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Research Article
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An Assessment of Climate Change-Natural Disaster Linkage in Indian Context

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Abstract

Natural disasters and climate change are fast emerging as the most defining challenges of the 21st century. India`s unique geo-climatic condition makes it highly susceptible to climate change and natural disasters. The country has observed significant anomaly in natural variability of temperature and rainfall patterns and has experienced more frequent and lethal disasters in recent decades. Almost unanimous but uneven temperature rise over the Indian subcontinent has propelled more energy in regional and local climate systems, and thus, has magnified climate anomalies and frequency as well as severity of natural disasters. The paper investigates the climate change and natural disasters propensities and highlights the climate change-disaster linkage in Indian context. It also identifies vulnerable areas and suggests some policy measures which may be of great help in reducing the impact of these catastrophes on society.

Keywords: Geo-physical events; Climate variability; Erratic rainfall; Poverty heartland; Silver bullet

Introduction

Natural hazards are balancing templates of the terrestrial system. These geo-physical events reoccur periodically to maintain the equilibrium between internal and external environment of the Earth. Before evolution of man, these events occurred threatening only prevailing flora and fauna but millions of years later, the human`s interaction with nature and their associated vulnerabilities towards these events transformed natural hazards into disasters. Climate has always been linked with disasters, so far, through climate variability manifesting in extreme weather events such as cyclones, storms, floods, droughts, heat waves, windstorms etc., with potential for catastrophic loss of human lives, damage to infrastructure and environment. Centre for Research on the Epidemiology of Disasters (CRED) categorizes natural disasters into hydro-meteorological disasters (floods, landslides, mudflows, avalanches, tidal waves, windstorms, cyclones, droughts, extreme temperatures, and complex disasters associated with drought) resulting from climatic variability and other climatic and meteorological causes, and geological disasters (earthquakes, volcanic eruptions and tsunamis) [1].

Natural disasters directly impact economies, agriculture, food security, water, sanitation, environment and health. Therefore it is one of the single largest concerns for most of the developing nations where they occur very often. Developing or poor countries are located to a great extent in zones largely affected by volcanic activity, seismicity, flooding, etc. and their economic, social, political and cultural conditions are not good, and consequently act as factors of high vulnerability to natural disasters.

India is traditionally vulnerable to natural disasters on account of its unique geo-climatic conditions. Swiss Re reports [2,3] related to 20 worst catastrophes in terms of victims indicates that India is one of the most victim-prone countries compared with others. Studies corroborate significant change in natural variability of temperature and rainfall patterns of the country, surmise a unison of climate change and disaster trends, and warn for more frequent and lethal disasters in foreseeable future [4-9]. For the Indian subcontinent, the projected temperature changes by IPCC, based on the General Circulation Model, project warming of 2-4.7°C, with the most probable level being around 3.3°C by the year 2100 [10]. Assessments by Indian Scientist using the Hadley Centre Regional Climate Model, show similar outputs and indicate that over the Indian region the temperatures will increase by 3 to 4°C towards the end of the 21st century [11-13]. The warming may be about 2.1 to 2.6°C in the 2050s and 3.3 to 3.8°C in the 2080s [14]. The warming is projected to be widespread over the country, and relatively more pronounced over northern parts of India [11]. While the rainfall is projected to increase, there would be variations in the spatial pattern, with some pockets showing increase and others experiencing decline in rainfall [15]. Most models project an increase in rainfall between 10 and 40 percent from the baseline period (1961–90) to the end of 21st century, with the maximum expected increase in rainfall over north western and central India [11]. The effect of possible changes in the intensity of the monsoons would be particularly sensitive, because large parts of India receive the majority of their annual precipitation during the summer monsoon rains, which already vary noticeably in different regions [12]. The summer monsoon is crucial to the annual precipitation total of the Indian subcontinent. The effect, this warming will have on the Indian monsoon, is still unclear, but increased variability in the monsoon rains as well as in climatological disasters is probable [10].

Although most of the climate projections are based on trend analysis of 30-40 years span and inherit high spectrum of uncertainty. Therefore amid thick discussions and varied speculations on climate-disaster commixture, a fresh interpretation is needed to evaporate confusions and make planners more aware about ground realities. The study makes an attempt to identify climate-disaster linkages in Indian context and investigate whether climate change has any footprint over disaster profile of the region. The main objectives are; a). to assess the trend and pattern of natural disaster and climate change, and to identify relationships between the two through a retrospective study covering the period 1909–2010; and b). to identify geographical areas within the country at risk of adverse impacts of climate change and natural disasters.

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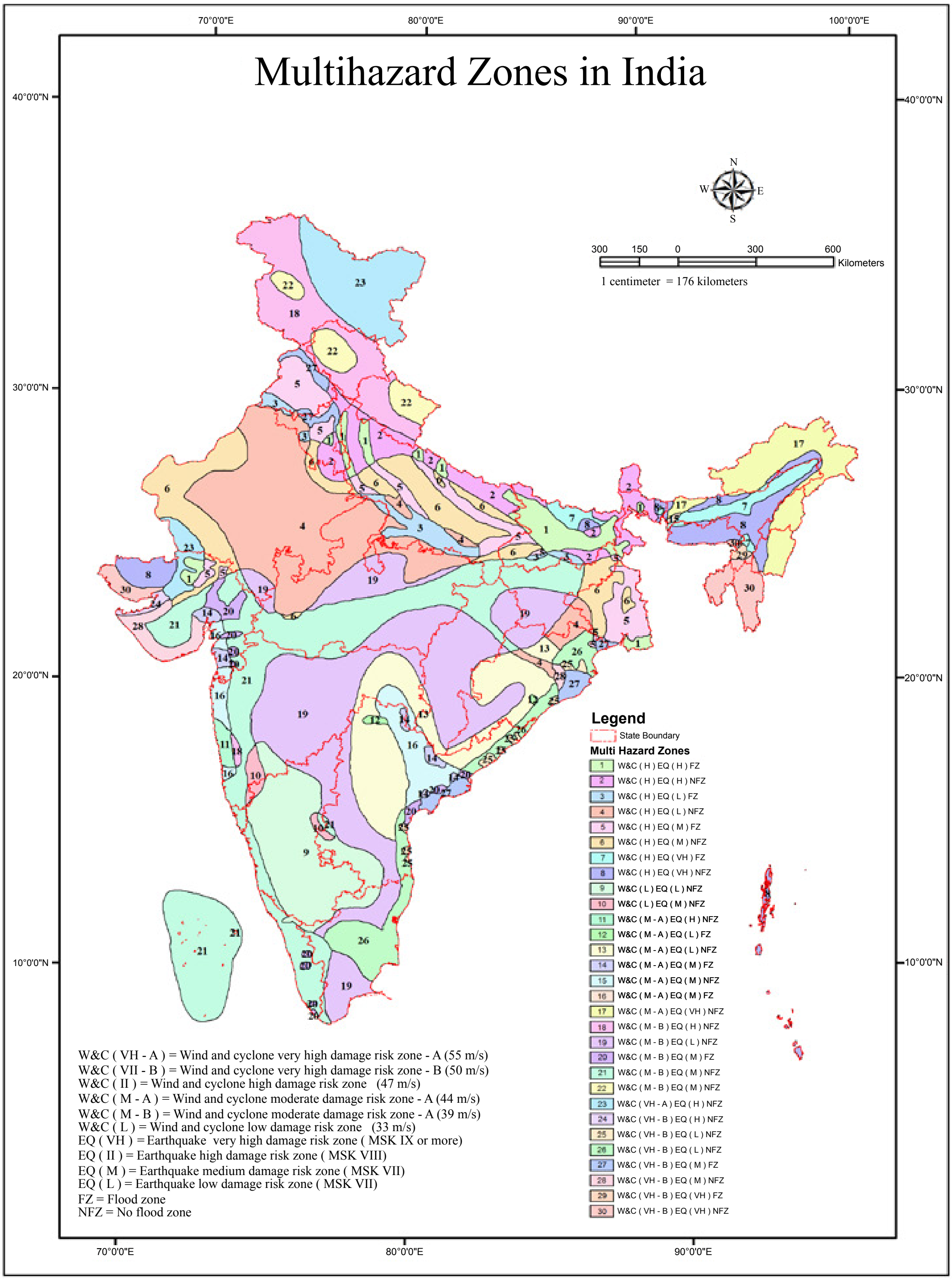

Figure 1: Based on Vulnerability Atlas of India, BMTPC.

