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Schematic Natural Hazard Zonation of Bihar using Geoinformatics

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By

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We truly appreciate the support of the people of Bihar whom we met during our field visits for not only sharing their knowledge, but also for providing important information.

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Abbreviation

ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer

AVHRR: Advanced Very High Resolution Radiometer

BSDMA: Bihar State Disaster Management Authority

DEM :Digital Elevation Model

ETM :Enhanced Thematic Mapper

FEMA: Federal Emergency Management Authority

FMISC: Flood Management Improvement Support Center

GDEM: Global Digital Elevation Model

GDP: Gross Domestic Product

GHG: Green House Gas

GIS: Geographical Information System

GPS: Global Positioning System

GRUMP: Global Rural-Urban Mapping Project

GSI: Geological Survey of India

IIRS: Indian Institute of remote Sensing

IMD: Indian Meteorological Department

InSAR: Interferometric Synthetic Aperture Radar

IR: Infrared Band

IRS: Indian Remote Sensing Satellites

JAXA: Japan Aerospace Exploration Agency

LBSNAA: Lal Bahadur Shastri National Academy of Administration

LISS: Linear Imaging Self Scanning Sensors

LST: Land Surface Temperature

MODIS: Moderate Resolution Imaging Spectro-radiometer

NASA: National Aeronautics and Space Administration

NATMO: National Atlas and Thematic Mapping Organization

NDVI: Normalized Difference Vegetation Index

NGRBA: National Ganga River Basin Authority

NOAA: National Oceanic and Atmospheric Administration

NRSC: National Remote Sensing Center

SDSS: Spatial decision support system

SoI: Survey of India

TCI: Temperature Condition Index

TM: Thematic Mapper

TMI:TRMM Microwave Imager

TRMM: Tropical Rainfall Monitoring Mission

UHI: Urban Heat Island Effect

UNDP: United Nations Development Programme

VCI: Vegetation Condition Index

VHI: Vegetation Health Index

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Executive Summary

With increased climate variability, aggravated natural hazards, through extreme events, are affecting the lives and livelihood of people. Climate change is expected to exacerbate the conditions causing such problems. Bihar is vulnerable to various kinds of natural hazards of varying magnitude and levels of impact. The initial objective of this research programme was to understand the occurrence of natural hazards in Bihar. The output of this project may act as a basis for the formulation of Natural Hazards Preparedness Plan to minimize the loss of life and other resources. Also, it can hopefully assist policymakers in formulation of different development plans within the state. The local economy of Bihar is largely based on agriculture and is highly dependent on natural resources (such as water, soil and vegetation). Although the people of Bihar are from varied climatic geomorphology, the ways they address natural hazards are influenced by changing political, socio-economic and cultural, as well as climatic conditions. Community perspectives on natural hazards and attitudes towards their impacts are gradually changing over time.

People have evolved strategies, from their experiences and traditional practices, to cope with, and adapt to, the extreme conditions pre/syn/post- disaster situations. However, a large section of the population has experienced that these responses are becoming less effective and that they need further interventions to deal with these adverse situations. They also feel that these conditions will be more severe in future, without having any scientific basis for this belief. Increased demand and competition with wide range of variability, have forced people to struggle towards managing the situations to keep them sustainable and help them flourish. Governance with strong policy formulation is necessary to create a resilient society.

The findings of the present study are being documented with an aim for invoking a paradigm shift in the attitudes and perceptions about natural hazards; this shift should make the state and the people more prepared to face such calamities, and consequently minimize the loss of life and property, as well as environmental degradation, and hence directly affect the state's growth prospects.

More concretely, this study attempts to analyse natural hazards in Bihar and to prepare schematic hazard zonation maps using remote sensing and GIS techniques. Remote sensing is an important tool for monitoring of natural hazards and any environmental phenomena, both for large and small regions. Various open source satellite data have been utilized to analyse the same. Another important dimension of this project is to show the effectiveness of open source data with free software for large-scale policy formulation.

The major natural hazards in Bihar have been identified as flood, drought, and earthquake. Rapid urbanization and industrialization create more temperate urban environment compared to their rural surroundings. These phenomena produce heat islands, which can also be considered as an important environmental hazard.

