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RESEARCH ARTICLE

IMPACT OF CHANGE IN CLIMATE ON THE HISTORICAL MONUMENTS IN WESTERN HIMALAYAN REGION (LADAKH)

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ABSTRACT

Jammu And Kashmir State is divided into three divisions Jammu, Kashmir and Ladakh. Ladakh was added to the state as a result of fierce campaigns of the ruler of Jammu, Gulab Singh to whom the British subsequently take over in 1846 the land of Jammu and Kashmir. The present research paper is an attempt to provide an outlook and effect of climate change on the historical monuments of Ladakh. Traditional Ladakhi structures are constructed with locally available material in harmony with the region's climatic conditions. The mud bricks in the upper storeys help to reduce the weight of the superstructure and have excellent thermal properties. Unlike modern concrete structures, these ancient historical mud structures remain cool in summer and warm in winter: they are well suited to the extreme variations in temperature in Ladakh, which range from -30^{o} C to $+30^{o}$ C. However, unfortunately, old mud structures are unable to withstand heavy rainfall, and in the last few years there has been a trend towards much heavier precipitation compared with earlier decades. Mud structures are easily eroded by water and, all too often, more than 1000 years old precious wall paintings have been washed away. Recent changes in Ladakh's climate therefore pose considerable challenges for the conservation of the region's historical buildings.

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INTRODUCTION

Leh-Ladakh is the largest district in the country with an area of 45,100 Km^2. It is the northern most part of the country bordering with Pakistan and China in the west and the east, respectively. Agriculture is the basic occupation of this cold arid zone. Whole of the area is irrigated and the source of irrigation water is mainly streams originated from glaciers. Both diurnal and seasonal variation of temperature is very high with a range of temperature from 35°C during summer and -35°C during winter season. Annual average rainfall of Leh is 100 mm, which mainly occurs during May-September and snowfall during winter (November to March) is a common weather phenomena. The cold desert region of India is characterized by harsh climatic condition i.e. dry and cold weather, heavy snowfall, low temperature, which sometimes on an average goes down to as low as -30^{o}C in late nights. Some time in summer months, on an average temperature reaches to as high as $+30^{o}$C in after noon (Sharma et al., 2011). Analysis of meteorological data for last 35 years indicated that there was rising trend of minimum temperature at Leh nearly 1^{o}C for the winter months and 0.5^{o}C for summer months (Singh and Dwivedi 2011). Apparently over the past few years rising temperature and increased precipitation is slowly turning this cold and dry Himalayan desert into a warmer and wetter place with shorter winters and moderate summers (IPCC, 1995). The cultural landscape of this region especially at higher terrains, previously devoid of trees and vegetation is slowly converting into small farmlands and orchards. Recent climate change has triggered fast and large-scale impacts on cultural heritage of the landlock "Ladakh". Increased rainfall and rise in over all temperature has potentially dangerous effect on ancient structures and threatened the existence of historic monuments in the region. Changes in the climate not only affect the historic structures but impact on socio-economic status that in turns influences ever changing and developing cultural landscape. Traditional building materials and techniques that are unable to cope up with changing environment are replaced with technologies and materials from foreign lands. Experimentation and adaptation to new building materials and technologies without understanding their compatibility with the existing buildings and environment has resulted in rapid deterioration and disappearance of a cultural landscape developed and sustained for several centuries in this region. A strategy to conserve the historic structures in such dynamic and changing

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environment requires a scientific and multi dimensional approach that not only addresses the issue of materials and structural preservation through compatible intervention but at the same time puts forward a plan for sustainability through a designed maintenance and monitoring plan.

MATERIALS AND METHODS

The Leh-Ladakh region (Figure 1), one of the most elevated (2900m to 5900m asl) and coldest region (-35^{0}C to +35^{0}C) of the earth. It lies between 31^0 44’ 57’’ to 32^0 59’ 57” N latitude and 76^0 46’ 29’’ to 80^0 41’ 34’’ E longitude. Its eastern and western borders form the line of actual control (LAC) between India and China and line of control (LOC) between India and Pakistan, respectively (Fig. 1). Weather data of Leh district were collected for 2000-2013 from Defence Institute of High Altitude Research (DIHAR), Leh and State statistical department, Leh-Ladakh, J&K. These weather data are mainly of temperature (°C) (minimum and maximum), relative humidity RH (%), and precipitation (mm). Analysis of weather data and acreage data were carried out in MS excel, 2007. The survey was conducted via visit to the ancient structures, questionnaires and interviews with elderly people and head *lamas* regarding the past and present status of histrorical monuments in Leh ladakh of Jammu and Kashmir.