Climate elements are interdependent and mutually reinforcing. Therefore trend of any component, e.g. temperature, rainfall etc., encompasses the conjoined impact of all components inherently. General Circulation Models, used widely for climate projection, consider effect of every component separately, and thus, may cause multiplier effect and produce a hyper-exaggerated picture of climate change. To settle this conflict, the study uses simple regression analysis for tracing the path of future climate changes in the region. Five major natural hazards- flood, drought, landslide, cyclone and earthquake, have been analyzed on the basis of their frequency and impact during

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the past century. Although earthquake hazard has no climatological origin, but study is of the view that climate change, if occurring, may change the lithospheric balance, and thus may call for more frequent seismic activities. The analysis is mainly based on secondary data, obtained from the International Disaster Database (EM-DAT), Indian Meteorological Department (IMD) and Census 2011, Government of India. Multi hazard zones of the country have been identified on the basis of Vulnerability Atlas of India prepared by BMPTC. To portray the temperature and rainfall patterns over the subcontinent, district level data have been used and climate pattern of districts has been mapped on the basis of correlations between annual average temperatures and annual total rainfall of 101 years.

Natural Disaster in India

India continuously receives distress due to natural disasters where no part of the country lies under disaster free zone (Figure 1). The country loses almost 2 percent of its GDP every year due to these calamities [16].

Among the 35 total states/ Union Territories in the country, 27 are disaster prone [17], and more than 250 million people each year are affected by disasters caused by nature [18]. The states of Bihar, Jharkhand, West Bengal, Odisha, Chhattisgarh, Madhya Pradesh, Rajasthan, Uttar Pradesh and Assam account for India`s 55 percent population and 46 percent area (Figure 2), constitute the poverty

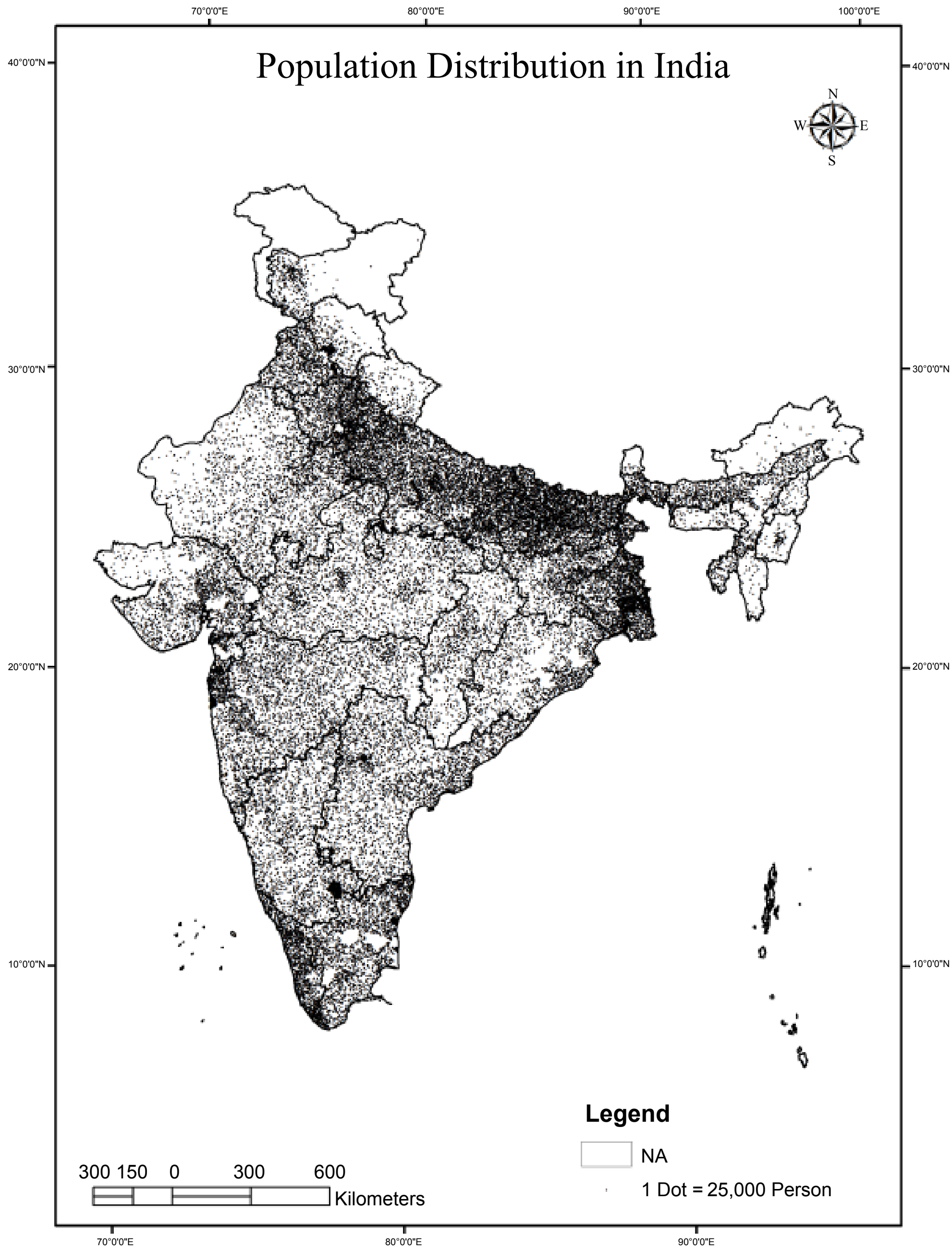

Figure 2: Based on Census 2011, Government of India .

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heartland of the country (Figure 3). These densely populated and mostly agrarian economy states record high loss of life and property almost every year due to natural disasters.

Owing to its diverse hypsographic and climatological conditions, many parts of the Indian sub-continent are susceptible to different types of disasters, but high magnitude floods during the monsoon season are considered to be country's recurring and leading natural disaster [19]. In India seventy five percent of rainfall is concentrated over four months of monsoon (June - September) and as a result almost all the rivers carry heavy discharge during this period. The flood hazard is compounded by the problems of sediment deposition, drainage congestion and synchronization of river floods with sea tides in the coastal plains. The Brahmaputra and the Ganga Basins are the most flood prone regions. The other flood prone areas are the western region due to over flowing rivers such as the Narmada and the Tapti, Central India and the Deccan region with major eastward flowing rivers like the Mahanadi, the Krishna and the Kaveri. The area liable to floods in India is about 34 million hectares which is shared mainly by Uttar Pradesh (21.9 percent), Bihar (12.71 percent), Assam (9.4 percent), West

