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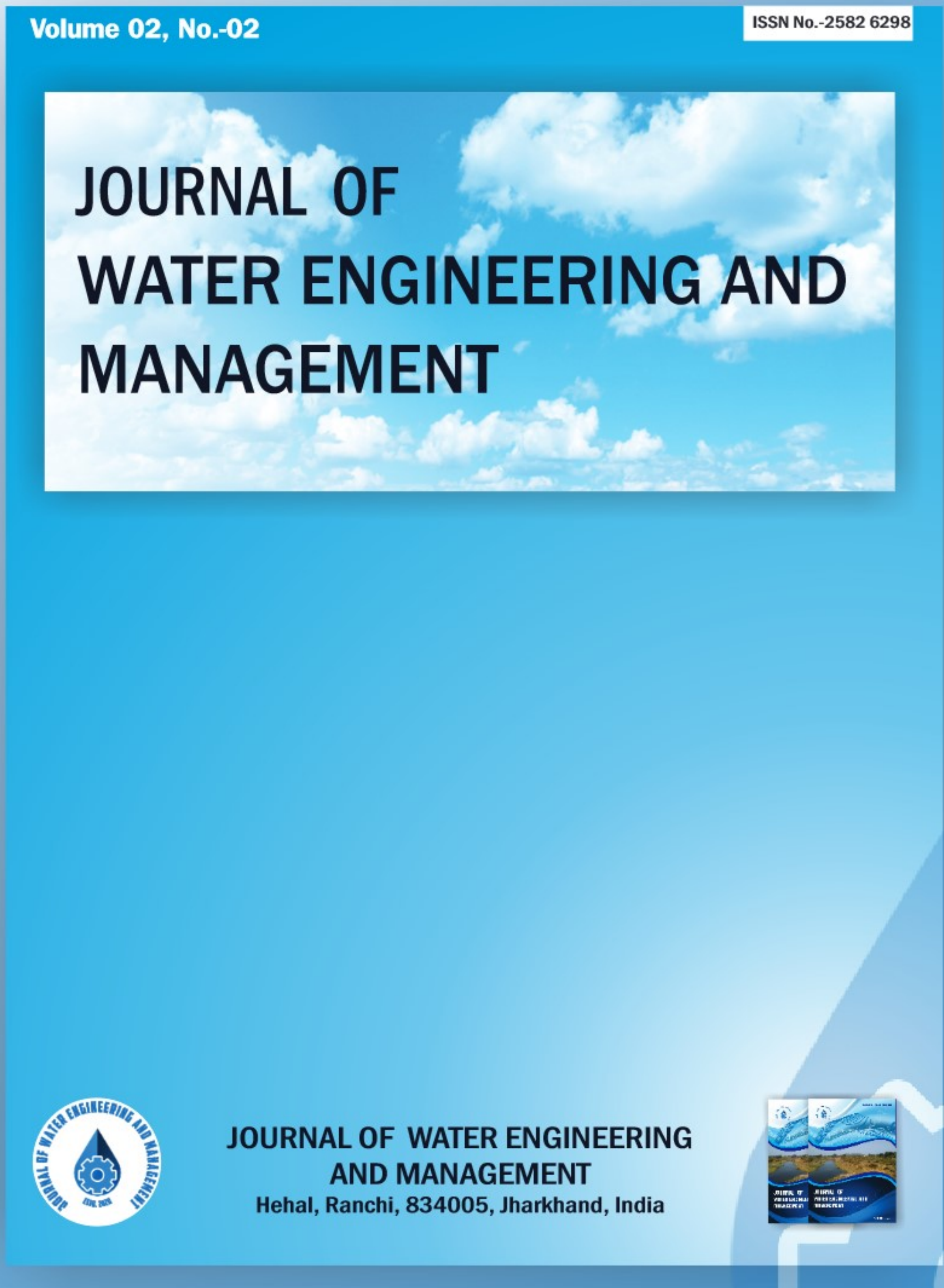

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Research Paper

Macro-level study on Climate Change effects on agriculture and human health in Western Himalayas: A Review

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ABSTRACT

The current study reveals that the western Himalayas has a fragile ecosystem, highly susceptible to rapid changes in land morphology due to the consequences of climate change. Land-use and climatic change in this region has negative impacts on agriculture and human health. Increasing temperature, erratic precipitation, and rising CO_2 concentrations are the main drivers which show adverse effects on agriculture and human health. The impacts trends in this region can be categorised into exacerbated pathogenicity are pathogens, and hence disease outbreaks, changes in the traditional agriculture techniques, and people's migration that directly changes in ecological and leading to social inequalities. In the last few decades, there have been changes in vector species distribution in agriculture and increases of forest pest species attacks by climate change in agriculture and forest pest increases, and parasites are emerging during periods of these last few decades. Enhancement of seasonal transmission and distribution of pests pushes food insecurity and vector-borne infections deteriorate human health. This review article tries to analyse different literature on the effects of climate change on agriculture and human health in the Western Himalayas and suggest agroforestry and agroecology is some of the strategies to overcome climate change impact.

Keywords: Western Himalayas; Climate change; Human health; Agriculture; Temperature; Precipitation; CO_2 concentration.

INTRODUCTION

Climate change has been described as the biggest global threat in the 21st century (Costello et al., 2009). The Himalayan mountain environment is very delicate to environmental change that led to cause risk in socio-economic development employments for the individuals to progress in mountain biological systems for their endurance and improvement (Negi et al., 2017). Environmental components such as water resources, agriculture, and biodiversity and food security are highly affected directly and indirectly due to climate change (Field and Christopher, 2014). The entire Himalayas have been categorized and isolated into three regions namely: (I) Western Himalayan Region (WHR), (ii) Central Himalayan Region (CHR) and (iii) Eastern Himalayan Region (HER). The WHR is the largest region of the Indian Himalayas comprising of Jammu and Kashmir, Ladakh, Himachal Pradesh, and Uttarakhand. (Das and Meher et al., 2019). Climate change can be easily and early identified in mountains (Singh et al., 2010). The trend of warming in the Himalayas seems to be greater than the average rate based on preliminary studies (Liu and Chen, 2000; Shrestha et al., 1999), Winter and autumn the temperatures were as recorded higher and it increases with the elevation gradient altitudes (Liu and Chen 2000). Due to changes in the trend of temperature and precipitation worldwide, agricultural production is adversely affected (Turral et al., 2011). A trend analysis of vegetation index time series has shown that lower and middle elevations of the Himalayas have a higher extent of the greening region while higher elevations have registered a modest part of browning at elevation (N 3800 m), comparatively browning in western high Himalayas is less than eastern high Himalayas due to cropped area and driven by increasing agricultural fertilization and anthropogenic land change could be possible human drivers for climate change in Himalayas (Mishra and Mainali, 2017). Climate change has already warmed the planet; from the preindustrial period (1850–1900) to the present (1998–2018), our planet has the significant trend of warming by gradualness of climate change which leads to an increasing in global average temperature by 1.41^{0}C (Anderson et al., 2020) and changes in the frequency and severity of weather events such as drought (Gamble et al., 2010; Spinoni et al., 2019; Stringer et al., 2009) and precipitation trends (Lehmann et al., 2015; Mearns et al., 1997). Climate change will put further pressure on the environment. There have been reports of less snow, receding glaciers, increasing temperature and decreasing precipitation throughout the globe (Dar et al., 2014).