Among all these hazards, floods are the most relevant in case of Bihar. Floods affect Bihar almost every year. The extremity of the floods depends on the variability of rainfall during monsoon, and on the huge monsoon runoff from upper Himalaya and Nepal region. Usually, northern, eastern, and central parts of Bihar are affected by floods, whereas the southern and western parts rarely are. The peak flooding period is between August and September every year. The analysis of flood situation in Bihar for last four years reveals that a total of 14,950 sq. km of land (15.88% of total area) is flood prone out of which 12,184 sq. km is agricultural land. As the economy of Bihar mainly depends on agriculture, flood is a major threat to the economy of Bihar. Darbhanga, Kathihar, Muzaffarpur, Purnia, Khagaria, Patna, and Champaran have been identified as major flood affected districts.

Drought is another natural hazard that affects Bihar at a large scale. Generally, southern and south-western parts of the state are affected by drought, although the variability of rainfall distribution may result in minor droughts in other parts of the state as well. Generally, droughts occur in the month of June (pre-monsoon) and October (post-monsoon). Analysis shows that droughts tend to shift towards east in October. The major drought affected districts are Kaimur, Rohtas, Aurangabad, Buxar, Bhojpur, Gaya, Jahanabad, Patna, Siwan, and Gopalganj.

Seismic Hazard (sudden release of accumulated stress in rocks due to tectonic and other deformations) analysis for updating the existing earthquake zonation map shows that northern districts such as Araria, Darbhanga, Madhubani, Sitamarhi and Supaul lie in Zone V. Southwestern districts of Aurangabad, Bhojpur, Buxar, Gaya, Jahanabad, Kaimur, Nawada, and Rohtas lie in Zone III. The remaining districts, including, the capital Patna, lie in Zone IV.

Due to increasing population growth, and resulting activities, the accumulation of heat is higher in urban areas and thus the temperature is higher as compared to rural areas. Major cities are found to be warmer by about 1.5ºC to 2ºC than the surrounding rural areas. This is of significant environmental concern.

As mentioned above, the largely agriculture-based economy of Bihar is facing a major threat from flood and drought. A comprehensive management plan is necessary to improve the level of preparedness in dealing with these hazards. A detailed baseline study for futuristic monitoring of meteorological, hydrological and climate-change aspects is highly recommended to address the issues related to environment, resources, and economy resulting from the probable impacts of climate-change.

Chapter 1

Flood hazard in Bihar

Introduction:

Amongst various kinds of natural disasters, floods are frequent and quite common. Floods have devastating impacts in tropical and temperate regions, as they inundate large areas causing damage to agricultural crops and property, disruption in services, and loss of human lives. India is a highly flood-prone country. As per National Flood Commission report (1980), around 40 million hectares of land in India is prone to floods. Bihar, in turn, is one of the most flood-prone states in India. Mainly, northern Bihar is affected by floods and about 76% of the population of northern Bihar lives under the recurring threat of devastation by floods. Floods in Bihar have become an annual disaster, which destroy thousands of human lives, apart from livestock and assets worth millions. Through flood analysis and implementing suitable structural and non-structural measures, damage from floods in Bihar can be minimized. For planning and preparation of any flood management system, reliable, accurate, and real time information are the foremost requirements. Hence, satellite remote sensing can certainly play an important role. For effective flood management and mitigation, an accurate demarcation of flood prone areas along with appropriate land use planning is the prime requisite. The knowledge of the spatial extent of inundated areas can also be applied during emergency relief efforts and to damage assessment after the event.

Flood mapping with traditional methods of ground survey and aerial observation is a difficult task. These methods are associated with longer time span, huge manpower, and high costs. During floods, it is almost impossible to use these techniques. So, the real time data always lags. Recently, optical data acquired by sensors has been used to map inundated areas, but bad weather conditions (such as clouds) are a constraint. Thus, optical sensors are often used to assess inundated fields only days after the event and for identifying vegetation stress present in the area (Michener and Houhoulis, 1997). Mapping can also be done from residual fluvial sediments left on the land using the same data. On the other hand, space borne radar systems, due to their exclusive cloud penetration capacity, offer great advantage for real-time assessment of inundated areas.

Satellite imagery has previously been used for distinguishing areas affected and not affected by floods as reflection from water bodies gets absorbed in the near infra-red spectrum *(*Sanyal and Lu*,* 2003*)*. Indian earth observation satellite datasets (IRS-1C, IRS-1D*)* were used for the demarcation of flooded area and estimation of damage due to floods *(*Raoet al, 1998*)*. AVHRR (Advanced Very High Resolution Radiometer) is also used for flood monitoring; coarse spatial resolution (1000 m) helps in flood mapping over a much wider area. It has high receptivity, and frequency of the global coverage make it useful for monitoring of floods *(*Jainet al, 2006*).* However as mentioned earlier, sometimes due to the atmosphere being cloudy, it is difficult to map the flooded areas using optical imagery. Radar imagery is more useful for flood monitoring. Microwaves can penetrate the clouds because of higher wavelengths. RADARSAT 1 has longer wavelength that transmits energy at 5.3 GHz of frequency and has the capability to penetrate clouds for acquiring real time information. In the microwave region, the radar backscatter is largely influenced by the dielectric properties of the object. Thus the radar backscatter increases with increasing water content (Wood et al., 2002).