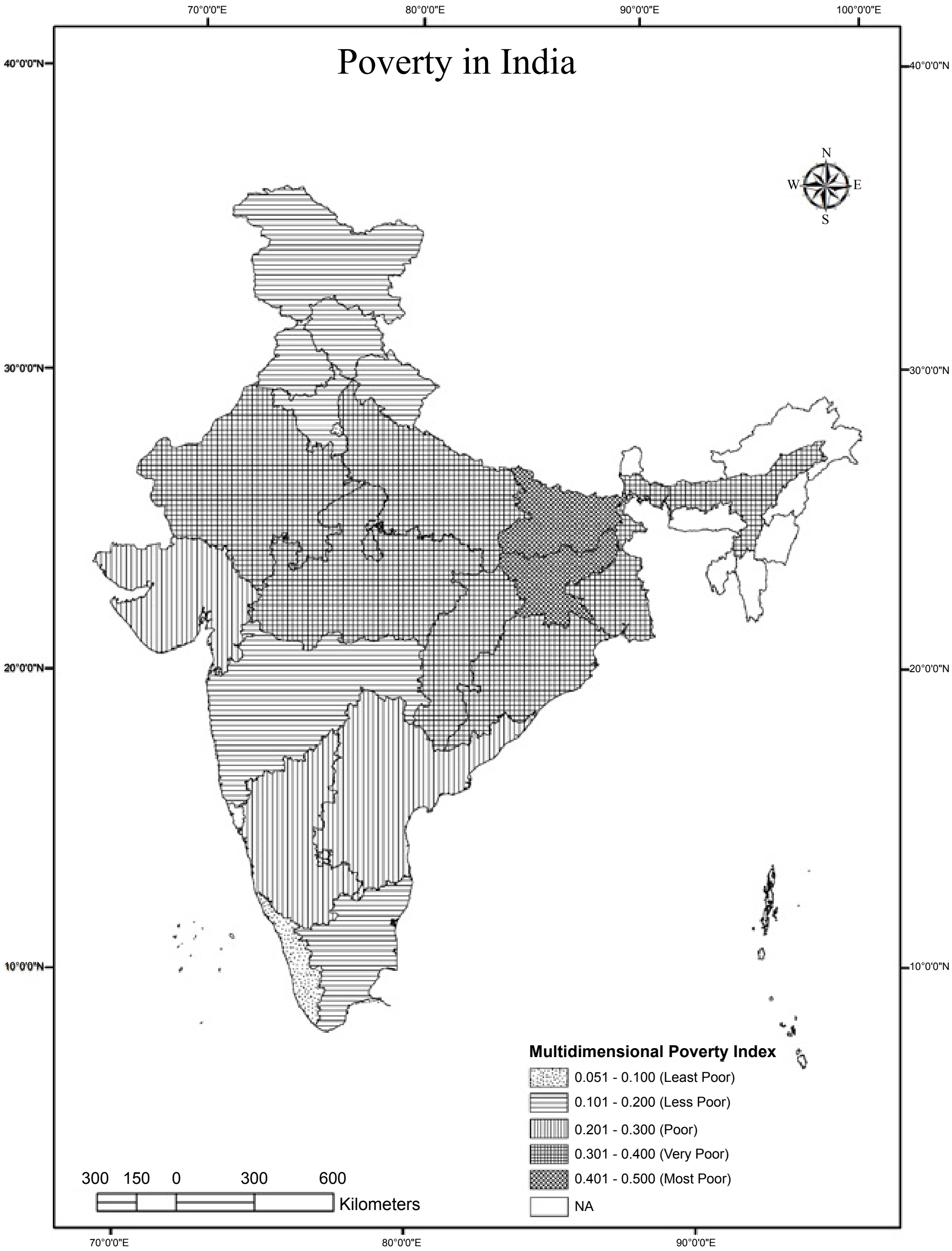

Figure 3: Based on UNDP Human Development Report 2011.

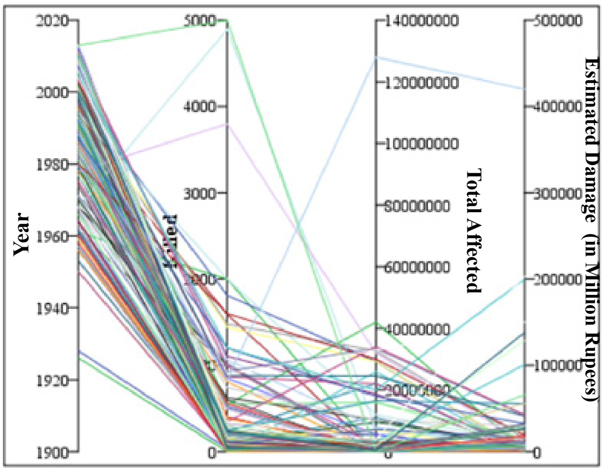

Figure 4: Floods and their Impacts in India (1901-2013) (Based on Disaster List, EM-DAT).

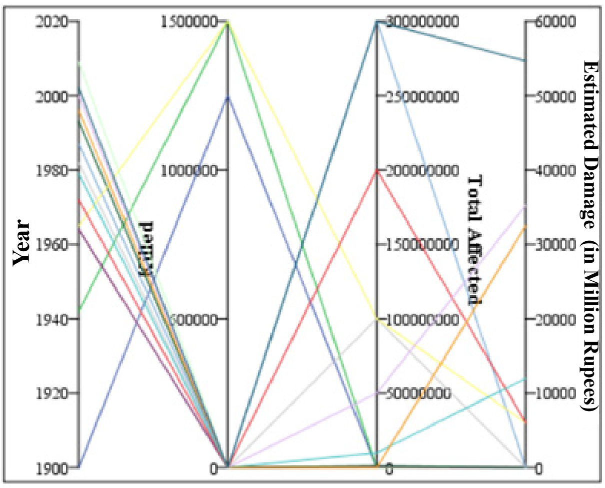

Figure 5: Droughts and their Impacts in India (1901-2013) (Based on Disaster List, EM-DAT).

Bengal (7.91 percent) and Orissa (4.18 percent), while Punjab (73.47 percent), Haryana (53.15 percent), Bihar (45.24 percent) and Assam (40.16 percent) are the major flood hit states of the country (Ministry of Water Resources). The country has witnessed more frequent and devastating floods in recent decades (Figure 4). Between 1900-2013, India has experienced 253 medium and perilous floods out of which 123 occurred during 2000-2013 and 201 during 1980-2013 (EM-DAT).

Drought makes a very perceptible impact on populations that are largely dependent upon agriculture and related occupations for their livelihood. The frequency of drought in the country has varied over the decades, but has intensified with time (Figure 5). A study by Chowdhury et al., [20] have ranked the year 1918 as the worst drought year of the last century- a year when about 68.7 percent of the total area of the country was affected by drought. From 1899 to 1920, there were seven drought years. The incidence of drought came down between 1941 and 1965 when the country witnessed just three drought years. Again, during 1965–87, of the 21 years, 10 were drought years and the increased frequency was attributed to the El Nino Southern Oscillation (ENSO) [21]. Among the drought years, the 1987`s drought affected 59–60 percent of the crop area and a population of 285 million [22]. In 2002 too, the overall rainfall deficiency for the country as a whole was 19 percent and over 300 million people spread over 18 states were affected by drought in varying degrees [23]. No other drought in the past had caused reduction in food grain production to this extent.

Storms and cyclones are a potential shock for India, especially for coastal regions and a significant decadal variability in their occurrence has been noticed [24,25]. Although studies suggest a decreasing trend in frequency of Tropical Cyclones and Monsoon Depressions over the north Indian Ocean in recent years [26,27], a significant increasing trends (20 percent per hundred years) during November and May over the past decades, have been registered [28]. The country faced maximum number of severe cyclones (34) during the decades 1981-90 and 1991-2000 and minimum (1) in 1911-1920. The last decade of the past century had 24 severe cyclones while 29 lethal storms hit the country during 1971-80 (EM-DAT). During past 3 years alone (2011-2013), India has faced 5 strong cyclones which affected the economy of Odisha, Andhra Pradesh and Tamil Nadu states badly. While these hazards show a notable variability, the damage and destruction from such systems do not seem to decrease (Figure 6).

