90	M	A	20-40	Suru Valley	Sankoo	26-08-2017
91	M	M	40-60	Suru Valley	Sankoo	24-08-2017
92	M	A	20-40	Suru Valley	Sankoo	25-08-2017
93	F	Y	< 20	Suru Valley	Badgm (Kargil)	24-08-2017
94	M	M	40-60	Suru Valley	Chechesna Sankoo	25-08-2017
95	M	A	20-40	Suru Valley	Sankoo	25-08-2017
96	M	M	40-60	Suru Valley	Sanker	23-08-2017
97	M	A	20-40	Suru Valley	Karpokhar	26-08-2017
98	M	A	20-40	Suru Valley	Duliber Sankoo	26-08-2017
99	M	Y	< 20	Suru Valley	Kargil (Latoo)	23-08-2017
100	M	A	20-40	Suru Valley	Hardass	23-08-2017
101	M	A	20-40	Suru Valley	Kargil	26-08-2017
102	M	A	20-40	Suru Valley	Kargil	26-08-2017
103	M	A	20-40	Suru Valley	Hardass	23-08-2017
104	F	A	20-40	Suru Valley	Kargil	23-08-2017
105	M	A	20-40	Suru Valley	Kargil	23-08-2017
106	F	Y	< 20	Suru Valley	Padum	23-08-2017
107	F	Y	20-40	Suru Valley	Padum	23-08-2017
108	F	A	20-40	Suru Valley	Gaslume	23-08-2017
109	F	Y	< 20	Suru Valley	Gaslume	23-08-2017
110	M	A	23	Suru Valley	Yasdass/Kargil	23-08-2017
111	M	A	20-40	Suru Valley	Kargil	23-08-2017
112	M	A	20-40	Suru Valley	Hardass Thang	23-08-2017
113	M	Y	< 20	Suru Valley	Kargil-Hardass	23-08-2017
114	M	A	20-40	Suru Valley	Sankoo	26-08-2017
115	M	M	40-60	Suru Valley	Sankoo	27-08-2017
116	M	A	20-40	Suru Valley	Thang Sankoo	25-08-2017
117	M	A	20-40	Suru Valley	Thang Sankoo	25-08-2017
118	F	Y	< 20	Suru Valley	Palam	23-08-2017
119	M	A	20-40	Suru Valley	Madh Urriba	23-08-2017
120	M	A	20-40	Suru Valley	Madh Urriba	23-08-2017
121	F	A	20-40	Zanskar Valley	Padun (Krishna)	27-08-2017
122	M	A	20-40	Zanskar Valley	Padun (Krishna)	27-08-2017
123	M	A	20-40	Zanskar Valley	Zanskar/Leh	29-08-2017

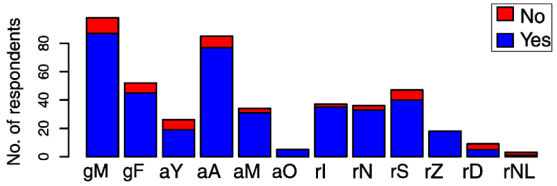
124	M	A	20-40	Zanskar Valley	Padun	28-08-2017
125	M	A	20-40	Zanskar Valley	Mone Gumpa	28-08-2017
126	M	M	40-60	Zanskar Valley	Ubara, Padum	24-08-2017
127	M	M	40-60	Zanskar Valley	Padum	24-08-2017
128	M	A	20-40	Zanskar Valley	Padum	24-08-2017
129	M	O	> 60	Zanskar Valley	Mone Gumpa, Zanskar	29-08-2017
130	M	O	> 60	Zanskar Valley	Mone Gumpa, Zanskar	30-08-2017
131	M	M	40-60	Zanskar Valley	Padun	31-08-2017
132	M	A	20-40	Zanskar Valley	Padum	30-08-2017
133	M	M	40-60	Zanskar Valley	Padum	01-09-2017
134	M	A	20-40	Zanskar Valley	Padum	26-08-2017
135	M	M	40-60	Zanskar Valley	Padun	27-08-2017
136	F	M	40-60	Zanskar Valley	Padun	27-08-2017
137	M	A	20-40	Zanskar Valley	Padun	27-08-2017
138	M	A	20-40	Zanskar Valley	Padun	26-08-2017
139	F	Y	< 20	Drass Valley	Shimsha Drass	24-08-2017
140	F	Y	< 20	Drass Valley	Drass Kargil	23-08-2017
141	F	Y	< 20	Drass Valley	Mushkoo Drass	23-08-2017
142	F	Y	< 20	Drass Valley	Kaksar Drass	24-08-2017
143	M	Y	< 20	Drass Valley	Karkit Mujadass	24-08-2017
144	F	Y	< 20	Drass Valley	Muskoo (Drass)	24-08-2017
145	F	Y	< 20	Drass Valley	Gindiyal Drass	23-08-2017
146	F	Y	< 20	Drass Valley	Drass Kargil	23-08-2017
147	F	Y	< 20	Drass Valley	Bhimbet (Drass)	24-08-2017
148	M	M	40-60	Nepal	Nepal	26-08-2017
149	M	A	20-40	Srinagar	Srinagar	28-08-2017
150	M	M	40-60	Jammu	Jammu	12-08-2017