Agricultural yield is influenced by a range of factors, including climate conditions, crop and land management practices, pathogens and pests, and the occurrence of extreme weather events (Bhattacharya et al., 2016; Joshi et al., 1996; Zhao et al., 2017; Pathak et al., 2018). Due to climate change, the rainfall pattern changes in a shorter period, and the temperature is fluctuating, these consequences have significantly resulted in significant reductions in reduced productivity in the Himalayan region (Moore and Lobell, 2015). Long term trends such as drought occurrence, heat stress, and floods variation on the Himalayan region on agriculture by the impact of climate change has been documented (Dahal et al., 2020; Rashid and Romshoo, 2020). Climate change makes the innovation in agricultural practices, replacement of traditional staple crop by cash crop, declining undesirable changes in of phenological character of various fruits and early flowering in wheat and mustard (Negi et al., 2012). Climate change can reduce the quantity of harvested food reduced by climate change which could lead to higher food prices and reduced consumption (Nelson et al., 2010). Climate changes have also increased pests, diseases and invasive plant species (such as Eupatorium, sp. Lantana sp. and Parthenium sp.) which has directly affected crop productivity and food security (Lamsal et al., 2018). Climate change shifts the distribution of plant pathogens and pests (Neupane and Ghimire, 2020; Bebberet al., 2013; Hunjan and Lore, 2020) and the climatic changes occurring in the Himalayan region is expected to alter plant pathogen virulence and infection rates (Srivastava et al., 2020; Velasquez et al., 2018) which could be exacerbating aggravate yield losses (Neupane and Ghimire, 2020).

Climate change is a critical big issue not only in the Himalayan region but overall, in the world. There are mainly three components that affect the environment due to climate change shows the climate change in a region i.) Temperature, ii.) Precipitation and iii.) CO_2 concentration. Taking into consideration the sensitive nature of the Himalayas to climatic changes. The current review depend basses upon the western part of the Himalayas shows what are the factors and effects of climate change on the people of this region? Western Himalayas, the prime main area of focusing is the impact of climate change on agriculture and people health of the people in this region.

The area studied for the review is the western part of the Himalayas. Several research articles and reviews which were already published for reviewing the cause and effect of climate change were perused. The research articles were searched using Google Scholar, Science Direct, Google, EBSCO with the main keyword's climate change, western Himalayas, Himalayas, temperature, precipitation, CO_2 concentration, agriculture, glaciers, pests, diseases.

CHANGES IN TEMPERATURE

In the last few decades, the temperatures trend of the last few decades has shown an increasing trend at a significant rate in the upland regions of countries like Nepal and India (Thakur et al., 2020). The global mean temperature is expected to increase by between 1.1°C and 6. 4°C as a result, with a good approximate range of 1. 8–4°C (Hodnebrog et al., 2020). Wiltshire (2014) observed a warming trend in the Hindu Kush, Karakoram and Himalayan region from 1971-2000 was observed with an increase in temperature of by 4- 5.5°C and highlighted that North Bhutan and Himachal Pradesh Himalayas are most vulnerable for environmental change as compared to the Karakoram and Hindu Kush (Wiltshire, 2014). In the 2010–2018 period, the Himalayan region experienced higher temperatures and less precipitation than decadal averages and reported an average 40% decline in yield of several crop species, including barley, wheat, and apple (Budhathoki and Zander, 2020; Sahu et al., 2020). Variation in temperature and snowfall trend using data at different ranges of western Himalayas whereas the change in the number of snowfall days due to climate change. Shekhar et al. (2010) have reported a significant increase in seasonal maximum and minimum temperatures in the Western Himalayas (Shekhar and Chand et al., 2010).

The scenario of agricultural product trends indicates an overall decline in wheat and barley yields of more than 5 and 8%, respectively (Chhogyel et al., 2020). The impacts are not evenly distributed, somewhere up to 8-10% or greater decline have been observed in the high-altitude Himalayan crops (Paudel et al., 2020). The increase of heat has impacted cereal production by 15% in the Himalayan regions while reducing global 10% during the last five decades only, and droughts on this same duration caused a higher reduction than the heat loss caused in the western Himalayan region and globally due to climate change (Gupta et al., 2017; Lesk et al., 2016). Wheat yield is expected to reduce by 4-6% for each degree of global temperature increase (Asseng et al., 2015; Das et al., 2020). Maize productivity has shown similar effects, with an expected reduction in yield in more than 50% of the world's area will experience the declined yield (Pandey and Arunachalam, 2020; Pugh et al., 2016). Temperature increases directly enhance the plant pathogen growth and developmental responses like that of Phytophthora infesting populations affects the field of potato (Mariette et al., 2016; Shakya et al., 2015) and temperature fluctuations also make bacterial communities more susceptible to invasion of novel taxa (Inaotombi and Sarma, 2020).

Health can be affected by climate change in various ways: both directly, due to changes in temperature, precipitation, and the occurrence of heatwaves, floods, droughts, and fires; or indirectly, due to ecological and social disruptions, such as crop failures, shifting patterns of disease vectors, and displacement of people (Smith et al. 2014). The pattern of vector-borne diseases in human populations are inherently sensitive to changes in environmental conditions that influence the life cycle dynamics of the pathogen, its vector, and its host. Malaria is already a problem in most countries in the Hindu Kush–Himalayas (Bhattacharya et al., 2016). Globally and regionally, many institutions and research groups have been running different statistical and biological models of a chance to predict the potential spread of malaria as the drawback result of climate change in poor, developing countries (Bhandari et al., 2020; Ebi et al., 2007; Hanafi-Bojd et al., 2020).