India is a seismically active region and the Himalayas frontal that are flanked by the ArakanYoma fold belt in the east and the Chaman fault in the west, constitute one of the most seismically active zones in the world. The country has suffered some of the greatest earthquakes with magnitude exceeding 8.0. For instance, in a span of about 50 years, four such earthquakes occurred: Assam earthquake of 1897 (magnitude 8.7) [29], Kangra earthquake of 1905 (magnitude 8.6) [30], Bihar-Nepal earthquake of 1934 (magnitude 8.4) [31], and the Assam-Tibet earthquake of 1950 (magnitude 8.7) [32]. During the last two decades, seven devastating earthquakes, chronologically, the 1991 Uttarkashi earthquake in the western Himalaya, the 1993 Killari and the 1997 Jabalpur earthquakes in the central part of peninsular India shield area, the 1999 Chamoli earthquake again in the western Himalaya, the 2001 Bhuj earthquake in the western part of peninsular shield area, the 2004 Sumatra-Andaman mega thrust tsunami earthquake in the Andaman-Sunda arc and the 2005 Kashmir earthquake in the western Himalaya syntaxis zone, caused severe damages and large casualties in various parts of India. Notably the intensity of earthquakes has been less in

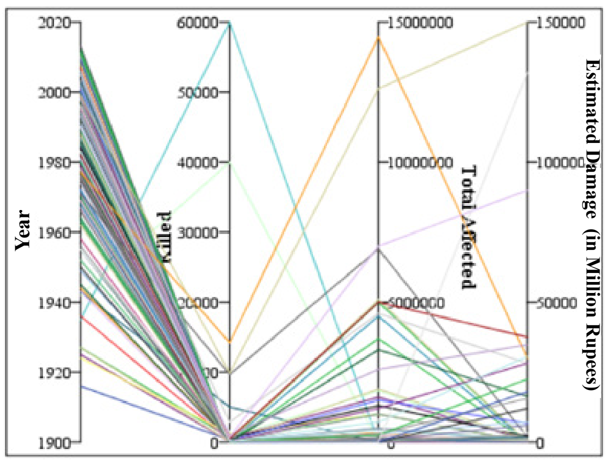

Figure 6: Storms/Cyclones and their Impacts in India (1901-2013) (Based on Disaster List, EM-DAT).

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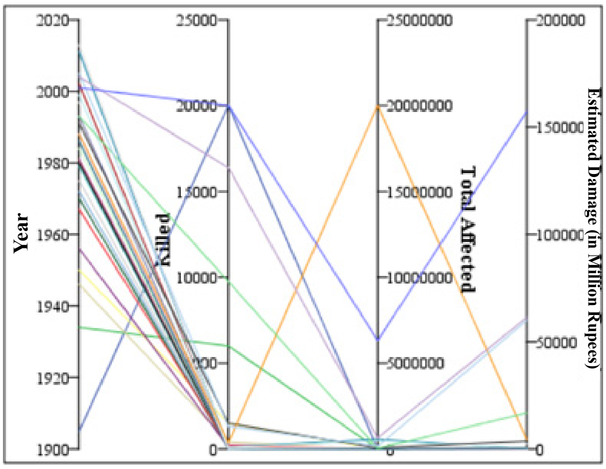

Figure 7: Earthquakes and their Impacts in India (1901-2013) (Based on Disaster List, EM-DAT).

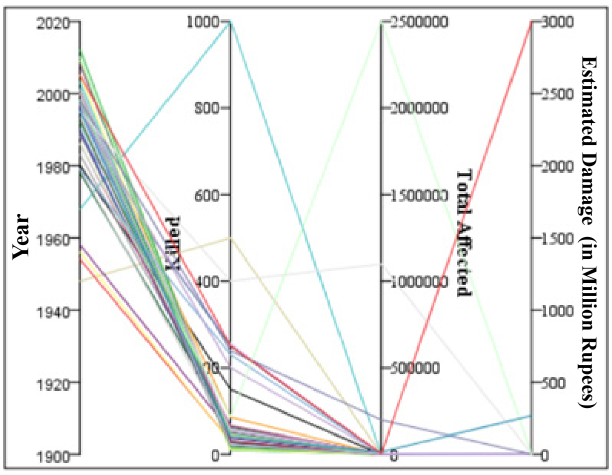

Figure 8: Landslides and their Impacts in India (1901-2013) (Based on Disaster List, EM-DAT).

recent decades as compared to earlier but their occurrence has sown significant increase (Figure 7).

Landslides are another major natural hazards that affect at least 15 per cent land area of the country- an area which exceeds 0.49 million km^2. Landslides of different types are frequent in geo dynamically active domains in the Himalayan and Arakan-Yoma belt of the North-Eastern parts of the country as well as in the relatively stable domains of the Meghalaya Plateau, Western Ghats and Nilgiri Hills. In all, 22 states and parts of the Union Territory of Pudducherry and Andaman and Nicobar Islands are affected by this hazard. The phenomenon of landslides is pronounced during the monsoon period. It has been estimated that, on an average, the damage caused by landslides in the Himalayas costs more than 60 billion rupees, besides causing about 200 deaths every year, which amounts to 30 percent of such losses occurring world-wide [33]. In 1998, due to massive landslides in Ukhimath area, Garhwal Himalayas, 101 people were dead and several families were affected [34]. Also, Malpa landslide wiped out the whole Malpa village in Uttaranchal during 1998 and at least 210 people were dead [35]. Other major landslides namely Phata landslide of 2001, Budhakedar landslide of 2002 and Uttarkashi landslide of 2003 are burning examples of Himalayan pang. The terrific memories of Kedarnath Flood of 2013, which caused large-scale human fatalities, displacements, resources damage and environmental-social destruction [36], are still alive in the land of gods. Studies suggest considerable increase in frequency and magnitude of landslides in recent times over the subcontinent, especially in Himalaya and Nilgiri regions [37,38] (Figure 8).

Noticeably human losses and economic damage from natural disasters show an upward trend. During the past 100 years (1913-2013) the country has received 51.4 percent of its natural disasters from floods, 32.7 percent from storms, 7.4 percent from landslides, 5.6 percent from earthquakes and 2.9 percent from droughts. Table 1 shows the uneven distribution of these disasters in different time regimes.

Source: EM-DAT

It is evident that the frequency and impact of natural disasters in the country has been higher during recent decades and studies attribute this trend to climate change [39-44].

Climate Change in Indian Perspective

Climate change stresses the key human needs for food, water, and shelter. Furthermore, it indicates that the world's poorest countries, which already struggle to meet these basic needs, will suffer the most from climate-related stresses. Climate systems are linked together by the energy cycle and they all are very precariously balanced. Temperature and pressure gradients determine the climate regime of a region and even a little variation in temperature can stimulate a great change in the natural ecosystem by propelling more power in mass-energy cycles. Temperature trend of past 101 years (1909-2010) suggests a continuous increase almost over the entire country, yet this rise is insignificant in states of Haryana, Punjab, NCT of Delhi and Northern Rajasthan (Figure 9). It is noteworthy that during the period, three districts of Rajasthan state in the country- Jaipur, Dausa and Sikar, recorded negative trend while the Alwar district of the state did not show any measurable change in average annual temperature.

Although country`s temperature pattern of the past century reveals significant rise especially during last 30 years, rainfall patterns show negative trend. Yet the variability of rainfall has been higher in recent decades (Figure 10).

Several studies have attempted to assess the effect of urbanization, industrialisation and mining activities on temperature trends [45-51]. It is assumed that large and densely populated urban, industrial and mining areas are key to temperature rise. However, India`s temperature and rainfall profile does not fully endorses this perception. The largest urban and industrial areas of the country- Delhi, Mumbai and Kolkata, are not the warmest regions while irrespective of their moderate urban population percentage, the North-east and South-east regions are warmer as compared to rest of the country (Figure 11).

As far as relationship between terrestrial temperature rise and mining is concerned, the states of Odisha, Rajasthan, Jharkhand, Chhattisgarh, Gujarat and Madhya Pradesh, contributing about 45 percent mineral produce of the country [52], show significant warming trend. The warming is more prominent in the states of Andhra Pradesh, Assam and Karnataka, while they share about 15 percent of India`s mineral produce (Figure 12). This correlation asserts the weight of mining activities over regional climate profiles. Mining areas face large scale deforestation and environmental stress. Tonnes of dust and mineral particles omitted in surroundings disturb the regional insolation profile and provide condensation nuclei to humid air and

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Natural Disaster	Number of Events	Percent Share			Number of Person Killed	Percent Share		
	1913-2013	1983-2013	1993-2013	2003-2013	1913-2013	1983-2013	1993-2013	2003-2013
Drought	14	42.86	28.57	7.14	4250320	0.01	0.0004	0
Earthquake	27	51.85	25.93	11.11	61817	53.76	34.89	2.3
Flood	250	74.4	56.8	37.2	61243	59.2	41.18	18.78
Landslide	36	72.22	52.78	11.11	3979	45.66	32.12	2.61
Storm	159	52.83	35.85	15.72	164334	12.74	10.52	0.62

Table 1: Natural Disasters in India.