Fig. S1-S4—Bar diagram showing the dichotomous (yes or no) responses of the interviewees to the 50 question asked during the survey.

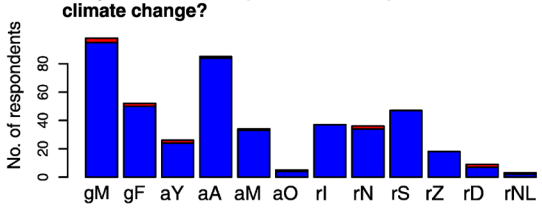



16 : Do you think that recent cloud burst resulting into flood is linked to climate change?
21 : Is there enough drinking water available during summers in your region?
26 : Do you think that humans are abusing the resources of planet earth?
17 : Do you think that the affects of climate change are going to be catastrophic?
22 : Based on the experience can you suggest that air pollution has affected you, your family or friend's health?
27 : Is there any link between energy consumption pattern and climate change?
18 : Have you noticed any seasonality changes in cultivation pattern over the years?
23 : Is air pollution increasing in your region?
28 : Do you believe that if people limit energy consumption then it will minimize the adverse effects of climate change?
19 : In your village, have you noticed any change in food habits of people?
24 : Do you believe that the affects of climate change can be mitigated?
29 : Do you believe that it is already too late to meet challenges of climate change?
20 : Is agriculture productivity increased in last 20 years?
25 : Do you believe that human contribution in global temperature increase is significant ?
30 : In your opinion, is biodiversity decreasing with increasing global warming?
No
Yes
No. of respondents
0 20 40 60 80
gM gF aY aA aM aO rI rN rS rZ rD rNL
Category

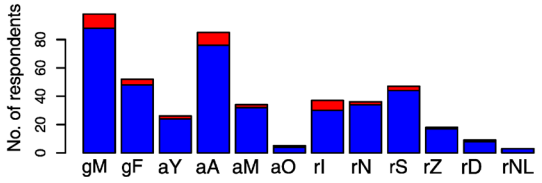
31 : Do you think that the rate of global warming can be controlled or reversed?



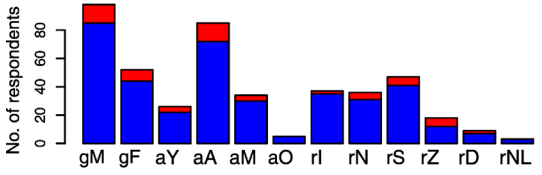
32 : Are you afraid of the possible consequences of climate change?



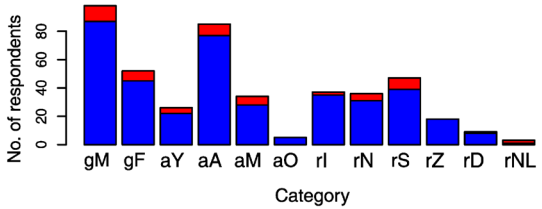
33 : Do you think that adverse impact of climate change can be addressed by applying science & technology?



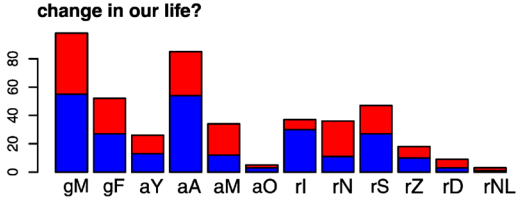
34 : Do you believe that human contribution in climate change is substantial?