RESULTS AND DISCUSSION

Precipitation

Annual rainfall of Leh district is less than 100 mm and mostly occurs in form of snow. In the month of May, Snowfall was recorded in 2010; however from 2003 to 2009 there was no snowfall in this month (Table 1). Monthly mean of precipitation variability of Leh during 2000-2013 (Fig.2). In general, rainfall occurred during April to September is too meager (Ahmad and Kanth, 2014).

Relative humidity

Initial analysis of the data revealed that mean relative humidity (%) is highest at Leh in the month of February (55.6 %) and December (55.3%). It was also observed that the relative humidity prevailed low during May to September as compared to other periods. During the last decade, decreasing trend of relative humidity was observed (Fig.3b).

Temperature

It is most important weather parameter in cold arid region (Ladakh) and July was observed as the hottest month with mean maximum temperature reaching up to 28.9 °C. January was observed as the freezing month with mean minimum temperature reaching up to -15.39 °C. Monthly mean of maximum temperature varied from -0.8 °C to 26.9 °C during the year, while ranged from 14.07 °C to 26.9 °C during the summer season. In case of minimum mean temperature, it was also varied from -14.5 °C to 13.6 °C and in crop growing season it ranged from -0.3 °C to 13.6 °C. During the winter season range of mean minimum temperature was - 1.5 to -12.9 °C. Minimum temperature was observed above freezing point only for 5 months (May to September) during 2000-2013. Trend of the 14 years annual mean temperature data (maximum and minimum) indicated that global warming has a significant effect in the regional climate of Leh (Fig.3a).

Impact of Climate Change on historical monuments

Geographical isolation as a natural barrier in the himalayas helped in the survival of historic buildings for centuries until the 1970s when the region was allowed visitors for the first time in 1974. The last thirty years have witnessed an irreversible erosion of cultural, social and architectural fabric of the heritage components. Regular rainfall and frequent seismic activity have further challenged the existence of these earthen structures and resulted in their rapid deterioration.