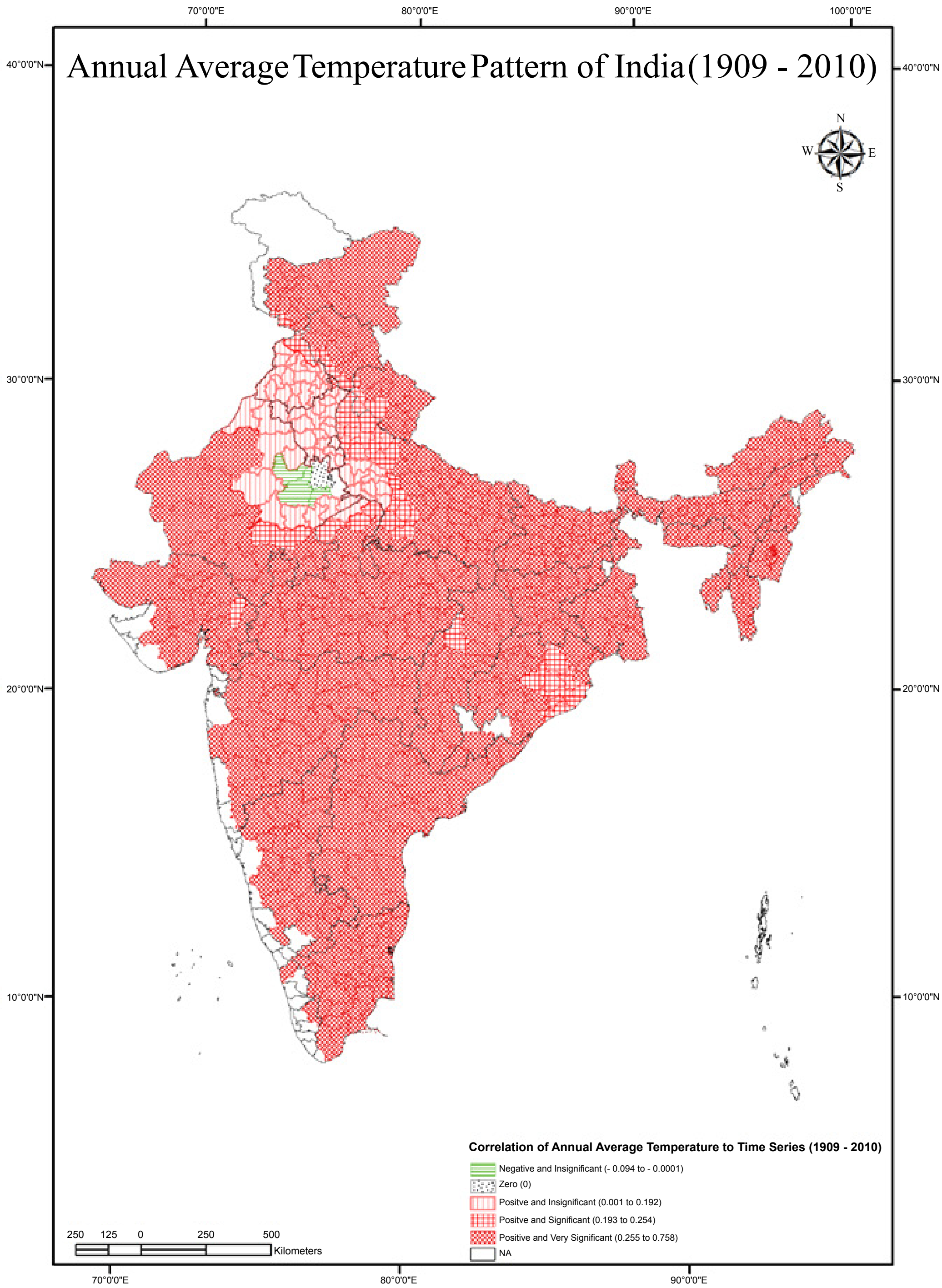

Figure 9: Based on 100 Years District-wise Temperature Records of India, IMD.

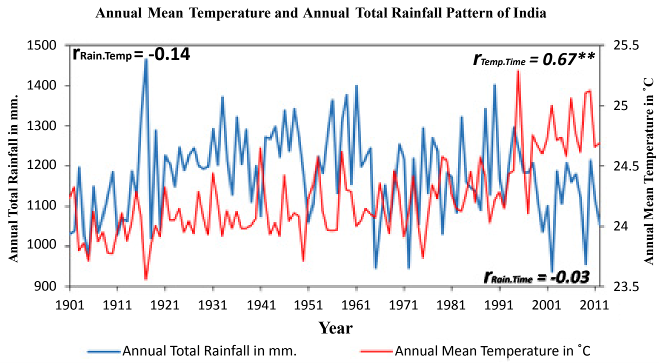

Figure 10: Based on 110 Years Temperature and Rainfall Records of India, IMD.

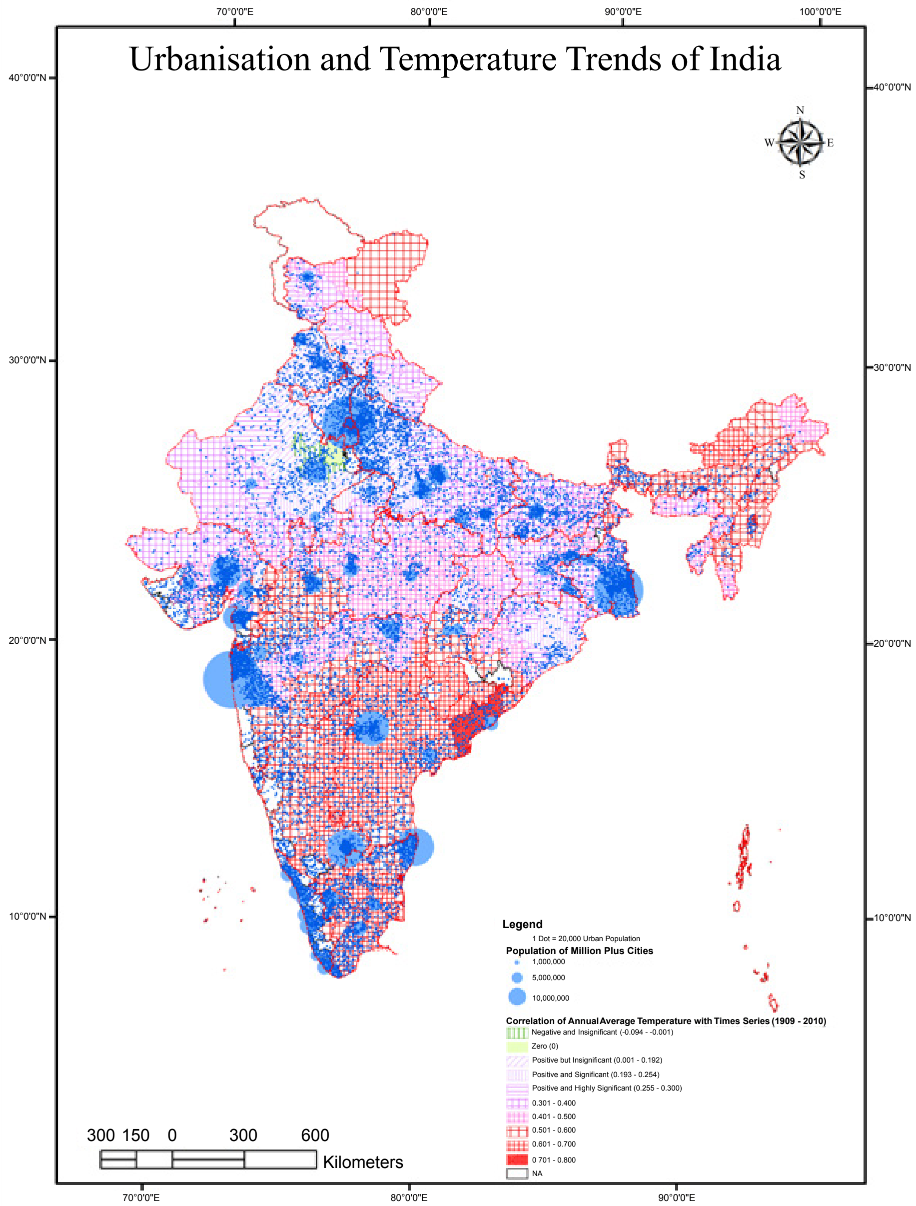

Figure 11: Based on 100 Years District-wise Temperature Records of India, IMD.