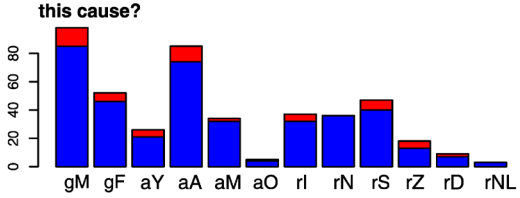
35 : Is it possible to limit ill effects of climate change?



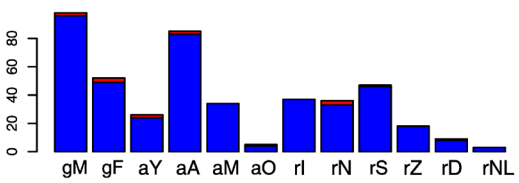
36 : Do you think that climate change can bring some positive change in our life?



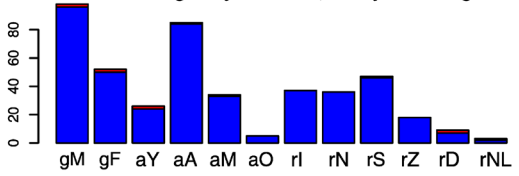
37 : Would you like to help in someway or the other for this cause?



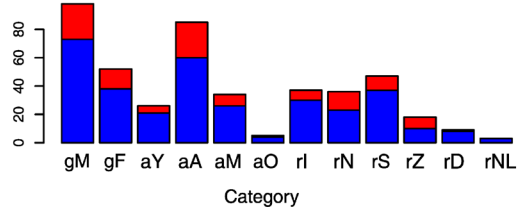
38 : Do you think awareness of this serious issue is important?



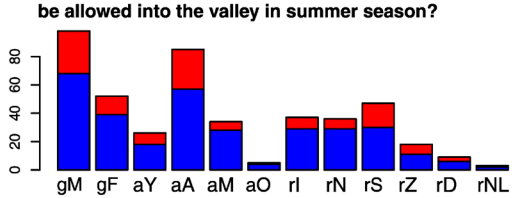
39 : Will you help in spreading the word of the consequences of climate change to your friend, family and village/society?



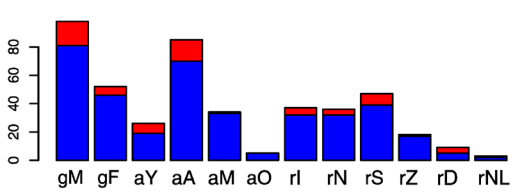
40 : Do you think the tourist coming to Ladakh is a boon or bane?



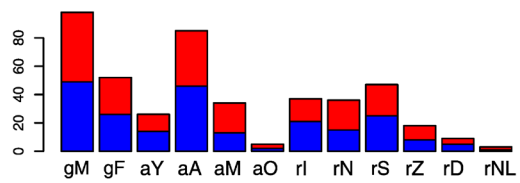
41 : Should there be a number as to how many tourists should be allowed into the valley in summer season?



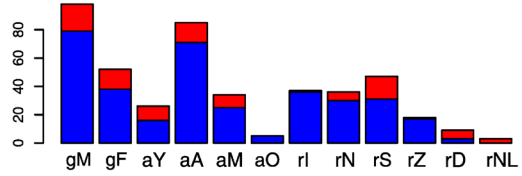
42 : Do you expect any help in this regard from the government?



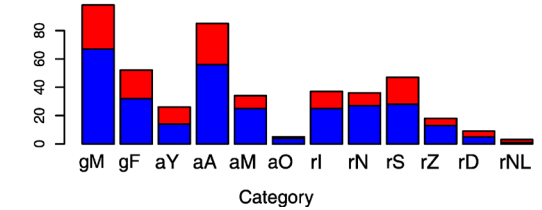
43 : Are the private agencies helping the locals to sort out the problems related to changing weather conditions?