CHANGING PRECIPITATION PATTERNS

Widespread deforestation in the Himalayas in the period from 2008 to 2018 have around decreased forest areas by 4732.71 km^2 forest area and about 56% of protected areas had a decreasing trend from 1998 to 2018 (over only the latest few decades) in the Himalaya region (Gu et al., 2020). Future scenarios (RCP 4.5 and RCP 8.5) reveal an increase in precipitation trend during summer and a decrease in the number of rainy days (Palazzi et al., 2013). The concentration of black carbon significantly increase due to anthropogenic activities and biomass burning due to forest fire and its concentration is negatively correlated with rainfall and humidity (Kant and Patel, 2012). The concentration of PM2.5 was maximum due to biomass combustion (Kumar and Attri, 2015). Climate change effect over the Hindu Kush increased snowfall and decreased precipitation (Wiltshire, 2014). A concern in the Himalayas region is whether climate change will affect the monsoon season (Gautam et al., 2009). Partial rainfall in the Himalayan region as well as increases in the magnitude of extreme rainfall events has been projected with climate change and is expected to increase the frequency and intensity of flooding in the region (Elalem and Pal, 2015). Weather and seasonal rain impact the agriculture of mountainous regions, and any change in climate changes the crop yield and food supply in the Himalayan region (Negi et al., 2012). The temperature and rainfall increase in Himalayan areas are expected to creating stress on the indigenous local communities by affecting agro-biodiversity, crop yield, cropping patterns and the species composition of forests (Pandey et al., 2017). The Hindu-Kush Himalayan region has experienced more due to an increase in extreme conditions over the last decade, with both droughts and increasing floods negatively affecting agricultural yields, and similar effects are expected for the western Himalayas (Chauhan et al., 2020; Manzoor et al., 2013). Mountainous parts of the Kashmir valley have shown a drastic decrease in precipitation while flood plains have shown a relatively less rate of decrease (Shafiq et al., 2019). In contrast, in the especially central part of the Himalayan in the last decades, high rainfall and cooler temperatures resulted in almost doubled flooding downstream (Kumar et al., 2020; Posthumus et al., 2009). About 70% of the summer flow in the Ganga comes from melting glaciers that act to regulate water runoff from the mountains to the plains between dry and wet periods, thus glaciers are instrumental in securing agricultural productivity and livelihoods for millions of people of this region (Ruane et al., 2013). Some shreds of evidence suggest that there have been alterations of snowmelt phenology with earlier commencement of snowmelt and faster melting in the spring leading to shifts in the total time of distribution of runoff and runoff related projects in low land people and livelihood (Bhandari et al. 2020; Guntukula and Goyari, 2020; Panwar, 2020). These changes could affect the availability of freshwater for natural systems and human use (Cristea et al., 2014).

Glacial lake outburst events have caused catastrophic downstream flooding and loss of life due to climate change frequently in the Himalayan region (Harrison et al., 2018). Human well-being, as well as mortality, is greatly affected by glacial lake floods, which wash out agricultural land and bridges and sever communication networks for substantial periods between people living on either side of the rivers or ravines in the Himalayan region for substantial periods (Bajracharya and Mool, 2009). Rain, high humidity, and high soil moisture favour many plant diseases by increasing fungal infection rates (Hunjan and Lore, 2020). A close trend of irregularity is present in the plant immunity process, where plant species and communities exhibit contrasting reactions or responses to increasing temperature and humidity (Lamaoui et al., 2018; Sundriyal et al., 2020). This may affect agricultural production severely in the future. Many diarrheal diseases have more than one means of transmission, and all modes are possible in mountainous regions (Ebi et al., 2007). Diarrheal diseases are already a major cause of morbidity and mortality in the Himalayas developing countries (Moors et al., 2013). There is highly enough evidence to suggest that water-related diseases are directly and indirectly influences the occurrences and prevalence of diseases by the change in the pattern, quantity, and timing of runoff from snowmelt and glaciers (Ebi et al., 2007). During the wet season, floods flush into water sources, while during the dry season, lack of water increases the risk of water-washed diseases that might chance increase the risk of waterborne and water-based infections. (Sharma et al., 2018).

EFFECTS OF RISING CO_2 CONCENTRATIONS

Continuous rise in the concentration of greenhouse gases (GHGs) like carbon dioxide, methane, nitrous oxide, water vapour, CFCs, etc in the environment is the reason for climate change and the rise in CO_2 concentration mainly led to global warming (World Climate News, 2006). By 2100, global atmospheric concentrations of CO_2 are anticipated to ranges into being between 490 and 1260 ppm (75% – 350% above the concentration of 280 ppm in the year 1750) (Hodnebrog et al., 2020). The burning of fossil fuels after industrialization has increased CO_2 concentrations by 90% mainly in latitudes between 200 - 600 N (Marland et al., 1985). The concentration of atmospheric CO_2 was about 280 ppm during the pre-industrial period exceeded 400 ppm in recent times, the average growth rate has been estimated at 2.11 ppm per year during the last decade, and a value of 410 ppm was observed in 2018 (Chakraborty et al., 2020) Increases in global population (Kintigh and Peeples, 2020) have contributed to continued deforestation and increased demands for land, leading to continued elevated Green House Gases (GHG) emissions (Ray et al., 2015).