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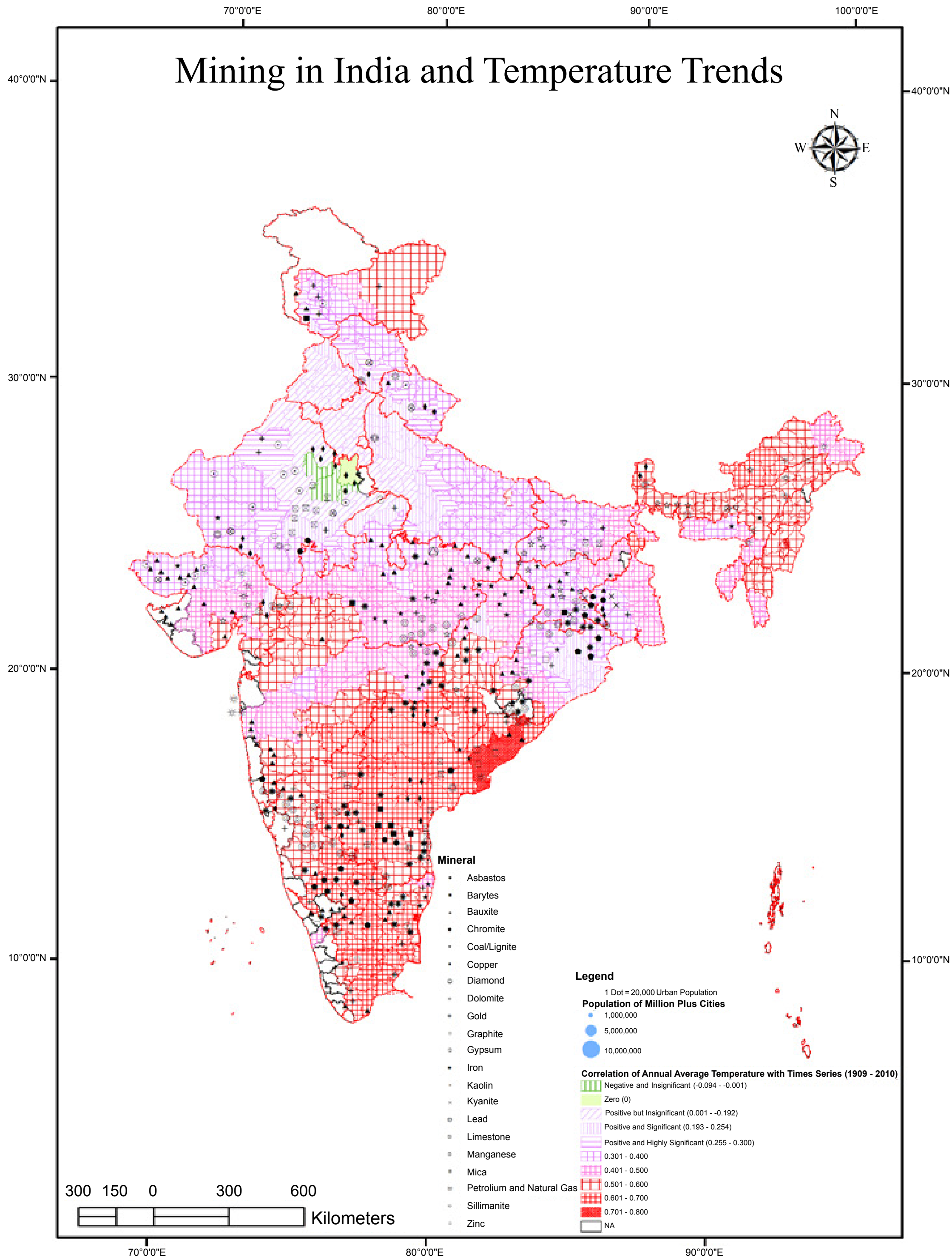

Figure 12: State-wise Mineral Scenario, Ministry of Mines, Government of India.

thus lead to fragmented weather and uneven rainfall pattern over the region.

Vegetation cover moderates the climate profile of a region and supports regional sustainability as it play a critical role in hydrological and carbon cycles. Change in vegetation cover changes the albedo and brings spatial imparity in rainfall and temperature patterns [53-55]. Observations suggest that extensive deforestation often reduces cloud formation and rainfall, and accentuates seasonality [56]. Vegetation loss has been implicated as contributing to declining rainfall in India, as well as to weakening monsoons [57-59]. However, it is difficult to attribute temperature and rainfall variability directly to land forest ratio. The states of Karnataka, Tamil Nadu and Andhra Pradesh, having

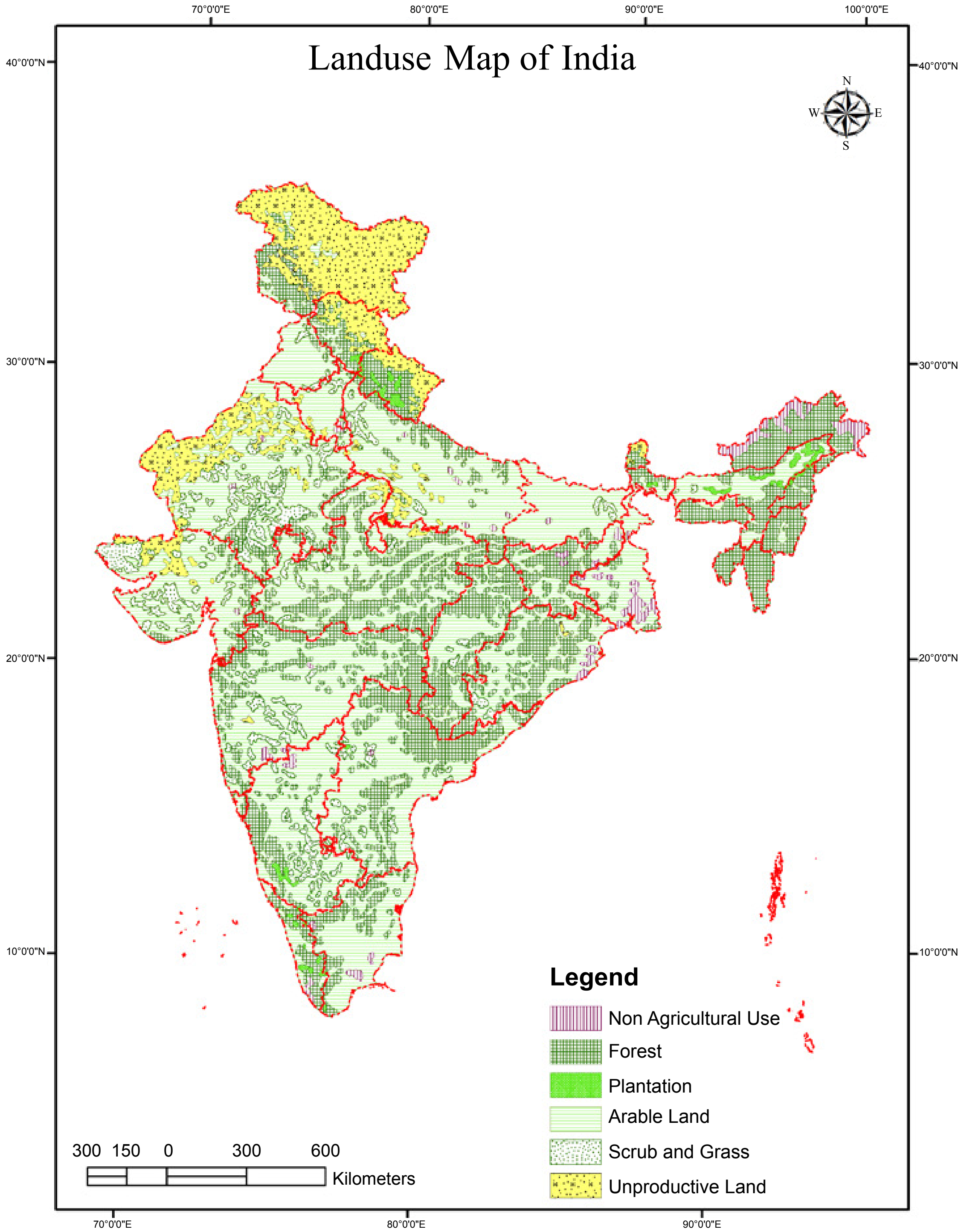

Figure 13: Based on Environmental Atlas of India, Central Pollution Control Board, GOI.