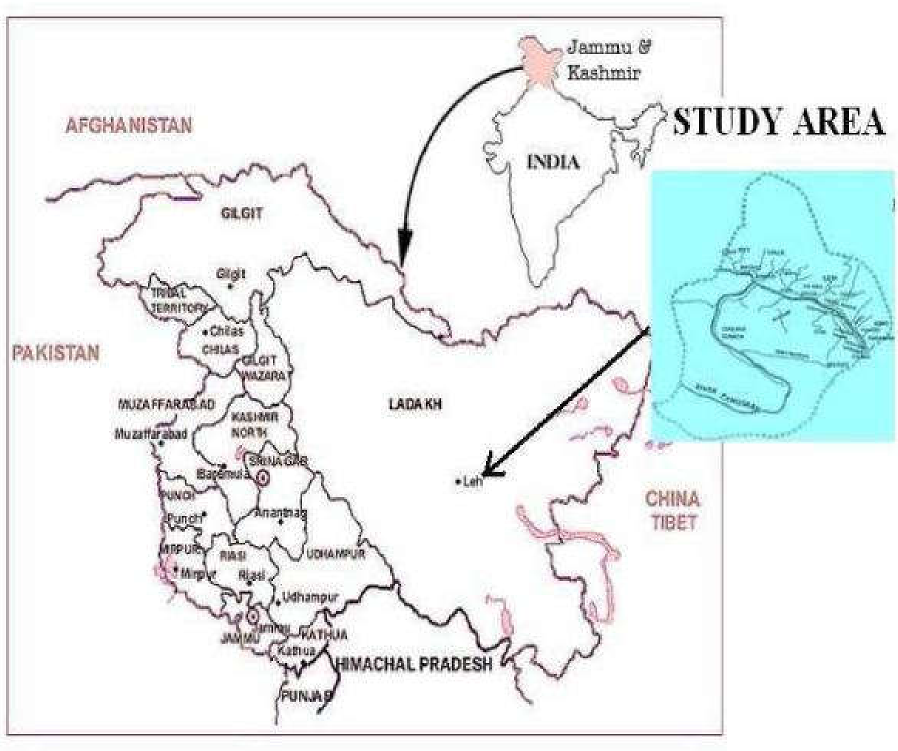

Fig.1. Map of study area

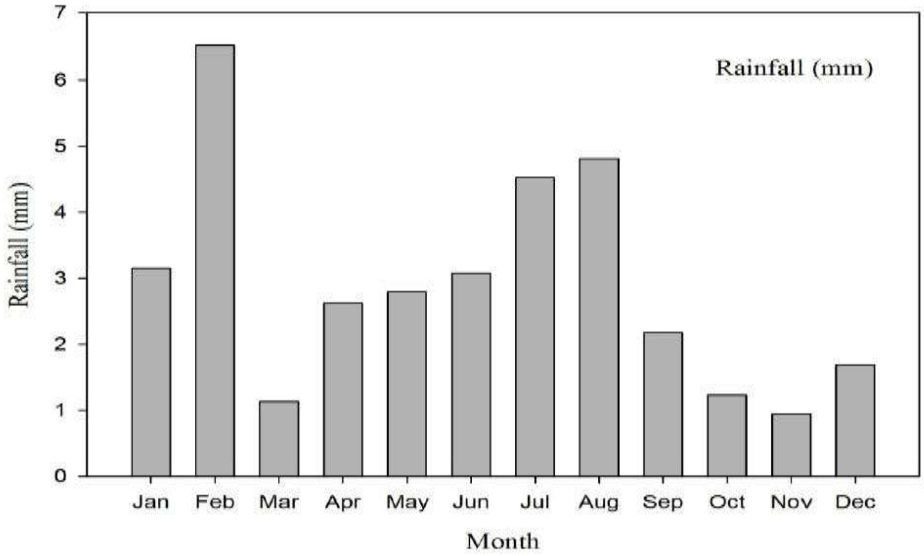

Fig.2. Monthly mean of rainfall during 2000-2013

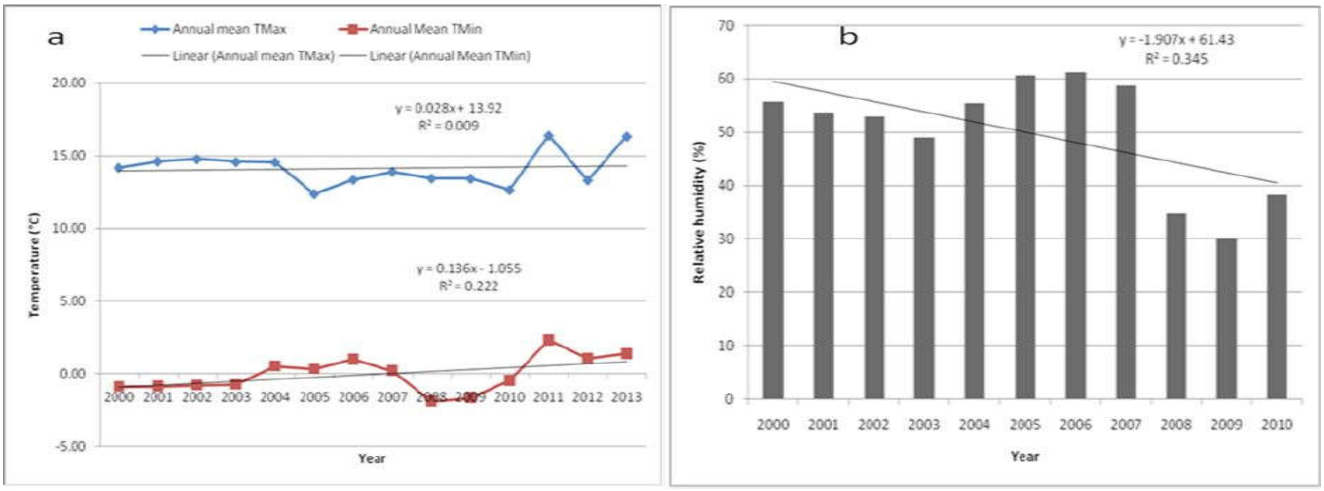

Fig.3. a) Mean annual temperature (maximum and minimum) trend during 2000-2013, b) Annual mean of relative humidity trend during 2000-2010

Table. 1: Monthly mean of precipitation (mm) (R-rainfall and S-snowfall) during 2004-2010

Month	2004	2005	2006	2007	2008	2009	2010
Jan	55 (S)	58(S)	29(S)	NIL	21(S)	66(S)	15(S)
Feb	5(S)	135(S)	115(S)	41(S)	25(S)	20(S)	70(S)
Mar	48(S)	165(S)	NIL	NIL	NIL	5(S)	11(S)
Apr	12(S)	87(S)	24(R)	NIL	6.6(R)	NIL	42(R)
May	0.5 (R)	0.4(R)	NIL	NIL	8.7(R)	NIL	19.6(R)
Jun	9.5(R)	2.7(R)	NIL	5.2(R)	0.9(R)	4.4(R)	35.5(R)
Jul	NIL	28(R)	NIL	11.4(R)	10.3(R)	3.0(R)	2.5(R)
Aug	7(R)	NIL	78(R)	NIL	23.9(R)	5.5(R)	74.4(R)
Sep	6.5(R)	NIL	50(R)	NIL	23.5(R)	10(R)	12.5(R)
Oct	25(R)	NIL	NIL	NIL	NIL	40(S)	9(S)
Nov	NIL	NIL	3(S)	NIL	NIL	190(S)	NIL
Dec	NIL	NIL	615(S)	NIL	30 (S)	30(S)	97(S)

Source: Defence Institute of High Altitude Research, C/o 56 APO

The higher rate of rainfall in the western Himalayas (Ladakh) over the past few years has increased water intrusion into the walls of historic structures, causing erosion and washing away of finer particles from the internal and external plaster. The wide temperature fluctuations throughout the year, as well as heavy snowfall in winter and the accumulation and melting of snow, have not only caused leakage but also several structural problems, such as the sagging of wooden items due to excessive snow load.