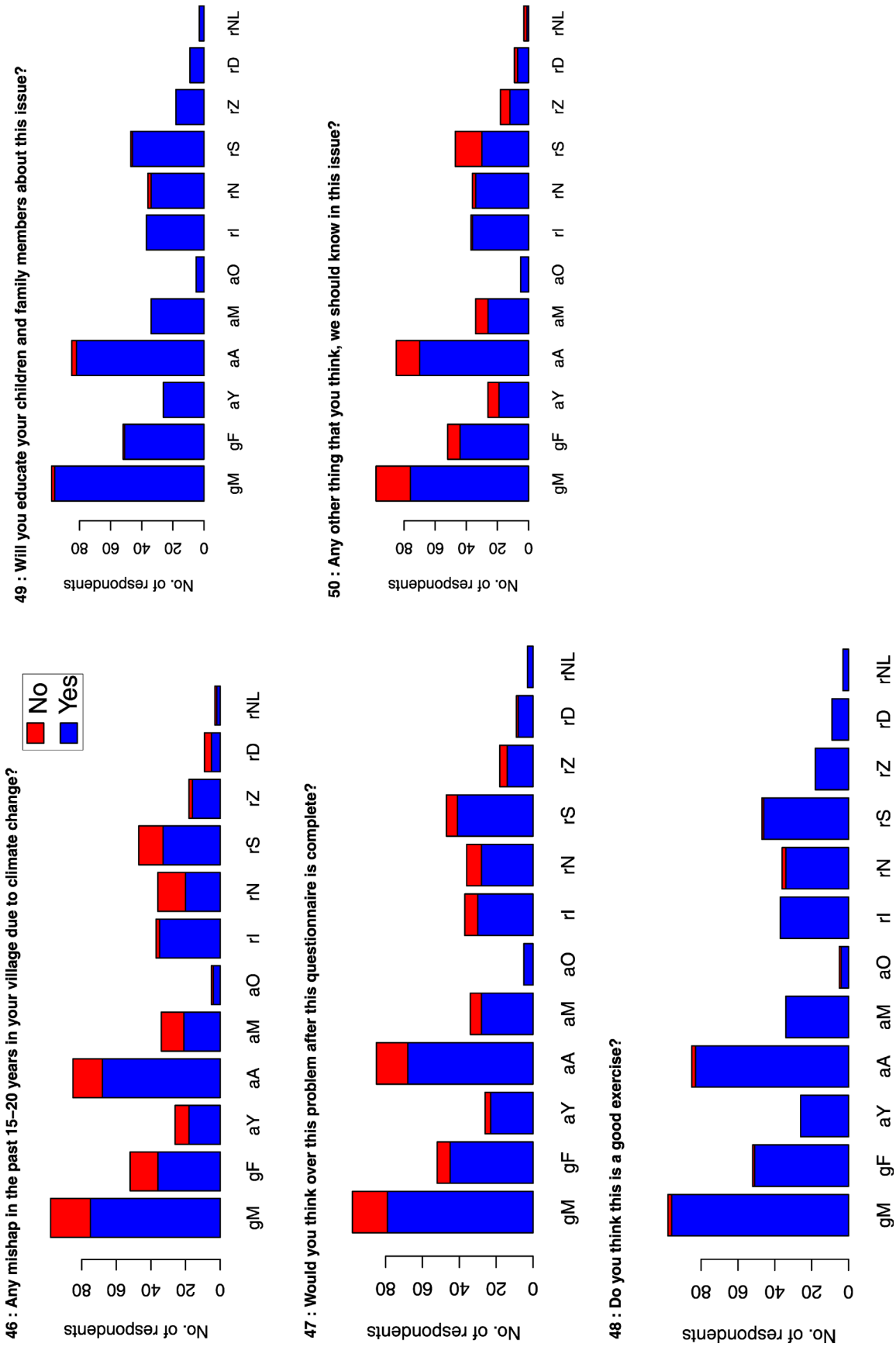


44 : Does the government have some schemes to combat climate change issue?



45 : Any incident you want us to know to access the severity of climate change that you or your near ones have experienced?




46 : Any mishap in the past 15–20 years in your village due to climate change?
No
Yes
No. of respondents
0
20
40
60
80
gM
gF
aY
aA
aM
aO
rl
rN
rS
rZ
rD
rNL
47 : Would you think over this problem after this questionnaire is complete?
48 : Do you think this is a good exercise?
49 : Will you educate your children and family members about this issue?
50 : Any other thing that you think, we should know in this issue?