18.87 percent, 18.16 percent and 16.86 percent of their area under forest cover (Figure 13), are witnessing very significant temperature rise. On the other hand, having the highest percentage area under forests, states of Arunachal Pradesh (80.50 percent), Nagaland (80.33 percent) and Manipur (76.54 percent) [60] too are experiencing notable warming trend.

Primarily it seems quite confusing to attribute this warming to anthropogenic activities, but when we combine all the factors, it reflects the human weight over physical factors for enhanced terrestrial temperatures as areas of high population density, high urbanisation and intense mining activities are the most warmed regions.

Indian monsoon rainfall is highly influenced by atmospheric factors such as regional pressure anomalies [61], cyclonal activities [62] and sea surface temperature variations [63]. Rainfall pattern of past

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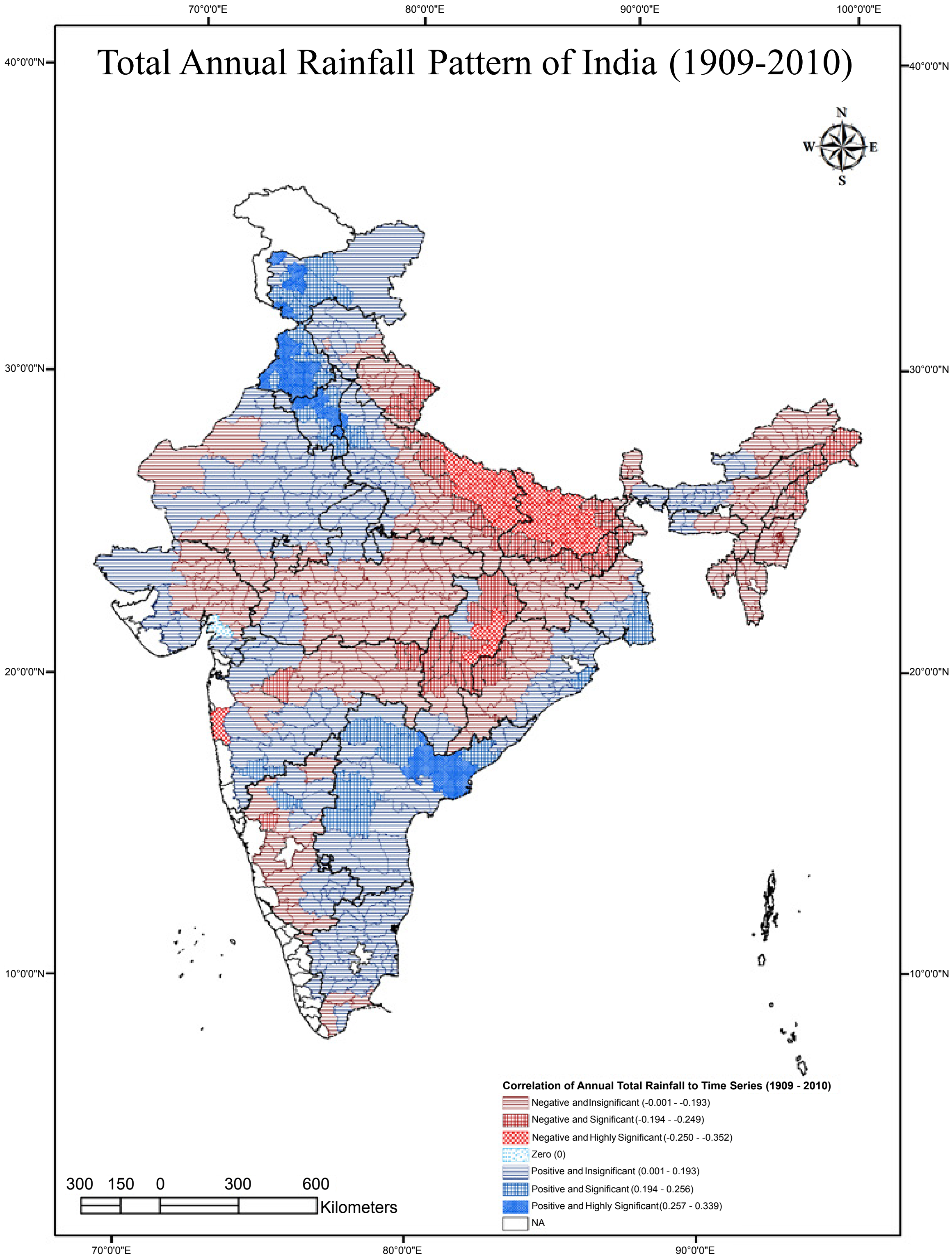

Figure 14: Based on 100 Years Rainfall Records of India (Total annual rainfall pattern of India).

100 years of the country (Figure 14) reveals that Eastern-coastal, North and North-west regions have received more rainfall than usual while the Central and North-east regions have recorded a decreasing rainfall trend. Correlates of temperature and rainfall of the country shows very significant change in climate pattern (Figure 15) and it is indicative that most of the portion of the country is likely to witness drier seasons and frequent droughts than normal.