Increased CO_2 concentration in the atmosphere through climate change directly affect the function process of open stomata for gas exchange (lower numbers open) due to higher concentrations of CO_2 (Sharma et al., 2020) that directly affect respiration evapotranspiration, photosynthesis rates means all biological function pressurized mostly drought stress resilience plants that mainly found in the Himalayan region of narrow niche environment which leads to support the plants for extinction. IPCC short-term predictions indicate that under several climate change scenarios, yield gains are positively expected in the Himalayan region due to warmer conditions that extend the growing season at high latitudes (Nanditha et al., 2020) due to elevated CO_2 fertilization, but in the long-term climate change will alter all ecological functions (Chettri et al., 2020) and there might be extinction of local or native crops or domination ted of by invasive species (Pramanik et al., 2020). Moreover, many researchers have found that the nutritional quality of some C3 crop species was reduced in terms of protein, zinc, and iron, due to increased CO_2 concentrations (Myers et al., 2014; Uddling et al., 2018). GHG emissions have led to major changes in agriculture ecosystems (Anyamba et al., 2014) of the Himalayan regions (Martin et al., 2010). Increases in atmospheric CO_2 concentrations can aggravate pathogenicity virulence is influenced by increases in atmospheric CO_2 concentrations (Corredor et al., 2020; Shaw and Osborne, 2011) virulence of Fusarium gramine arum on wheat, and potato (Váry et al., 2015; Neupane and Ghimire, 2020).

SYNTHESIS

Nowadays a lot of research is focused on response modelling to control the outbreaks of pests minimize the impacts on food security in the western Himalayan region (Sekhri et al., 2020). Many research suggested and approved that due to climate change in the Himalayan region where finds fragile ecosystem could affect more human population health due that In the Himalayan region most of the poor people are with low health facilities accessibility, therefore there are high chances of the creation of favourable conditions for disease vectors, malnutrition, rodent-borne diseases, forest fires, avalanches, heavy snowfalls, major storms, floods, and droughts, changes in intensity and frequency of snowfall cover and length of the snow-free season, changes in daylight temperature pattern, range between daylight duration of sunlight (Ebi et al., 2007). Climate zones are expected to shift at high altitudes due to climate change and this will change the distribution of highly productive agricultural areas (Bagaria et al., 2020; Hunter et al., 2017; Scheben and Edwards, 2018). The plant pathogen may spread, attack and distribution trend changes easily if also new cultivars are introduced expose by local people in the Himalayan region due to the increase of precipitation irregularity, temperature, and CO_2 trend in high land that faces more vulnerability (Sekhri et al., 2020) or more virulent strains (Saarinen et al., 2019). Variations from the mean temperature and precipitation, or in vegetation, can alter the geographic distribution and abundance of vectors and the rate of pathogen replication within vectors. Natural vegetation and crops which require longer growth periods (such as forestry and orchard crops) may be at a higher risk of plant-pathogen infection, as management procedures and cultivars are less flexible. (Maqbool et al., 2020; Sahu et al., 2020). The complexity of pathogen infection and plant susceptibility, together with the ability of pathogen populations (Patle et al., 2020) to rapidly respond to their environment predicts pests and disease outbreaks incredibly complicated (Bhusal, 2020).

CONCLUSIONS AND RECOMMENDATIONS

The western Himalayan region is facing major challenges of climate change. People are depending upon the agriculture-related system, so agriculture and human health are closely bonded. Human health is directly and indirectly affected depending on the changing climate. The fifth assessment report is concerned with the rise in global temperature due to human activities (Russill, 2016), it is strange human activities are responsible for climate change, changing climate affects the day to day life of humans directly. Issues like extreme climate events and natural impacts are extremely complex and costly ventures, and to addresses, such issues global level policies are required. Understanding the issues and linking research on environmental processes, ecosystems, and human health requires an interdisciplinary approach. Increasing temperature, precipitation and CO_2 concentration are the main criteria as which impacts agriculture, local vegetation, and human health by increasing plant pathogens attack, pests attack and increasing vector-borne diseases.

People of western Himalaya's area adopt certain changes to overcome the climate change impact like innovating agricultural techniques and, replacement of traditional crops. Decreasing the source of earning males of these areas have started rural-urban migration. Climate change increases the flourishing of invasive species cause local vegetation damage and low regeneration. Agroforestry and agroecological intensification reduce the vulnerability of climate change, it provides a wide variety of agricultural and forest products, fruit, fodder and thereby facilitate environmental amelioration helps in benefiting farmers directly (Pandey et al., 2016).

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REFERENCES

Abid, H., Rasul, G., Mahapatra, B. and Tuladhar, S. 2016. Household food security in the face of climate change in the Hindu-Kush Himalayan region, Food Security, 8 (5): 921-937.

Ahmad Ali, H. B., Vatandoost, H. and Yaghoobi-Ershadi, M. R. 2020. Climate Change and the Risk of Malaria Transmission in Iran, Journal of Medical Entomology, 57(1): 50-64.

Ahmad, D. R., Rashid, I., Romshoo, S. A. and Marazi. A. 2014. Sustainability of Winter Tourism in a Changing Climate over Kashmir Himalaya, Environmental Monitoring and Assessment, 186 (4): 2549–62.

Ajay, K. and Attri, A. K. Biomass combustion a dominant source of carbonaceous aerosols in the ambient environment of Western Himalayas, Aerosol and Air Quality Research, 16(3): 519-529.

Amir, M., Rather, S. U., Akbar, S. A. and Wachkoo, A. A. 2020. Preliminary Survey of Ladybird Beetle Composition (Coleoptera: Coccinellidae) in Unmanaged Apple Orchard Ecosystems of Kashmir Himalayas, in Proceedings of the Zoological Society, 1-15. Springer India.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., Friel, S., Groce, N., Johnson, A., Kett, M., Lee, M., Levy, C., Maslin, M., McCoy, D., McGuire, B., Montgomery, H., Napier, D., Pagel, C., Patel, J., de Oliveira, J. A. P., Redclift, N., Rees, H., Rogger, D., Scott, J., Stephenson, J., Twigg, J., Wolff, J. and Patterson, C. 2009. Managing the Health Effects of Climate Change, Lancet and University College London Institute for Global Health Commission, The Lancet. 373(9676):1693-1733, https://doi.org/10.1016/S0140-6736(09)60935-1.

Anthony, M. J., Woodruff, R. E. and Hales, S. 2006. Climate change and human health: present and future risks, The Lancet, 367 (9513): 859-869.

Ashwagosha, G. and Negi, H. S. 2020. Implications of Changing Climatic Pattern on the Geopolitical Situation of North-Western Himalaya, India, in Climate Change and the White World, 157-168. Springer, Cham.

Assaf, A., Small, J. L., Britch, S. C., Tucker, C. J., Pak, E. W., Reynolds, C. A., Crutchfield, J. and Linthicum, K. L. 2014. Recent weather extremes and impacts on agricultural production and vector-borne disease outbreak patterns, PloS One, 9(3): e92538.