Roofs, supported with structural wooden beams and rafters, rest directly on the load-bearing mud walls. Point loads developed by structural members resting on the walls without interstitial wall plates have created enormous stress on the walls, especially with vertical loads, such as snow-related dead load, or during oscillations caused by an earthquake. This stress has resulted in major and minor structural cracks below the ceiling level at the junctions between the roof and the walls. These cracks have now become the inlet points for water into the interiors. Moisture intrusion, temperature fluctuation, and lack of ventilation have made the interiors of the buildings humid, resulting in accelerated deterioration of the internal plaster and wooden structural things. Damp walls also impact the structural integrity of the polychrome clay sculptures by threatening the stability of their wooden supports in the walls. The addition of layers of clay intended to waterproof the earthen roof have contributed to the roof load even further. This has not only caused sagging of structural members but also deformation of load bearing walls especially in the upper courses just below the ceiling level. Below ground and semi-subterranean structures are the worst affected due to increased moisture level in the surrounding ground which seeps into the structure and its foundation in absence of a proper drainage system. Water intrusion into the foundations and seismic vibrations has also caused settling of load-bearing walls. It is known that the deteriorating agents do not act alone; action of one renders the surface or the structure susceptible to the subsequent action of another. Environmental humidity is another decay agent, which causes water-induced stress in the outer most porous surface of the walls and helps in the development of plants and microorganisms. Wind has been a main factor in the erosion of external renders, which with the impact of rain results in the loss of surface material. The surface exposed to several wet-dry cycles is easily abraded by coarse sand and dust particles carried by these high velocity winds in the region. Traditional adobe buildings, which are susceptible to the changing climate, have lost their creditability among the locals who now adapt moisture resistant cement concrete blocks or cement stabilized compressed mud blocks for new construction, additions and repairs to the existing buildings.

The traditional compacted mud roofs are either replaced with cement concrete slabs or with corrugated galvanized sheet metal roofing system. These actions are slowly changing the whole cultural landscape into a concrete and sheet metal jungle and resulting in a large-scale depletion of nearly a 1000 years old historic Man – Nature – Material relationship (Sikka, 2008). Cement, corrugated sheet metal, steel rebars and compacted cement stabilized block is manufactured and transported to the regions 100s or 1000s of kilometers from the lower regions of India contributing further to the deterioration of not only the region’s and the world’s environment but also the local economy and culture. Building materials are not in themselves good or bad. They are appropriate or inappropriate depending on the geographical, climatic and supply factors which also make them practical and sustainable. Changing climate certainly calls for re-evaluation of the entire situation from a scientific, environmental, social, cultural and economic perspective. A 1000-year-old cultural landscape that preserves in its terrains rare artwork, art forms and architecture requires a compatible yet sustainable modification to the traditional building materials and technologies, which not only responds to the changing environment but also at the same time alleviates dependence on imported materials. Reduced dependency on alien materials would not only improve the local economy but would ensure appropriate development and growth of cultural landscape.

Conclusion

Instead of undermining the durability of these structures in the present context, it is important to trace their evolution in history and understand the deterioration processes in order to further evaluate the structure, materials and the techniques that are specific to the Himalayan context in the light of changing times and needs. There is also a need to understand and implement conservation ethics. Knowing the soil types allows one to draw upon the scientific classification system for soil chemistry and mechanical properties. Such information is helpful for modification of these properties to achieve the desired performance. The last few years have witnessed the introduction of stronger and stiffer materials with more compressive strength, which have lead to a decrease in the durability of historical structures. The criteria for evaluation of different factors in the materials depend on their position in the whole structure. The roofs are too heavy for historic walls and the walls have undergone serious deformations due to previous seismic activity. Retrofitting of roofs would alter and interfere with the historic fabric. Such upgrading of the performance characteristics of historic buildings without making significant alterations in the architectural typology is a matter of great challenge for designers and craftsmen alike. These interventions were made to the historic roofing by insertion of waterproofing layer and perimeter drainage. Large-scale applications of conservation science like this must involve local craftsman. Dedicated craftsmen ensure sustainability and quality control of procedures and materials of the proposed interventions.

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