Since temperature is the most important parameter controlling

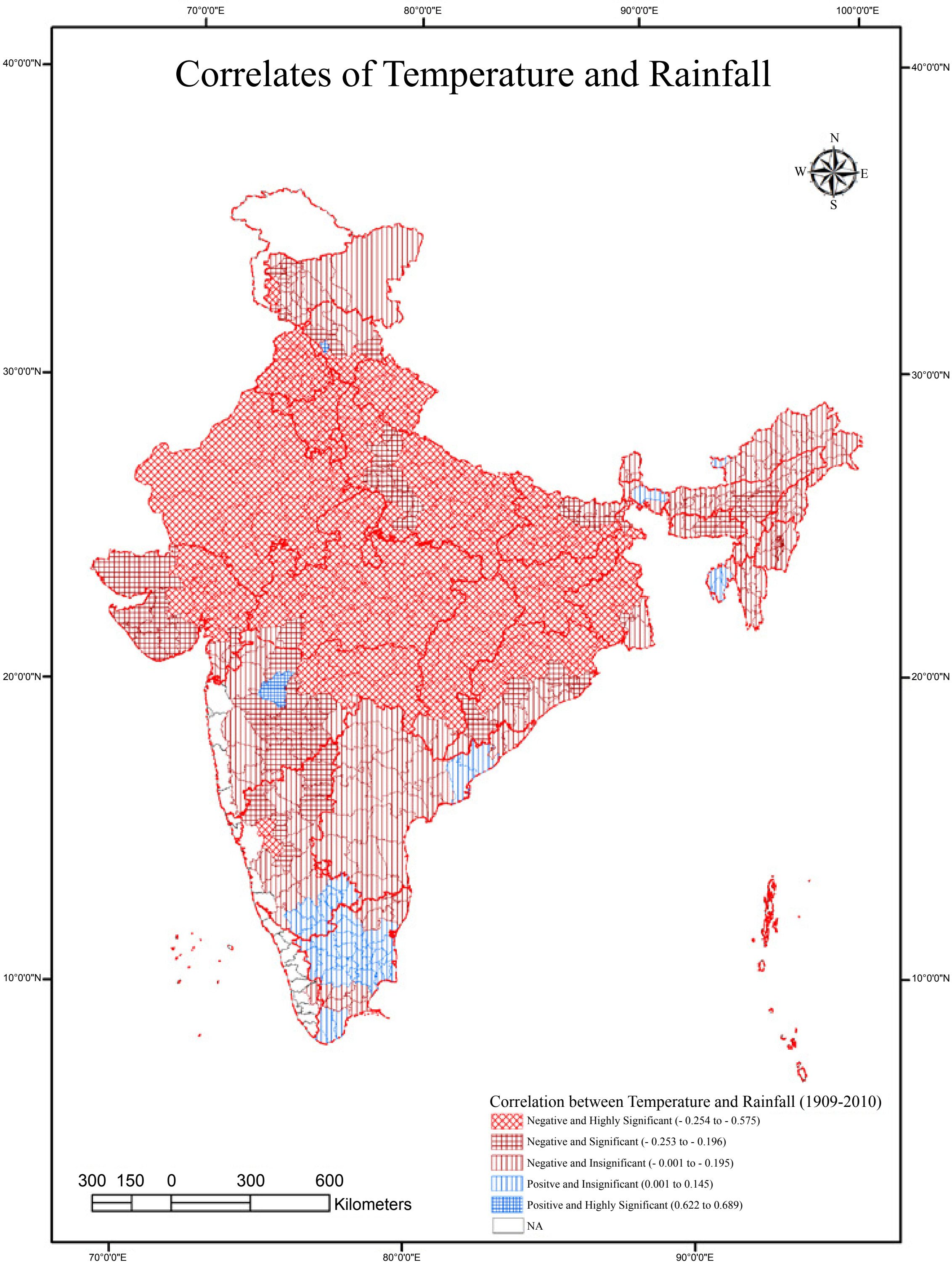

Figure 15: Based on 100 Years District-wise Temperature and Rainfall Records of India, IMD.

the overall weather and climate of a place, once it undergoes non-uniform temporal and spatial changes, the consequences are the likely intensification of the general impacts of climate change. Due to the heterogeneity in the topography and climatic conditions, the rise in the surface temperature is not the same in all parts of the country. The North-west region which is the key to trigger monsoon, has recorded moderate while the Southern region has recorded a very significant rise in temperature during the past century. This has great bearing on the pressure gradient between these two monsoon defining locations, and indicates for weak monsoon and its untimely trigger over the

	Time Series(1901-2013)	Drought	Earthquake	Flood	Landslide	Storm	Annual Rainfall in mm.	Annual Mean Temperature in˚C
Time Series(1901-2013)	1							
Drought	.227*	1						
Earthquake	.347**	-0.001	1					
Flood	.722**	0.140	.265**	1				
Landslide	.503**	.198*	.206*	.374**	1			
Storm	.669**	.282**	.200*	.409**	.405**	1		
Annual Rainfall in mm.	-0.030	-.271**	-0.030	-0.074	-0.020	-0.017	1	
Annual Mean Temperature in ˚C	.677**	.291**	0.160	.611**	.448**	.441**	-0.141	1

Table 2: Correlation Matrix of Rainfall, Temperature and Major Natural Disasters in India (1901-2013) (*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level).

Indian Sub-continent. The uneven warming trend has developed local warm patches affecting the monsoon mechanism. This local influence has fragmented the Indian monsoon and increased the frequency and intensity of climatological disasters in the country. The Indian mountains are also warming and thus attracting more clouds and torrential rains. Heavy rain increases the viscosity between rock layers and brings massive landslide in these areas. High temperatures than usual in the coastal and North-east regions of the country has increased the instances of storms hit in recent time. Extended deep-depression over these regions provide more energy to cyclonic winds on account of which these cyclones are becoming more lethal day by day, even after sufficient technological development and increased awareness.

Climate Change - Natural Disaster Nexus

Natural disasters are regarded as the ultimate expression of the destructive forces of nature. They have a distinct geography and feature often on the evening news around the world. While natural variability continues to play a key role in climatological disasters, climate change has shifted the odds and changed the natural limits, making certain types of disasters much more frequent and more intense. The impact of climate change on natural disaster is the most widely discussed consequence of climate change. In fact, it is often the only area addressed in several climate change vulnerability studies [64-66]. Natural disasters are a function of the hazard itself, exposure and resilience. Hence, if climate change increases the frequency and magnitude of certain natural hazards, it may lead to more frequent and more severe disasters, depending on direction and magnitude of changes in exposure and resilience. There is now evidence that with increasing temperatures, precipitation extremes above a certain temperature may increase twice as fast as predicted by the Clausius-Clapeyron relationship between temperature and atmospheric water holding capacity [67]. In addition, duration and frequency of atmospheric circulation, that determine the duration of rainfall, may shift because of climate change. Statistics of climate-related natural disasters since 1901 reveal very clearly that there has been a dramatic increase in losses resulting from such catastrophes in recent decades.

A trend analysis of past 112 years (1901-2012) shows decrease in normal rainfall over the country (Table 2), although this change is so insignificant to incriminate human activities. During the same period drought occurrences increased significantly which indicate for unequally distributed but torrential rains. Human encroachment and heavy siltation in river beds and other water bodies have exacerbated the flood risks.

The study suggests that surface temperature over the country may increase by 0.6-0.7˚C up to 2050 and 0.9-1.1˚C up to 2100 A.D., and alludes that southern part of the country may experience more warming than the north. The North-east states too are facing significant temperature rise. This may lead short duration torrential rains, and would promote stormier and drier seasons in the area. Storm occurrences over the country have also increased significantly during the past century and its highly positive correlation with increasing temperature warns for more frequent and strong storms hitting the country in near future. South-eastern states - Odisha, Andhra Pradesh, and Tamil Nadu, are at the highest risk of Cyclones and recent catastrophe of Laila and Phailin (showed there grave concerns. Over the great roar of Himalayan melt down, the study supports the view of up-shifting of glacial line but in the meantime increased monsoon sucking force over the region has stimulated thick snowfall and heavy downpour in recent times. Short duration Torrential rains have increased the frequency and intensity of landslide disasters in the mountainous regions and especially in the Himalayas.

It is worth mentioning that the rivers flowing from Himalayan glaciers may shrink greatly on account of less rainfall in their catchment areas. The country has faced more frequent droughts in recent past. Due to decreasing precipitation and significant temperature increase, the entire northern region of the country is becoming drier. This region is dependent mainly on agriculture and declining water availability in external channels will increase the groundwater extraction and depletion of water table. Groundwater aquifers help maintaining pressure between lithospheric layers and depleting aquifers may call for a collapse of these layers resulting into earthquakes and ground tremors. The country has witnessed frequent earthquakes in recent decades and although direct attribution may not be justifiable, climate change seems to have significant impact on it.

Apart from these natural agents influencing climate and thereby natural disasters, mining, urbanisation and deforestation too have significant and determining impact on the climate systems of the country.

Conclusion

Although natural disasters are beyond the control of human being, however, their impacts can be reduced by setting up of advanced warning systems. Technology may provide a “silver bullet” to cope the consequences of climate change and increasing disasters in the country. The catastrophic weight of these events on society can also be reduced through effective disaster management, and in formulating the management and mitigation policies, a composite disaster lethality index will be worth practicing. Present day natural disaster scales- the Volcanic Explosivity Index, the Richter Scale, the Palmer Drought Severity Index, the Saffir-Simpson Scale, and the Fujita Tornado Scale, which are used to warn communities, measure the nature disaster in terms of intensity of these hazards but do not include human vulnerability as a component. This index will address human vulnerability and will measure the severity of the disaster in terms of development setbacks. This Index may be calculated as: Natural Disaster Lethality Index=Percent GDP Loss/100+Percent People Died/100+Percent People Affected/1000.

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