Bing, L., Asseng, S., Muller, C., Ewert, F., Elliott, J., Lobell, D. B. Pierre Martre et al. 2016. Similar estimates of temperature impacts on global wheat yield by three independent methods, Nature Climate Change, 6(12): 1130-1136.

Boris, O. and Seneviratne, S. I. 2012. Global changes in extreme events: regional and seasonal dimension. Climatic Change, 110 (3-4): 669-696.

Canovas, B., Antonio, J., Trappmann, D., Gonzalez, J. M., Eckert, N. and Stoffel, M. 2018. Climate warming enhances snow avalanche risk in the Western Himalayas. Proceedings of the National Academy of Sciences, 115(13): 3410-3415.

Changjun, G., Zhao, P., Chen, Q., Li, S., Li, L., Liu, L. and Zhang., Y. 2020. Forest Cover Change and the Effectiveness of Protected Areas in the Himalaya since 1998, Sustainability, 12 (15): 6123.

Chhogyel, N., Kumar, L., Bajgai, Y. and Hasan, M. K.2020. Perception of farmers on climate change and its impacts on agriculture across various altitudinal zones of Bhutan Himalayas, International Journal of Environmental Science and Technology, 17, 3607–3620.

Corey, L., Rowhani, P. and Ramankutty, N. 2016. Influence of extreme weather disasters on global crop production, Nature, 529(7584): 84-87.

Daniel, P.B., Ramotowski, M. A. T. and Gurr, S. J. 2013. Crop pests and pathogens move polewards in a warming world, Nature Climate Change, 3 (11): 985-988.

Dinesh, B., Bi, P., Sherchand, J. B., Dhimal, M. and Easey, S. H. 2020. Climate change and infectious disease research in Nepal: Are the available prerequisites supportive enough to researchers? Acta Tropica, 204: 105337.

Douglas, W. G., Campbell, D., Allen, T. K., Barker, D., Curtis, S., McGregor, D. and Popke, J. 2010. Climate change, drought, and Jamaican agriculture: local knowledge and the climate record. Annals of the Association of American Geographers, 100(4): 880-893.

Eddy, M., Singh, T., Siderius, C., Balakrishnan, S. and Mishra, A. 2013. Climate change and waterborne diarrhoea in northern India: Impacts and adaptation strategies, Science of the Total Environment, 468: S139-S151.

Elias, G. 2020. Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future, Environment, Development and Sustainability, 22 (6): 4979-4998.

Elisa, P. von Hardenberg, J. and Provenzale, A. 2013. Precipitation in the Hindu-Kush Karakoram Himalaya: observations and future scenarios, Journal of Geophysical Research: Atmospheres, 118(1): 85-100.

Field, C. B. 2014. Climate change 2014–Impacts, adaptation and vulnerability: regional aspects. Cambridge University Press.

Frances, M. C. and Lobell, D. B. 2015. The fingerprint of climate trends on European crop yields, Proceedings of the National Academy of Sciences, 112(9): 2670-2675.

Gerald, C. N., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., et al.2010. Food security, farming, and climate change to 2050: scenarios, results, policy options, Intl. Food Policy Res. Inst., 172.

Harma, N., Kumar, R. and Sharma, R. C. 2018. Microbiological water quality of the sacred River Bhagirathi, Garhwal Himalaya, India, Journal of Water, Sanitation and Hygiene for Development, 8(4): 698-706.

Stephan, H., Kargel, J. S., Huggel, C., Reynolds, J., Shugar, D. H., Betts, R. A., Emmer, A., et al. 2018. Climate change and the global pattern of moraine-dammed glacial lake outburst floods. The Cryosphere 12(4): 1195-1209.

Helena, P., Morris, J., Hess, T. M., Neville, D., Phillips, E. and Baylis, A. 2009. Impacts of the summer 2007 floods on agriculture in England, Journal of Flood Risk Management, 2 (3): 182-189.

Hodnebrog, O., Aamaas, B., Fuglestvedt, J. S., Marston, G., Myhre, G., Nielsen, C. J., Sandstad, M., Shine, K. P. and Wallington, T. J. 2020. Updated global warming potentials and radiative efficiencies of halocarbons and other weak atmospheric absorbers, Reviews of Geophysics, 58(3): e2019RG000691.

Hunjan, M. S. and Lore, J. S. 2020. Climate Change: Impact on Plant Pathogens, Diseases, and Their Management, in Crop Protection Under Changing Climate, 85-100. Springer, Cham.

Hunter, M. C., Smith, R. G., Schipanski, M. E., Atwood, L. W. and Mortensen, D. A. 2017. Agriculture in 2050: recalibrating targets for sustainable intensification, Bioscience, 67(4): 386-391.

Irfan, R. and Romshoo, S. A.2020. Impact of climate change on vegetation distribution in the Kashmir Himalaya, in Biodiversity of the Himalaya: Jammu and Kashmir State, 1029-1047. Springer, Singapore.

Ishfaq, A., Ahmad, B., Boote, K. and Hoogenboom, G. 2020. Adaptation strategies for maize production under climate change for semi-arid environments. European Journal of Agronomy, 115: 126040.

Jascha, L., Coumou, D. and Frieler, K. 2015. Increased record-breaking precipitation events under global warming, Climatic Change, 132(4): 501-515.

Jew, D., Poonia, V., Jha, S. and Goyal, M. K. 2020. Understanding the climate change impact on crop yield over Eastern Himalayan Region: ascertaining GCM and scenario uncertainty, Theoretical and Applied Climatology, 142:467–482.

Jonathan, S., Barbosa, P., Jager, A. D., McCormick, N., Naumann, G., Vogt, J. V., Magni, D., Masante, D. and Mazzeschi., M. 2019. A new global database of meteorological drought events from 1951 to 2016, Journal of Hydrology: Regional Studies, 22: 100593.

Joshi, M., Singh, S. P. and Rawat, Y. S. 1996. Foraging behaviour of cattle and goats in the grazing-lands of the forested zone of Indian Central Himalaya, Oecologia Montana, 5(1): 1-12.

Kaji, B. N. and Zander, K. K. 2020. Nepalese farmers' climate change perceptions, reality and farming strategies, Climate and Development, 12(3): 204-215.

Katarzyna, A., Turner, L. R. and Tong, S. 2012. Floods and human health: a systematic review, Environment International, 47: 37-47.

Kintigh, K.W. and Peeples, M.A., 2020. Estimating Population Growth Rates and Instantaneous Population from Periodized Settlement Data. *Journal of Computer Applications in Archaeology*, 3(1):197–209.

Khan, S. M., Page, S., Ahmad, H., Shaheen, H. and Harper, D.M. 2012. Vegetation dynamics in the Western Himalayas, diversity indices and climate change, Sci., Tech. and Dev, 31(3): 232-243.

Kristie, L. E., Woodruff, R., von Hildebrand, A. and Corvalan, C. 2007. Climate change-related health impacts in the Hindu Kush–Himalayas, Eco Health, 4(3): 264-270.

Lalu, D. and Meher, J. K. 2019. Drivers of climate over the Western Himalayan region of India: A review, Earth-Science Reviews, 198: 102935.

Latika, P. and Arunachalam, A. 2020. Potential Technologies for Climate Resilient Agriculture in the Indian Himalayan Region, in Climate Change and the White World, 77-85. Springer, Cham.

Linda, O. M., Rosenzweig, C. and Goldberg, R.1997. Mean and variance change in climate scenarios: methods, agricultural applications, and measures of uncertainty, Climatic Change, 35(4): 367-396.

Liu, X., and Chen, B. 2000. Climatic warming in the Tibetan Plateau during recent decades, International Journal of Climatology: A Journal of the Royal Meteorological Society, 20(14): 1729-1742.

Marland, G., Rotty, R. M. and Treat, N. L. 1985. CO_2 from fossil fuel burning: Global distribution of emissions, Tellus, B 37(4-5): 243-258.

Martin, D., Lal, T., Sachdev, C. B. and Sharma, J. P. 2010. Soil organic carbon storage changes with climate change, landform and land use conditions in Garhwal hills of the Indian Himalayan mountains, Agriculture, Ecosystems & Environment, 138 (1-2): 64-73.

Mats, E., Fang, J. and Dekens, J. 2008. How does climate change affect human health in the Hindu Kush-Himalaya region, Regional Health Forum, http://www.environmentportal.in/files/Regional_Health_Forum_Volume_12_No_1_RHF vol12.pdf#page=19.

Misbah, M., Bibi, S., Manzoor, M. and Jabeen, R. 2013. Historical analysis of flood information and impacts assessment and associated response in Pakistan (1947-2011), Research Journal of Environmental and Earth Sciences, 5(3): 139-146.

Mishra, V., Ganguly, A. R., Nijssen, B. and Lettenmaier, D. P. 2015. Changes in observed climate extremes in global urban areas, Environmental Research Letters, 10 (2): 024005.

Mouna, L., Jemo, M., Datla, R. and Bekkaoui, F. 2028. Heat and drought stress in crops and approaches for their mitigation, Frontiers in Chemistry, 6: 26.

Nakul, C., Shrestha, A. B. and Sharma, E. 2020. Climate Change Trends and Ecosystem Resilience in the Hindu Kush Himalayas, in Himalayan Weather and Climate and their Impact on the Environment, pp. 525-552. Springer, Cham.

Nanditha, J. S., van der Wiel, K., Bhatia, U., Stone, D., Selton, F. and Mishra, V. 2020. A seven-fold rise in the probability of exceeding the observed hottest summer in India in a 2° C warmer world, Environmental Research Letters, 15(4): 044028.

Nawaz, A. S., Dubey, J., Ghosh, R., Quamar, M. F., Sharma, A., Morthekai, P., Dimri, A. P., Shekhar, M., Arif, M. and Agrawal, S. 2018. High frequency abrupt shifts in the Indian summer monsoon since Younger Dryas in the Himalaya, Scientific Reports, 8 (1):1-8.

Negi, G. C. S., Samal, P. K., Kuniyal, J. C., Kothyari, B. P., Sharma, R. K. and Dhyani, P. P. 2012. Impact of climate change on the western Himalayan mountain ecosystems: An overview, Tropical ecology, 53(3): 345-356.

Neha, C., Shukla, R. and Joshi, P. K. 2020. Assessing the inherent vulnerability of farming communities across different biogeographical zones in Himachal Pradesh, India, Environmental Development, 33: 100506.

Nicolas, M., Androdias, A., Mabon, R., Corbiere, R., Marquer, B., Montarry, J. and Andrivon, D. 2016. Local adaptation to temperature in populations and clonal lineages of the Irish potato famine pathogen Phytophthora infestans, Ecology and Evolution, 6(17): 6320-6331.

Nicoleta, C. C, Lundquist, J. D., Loheide, S. P., Lowry, C. S. and Moore, C. E. 2014. Modelling how vegetation cover affects climate change impacts on streamflow timing and magnitude in the snowmelt-dominated upper Tuolumne Basin, Sierra Nevada, Hydrological Processes, 28(12): 3896-3918.

Niti, B. M. and Mainali, K. P. 2017. Greening and browning of the Himalaya: Spatial patterns and the role of climatic change and human drivers, Science of The Total Environment, 587: 326-339.

Pamela, B., Priyadarshani, S., Kumar, D. and Rai, I. D.2016. Bibliography on microflora (lichens, fungi and bacteria) of the Indian Himalayan Region, Bibliography on the Fauna and Micro flora of the Indian Himalayan Region, 17: 264.

Pandey, R., Aretano, R., Gupta, A. K., Meena, D., Kumar, B. and Alatalo, J. M. 2017. Agroecology as a climate change adaptation strategy for smallholders of Tehri-Garhwal in the Indian Himalayan region, Small-scale forestry, 16(1): 53-63.

Pandey, R., Kumar, P., Archie, K. M., Gupta, A. K., Joshi, P. K., Valente, D. and Petrosillo, I2028. Climate change adaptation in the western-Himalayas: Household-level perspectives on impacts and barriers, Ecological Indicators, 84: 27-37.

Panwar, S. 2020. Vulnerability of Himalayan springs to climate change and anthropogenic impact: a review, Journal of Mountain Science, 17(1): 117-132.

Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K. M. and Zaccaria, D. 2018. Climate change trends and impacts on California agriculture: a detailed review, Agronomy, 8(3): 25.

Patle, G. T., Sengdo, D. and Tapak, M. 2020. Trends in major climatic parameters and sensitivity of evapotranspiration to climatic parameters in the eastern Himalayan region of Sikkim, India, Journal of Water and Climate Change, 11(2): 491-502.

Paudel, B., Zhang, Y., Yan, J., Rai, R., Li, L., Wu, X., Chapagain, P.S. and Khanal, N.R. 2020. Farmers' understanding of climate change in Nepal Himalayas: important determinants and implications for developing adaptation strategies, Climatic Change, 158(3):485-502.

Pilar, M. C. and Saunders, D. G. O. 2020. Expecting the unexpected: factors influencing the emergence of fungal and oomycete plant pathogens, New Phytologist, 225: 118-125.

Piyush, D., Shrestha, M. L., Panthi, J. and Pradhananga, D. 2020. Modeling the future impacts of climate change on water availability in the Karnali River Basin of Nepal Himalaya, Environmental Research, 185:109430.

Pramanik, M., Diwakar, A. K., Dash, P., Szabo, S. and Pal, I. 2020. Conservation planning of cash crops species (Garcinia gummi-gutta) under current and future climate in the Western Ghats, India, Environment, Development and Sustainability: **23**:5345–5370.

Pramod, L., Kumar, L., Aryal, A. and Atreya, K. 2018. Invasive Alien Plant Species Dynamics in the Himalayan Region under Climate Change, Ambio, 47(6):697–710. https://doi.org/10.1007/s13280-018-1017-z.

Priyamvada, B., Sharma, L. K., Joshi, B. D., Kumar, H., Mukherjee, T., Thakur, M. and Chandra, K. 2020. West to east shift in range predicted for Himalayan Langur in climate change scenario, Global Ecology and Conservation, 22: e00926.

Pugh, T. A. M., Muller, C., Elliott, J., Deryng, D., Folberth, C., Olin, S., Schmid, E. and Arneth, A. 2016. Climate analogues suggest limited potential for intensification of production on current croplands under climate change, Nature Communications, 7(1): 1-8.

Raju, G. and Goyari, P. 2020. The impact of climate change on maize yields and its variability in Telangana, India: A panel approach study, Journal of Public Affairs, 20(3):e2088.

Ram, B. D. Insect Pollinators, Threats for Survival and Ecosystem Service: An Outlook From Hindu-Kush Himalaya Region, in Hindu Kush-Himalaya Watersheds Downhill: Landscape Ecology and Conservati2020.on Perspectives, pp. 565-576. Springer, Cham.

Ratna, B. S. and Mool, P. 2009. Glaciers, glacial lakes and glacial lake outburst floods in the Mount Everest region, Nepal, Annals of Glaciology, 50(53): 81-86.

Ray, D. K., Gerber, J. S., MacDonald, G. K. and West, P. C. 2015. Climate variation explains a third of global crop yield variability, Nature Communications, 6(1): 1-9.

Ray, D. K., Gerber, J. S., MacDonald, G. K. and West, P. C. 2015. Climate variation explains a third of global crop yield variability, Nature Communications, 6(1): 1-9.

Ridhima, G., Somanathan, E. and Dey, S. 2017. Global warming and local air pollution have reduced wheat yields in India, Climatic Change, 140(3-4): 593-604.

Ritesh, G., Hsu, N. C., Lau, K. M., Tsay, S. C. and Kafatos, M. 2009. Enhanced pre-monsoon warming over the Himalayan-Gangetic region from 1979 to 2007, Geophysical Research Letters, 36(7).

Robyn, A., Bayer, P. E. and Edwards, D. 2020. Climate change and the need for agricultural adaptation, Current Opinion in Plant Biology, 56:197-202.

Ruane, A. C., Major, D. C., Winston, H. Y., Alam, M., Hussain, S. G., Khan, A. B., Hassan, A., et al. 2013. Multi-factor impact analysis of agricultural production in Bangladesh with climate change, Global Environmental Change, 23(1): 338-350.

Russill, C. 2015. The climate of communication: from detection to dange, in Reframing Climate Change, 47-67. Routledge.

Saarinen, K., Lindstrom, L. and Ketola, T. 2019. Invasion triple trouble: environmental fluctuations, fluctuation-adapted invaders and fluctuation-mal-adapted communities all govern invasion success, BMC Evolutionary biology, 19(1): 42.

Sahu, N., Saini, A., Behera, S. K., Sayama, T., Sahu, L., Nguyen, V. T. V. and Takara, K. 2020. Why apple orchards are shifting to the higher altitudes of the Himalayas? Plos one, 15(7): e0235041.

Sakoda, K., Yamori, W., Shimada, T., Sugano, S. S., Nishimura, I. H. and Tanaka, Y. 2020. Stomatal density affects gas diffusion and CO_2 assimilation dynamics in Arabidopsis under fluctuating light, bioRxiv. https://doi.org/10.1101/2020.02.20.958603.

Samuel, M. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A. J., Carlisle, E., Dietterich, L. H., Fitzgerald, G. and Hasegawa, T. 2014. Increasing CO_2 threatens human nutrition, Nature, 510 (7503): 139-142.

Sandhya, N. and Ghimire, T. R. 2020. Towards a Landscape Perspective of Diseases in Plants: An Overview and Review of a Critical but Overlooked Ecology Issue in the Hindu Kush-Himalayan Region. In Hindu Kush-Himalaya Watersheds Downhill: Landscape Ecology and Conservation Perspectives, 135-168. Springer, Cham.

Scheben, A. and Edwards, D. 2018. Bottlenecks for genome-edited crops on the road from lab to farm, Genome Biology, 19(1): 1-7.

Sebastian, b., Dakos, V., Scheffer, M. and Lenton, T. M. 2018. Climate models predict increasing temperature variability in poor countries, Science Advances, 4 (5): eaar5809.

Senthold, A., Ewert, F., Martre, P., Rotter, R. P., Lobell, D. B., Cammarano, D., Kimball et al. 2015. Rising temperatures reduce global wheat production. Nature climate change, 5(2):143-147.

Shada, E. and Pal, I. 2015. Mapping the vulnerability hotspots over Hindu-Kush Himalaya region to flooding disasters, Weather and Climate Extremes, 8: 46-58.

Shafiq, M. U., Rasool, R., Ahmed, P. and Dimri, A. P. 2019. Temperature and precipitation trends in Kashmir Valley, north-western Himalayas, Theoretical and Applied Climatology, 135(1-2): 293-304.

Shaikhom, I. and Sarma, D. 2020. Vegetation affects photoprotective pigments and copepod distribution in the Himalayan lakes: Implication for climate change adaptation, Science of The Total Environment, 716: 137053.

Shakya, S. K., Goss, E. M., Dufault, N. S. and van Bruggen, A. H. C. 2015. Potential effects of diurnal temperature oscillations on potato late blight with special reference to climate change, Phytopathology, 105(2): 230-238.

Shaw, M. W. and Osborne, T. M.2011. Geographic distribution of plant pathogens in response to climate change, Plant Pathology, 60(1): 31-43.

Shekhar, M. S., Chand, H., Kumar, S., Srinivasan, K. and Ganju, A. Climate-change studies in the western Himalaya, Annals of Glaciology, 51(54): 105-112.

Shrestha, A. B., Wake, C. P., Mayewski, P. A. and Dibb, J. E. 1999. Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94, Journal of Climate, 12(9): 2775-2786.

Simran, S., Kumar, P., Furst, C. and Pandey, R. 2020. Mountain specific multi-hazard risk management framework (MSMRMF): Assessment and mitigation of multi-hazard and climate change risk in the Indian Himalayan Region, Ecological Indicators, 118: 106700.

Singh, A. K., Arunachalam, A., Ngachan, S. V., Mohapatra, K. P. and Dagar, J. C. 2014. From shifting cultivation to integrating farming: Experience of agroforestry development in the northeastern Himalayan region, in Agroforestry Systems in India: Livelihood Security & Ecosystem Services, 57-86. Springer.

Singh, S. P., Singh, V. and Skutsch, M. 2010. Rapid warming in the Himalayas: Ecosystem responses and development options, Climate and Development, 2(3): 221-232.

Smith, K., Woodward, A., Lendrum, D. C., Chadee, D., Honda, Y., Liu, Q., Olwoch, J. 2014. et al. Human health: impacts, adaptation, and co-benefits, in Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change, 709-754. Cambridge University Press.

Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C. and Mkwambisi, D. 2009. Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa, Environmental Science & Policy, 12(7): 748-765.

Sundriyal, S., Shukla, T., Tripathee, L. and Dobhal., D. P. 2020. Natural versus anthropogenic influence on trace elemental concentration in precipitation at Dokriani Glacier, central Himalaya, India, Environmental Science and Pollution Research, 27 (3): 3462-3472.

Supriyo, C., Tiwari, Y. K., Burman, P. K. B., Roy, S. B. and Valsala, V. 2020. Observations and Modeling of GHG Concentrations and Fluxes Over India, in Assessment of Climate Change over the Indian Region, pp. 73-92. Springer, Singapore.

Thakur, S., Negi, V. S., Pathak, R., Dhyani, R., Durgapal, K. and Rawal, R. S.2020. Indicator based integrated vulnerability assessment of community forests in Indian west Himalaya, Forest Ecology and Management, 457: 117674.

Turral, H., Burke, J. and Faures, J. M. 2011.Climate change, water and food security. No. 36. Food and Agriculture Organization of the United Nations (FAO).

Uddling, J., Broberg, M. C., Feng, Z. and Pleijel, H. 2018. Crop quality under rising atmospheric CO_2, Current opinion in plant biology, 45: 262-267.

Vary, Z., Mullins, E., McElwain, J. C. and Doohan, F. M. 2015. The severity of wheat diseases increases when plants and pathogens are acclimatized to elevated carbon dioxide, Global Change Biology, 21 (7): 2661-2669.
Vedwan, N. and Rhoades, R. E.2001. Climate change in the Western Himalayas of India: a study of local perception and response, Climate Research, 19(2): 109-117.

Velasquez, A. C., Castroverde, C. D. M. and He, S. Y. 2018. Plant–pathogen warfare under changing climate conditions, Current Biology, 28 (10): R619-R634.

Vikram, S. N., Maikhuri, R. K., Pharswan, D., Thakur, S. and Dhyani., P. P.2017. Climate change impact in the Western Himalaya: people's perception and adaptive strategies, Journal of Mountain Science, 14(2): 403-416.

Vinit, K., Shukla, T., Mehta, M., Dobhal, D. P., Bisht, M. P. S. and Nautiyal, S. 2020. Glacier changes and associated climate driver for the last three decades, Nanda Devi region, Central Himalaya, India, Quaternary International, 575-576:213-226.

Vivek, S., Griess, V. C. and Keena., M. A. 2020. Assessing the potential Distribution of Asian Gypsy Moth in Canada: A comparison of two Methodological Approaches, Scientific Reports 10(1): 1-10.

Wester, P., Mishra, A., Mukherji, A. and Shrestha, A. B. 2019. The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer Link.

Wiltshire, A. J.2014. Climate change implications for the glaciers of the Hindu Kush, Karakoram and Himalayan region, The Cryosphere, 8(3): 941-958.

World Climate News. 2006. Homing in on Rising Sea-Levels. WMO, Geneva, Switzerland, No. 29, June 29: 1-12.

World Health Organization. 2008. Climate Change and Health. A Tool to Estimate Health and Adaptation, Costs, https://www.euro.who.int/__data/assets/pdf_file/0018/190404/WHO_Content_Climate_change_health_DruckII.pdf.

Xu, J., Grumbine, R. E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y. and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods, Conservation Biology, 23 (3): 520-530.

Yadav, V. K., Deoli, J., Rawat, L. and Adhikari, B. S. 2014. Traditional Uses of Medicinal Tree Species in Renuka Forest Division, Western Himalaya, Asian Pacific Journal of Health Sciences, 1 (2): 72–77. https://doi.org/10.21276/apjhs.2014.1.2.7.

Yogesh, K., Patel, P., Mishra, A. K., Dumka, U. C. and Dadhwal, V. K. 2012. Diurnal and seasonal aerosol optical depth and black carbon in the Shiwalik Hills of the northwestern Himalayas: A case study of the Doon valley, India, International Journal of Geology, Earth and Environmental Sciences, 2(2): 173-192.

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., et al. 2017. Temperature increase reduces global yields of major crops in four independent estimates, Proceedings of the National Academy of Sciences, 114(35): 9326-9331.

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