Bihar falls under tropical monsoon climate with high temperature and medium to high rainfall. The temperatures are lowest during December-January with an average minimum of 8°C to 10°C, and maximum of 24°C to 25°C. The temperatures in the hottest months of April to June range from 23°C to 25°C (minimum) and 35°C to 38°C (maximum). The mean annual rainfall for the state is about 1256 mm. Almost 80 to 90% rainfall occurs during the monsoon period and commences from second week of June to second week of October depending upon the onset of monsoon (Source: Bihar Flood Management Information System Cell Report 2011).

Floods mainly occur due to excess flow in the river channel and/or over sedimentation in the riverbed, which subsequently cannot retain the volume of water. The rivers of Northern Bihar are fed by the glaciers of Himalaya and are perennial in nature. During the monsoon, these rivers receive huge amount of rainfall, which results in flooding. In northern Bihar, 73.63 % of the geographical area is considered to be flood prone. The major rivers are Gandak, Ghaghra, Kosi, Burhi Gandak, and Mahananda, which eventually merge with the river Ganga. Mainly rain-fed rivers drain Southern Bihar. These rivers originate either from the Vindhyachal hills or the hills of Chhotanagpur. The rivers are Rajmahal. Karmanasa, Sone, Punpun, Kiul, Badua, Chandan etc., which ultimately fall into river Ganga (Source: Bihar Flood Management Information System Cell Report 2011). The major river basins have been shown in Figure 1:

Figure 1: River basin map of Bihar

The loss of public property recorded by the Disaster Management Department of Bihar is taken from literature since year 2000, and is shown in Table 1:

Table 1: Loss of public property

YEAR	Number of Affected									Crop Damaged (INR in Lakh)	House Damage		Public Property Damaged (INR in Lakh)	Deaths	
	District	BLOCK	VILLAGE	(INR in Lakh)		Area (in Lakh hectre)									
				Human	Animal	Agric	Non-Agric	TOTAL	Cropped		Total	Value (INR in Lakh)		Human	Animal
2011(p)	24	154	3588	64.171	5.98	2.642	0.639	3.001	1.279	5,627.00	28067	12874.1	3578.6	143	33
2010(p)	8	41	489	7.22	0.56	0.631	1.112	1.743	0.03	202.45	8733	479.26	59.2	28	2
2009	16	91	1546	22.03	1.346	1.71	9.339	11.05	0.475	2182.57	7674	528.15	530.1	97	2
2008	18	116	2585	49.952	12.166	6.405	2.12	8.824	3.672	3420.25	297916	8451.4	9771.96	258	878
2007	22	269	18832	244.42	27.13	13.323	5.51	13.833	10.603	7683782	784328	83144.52	64241.5	1287	2423
2006	14	63	959	10.89	0.1	1.52	0.297	1.81	0.87	706.63	18637	1225.03	8456.17	36	31
2005	12	81	1464	21.04	5.35	3.434	1.261	4.6	1.35	1164.5	5538	382.79	305	58	4
2004	20	211	9346	212.99	86.86	20.99	6.01	27	13.99	52205.64	929773	75809.51	103050	885	3272
2003	24	172	5077	76.02	11.96	9.943	5.14	15.08	6.1	6266.13	45262	2,032.10	1035.16	251	108
2002	25	6	8318	160.18	52.51	14.45	5.244	19.69	9.4	51149.61	419.014	52621.51	40392.2	489	1450
2001	22	194	6405	90.91	11.7	9.042	2.91	11.95	6.5	26,721.79	222.074	17358.44	18353.8	231	565
2000	33	213	12351	90.18	8.09	6.57	1.476	8.05	4.43	8303.7	343.091	20933.82	3780.66	336	2568

(Source: Bihar Flood Management Information System Cell Report 2011).

*The figures for 2010 and 2011 are provisional.

Possible causes of the floods in Bihar can be enumerated as follows:

a) Heavy rainfall in northern river basins during monsoons causes rivers to overflow
b) Heavy rainfall in the Indian Himalayan region and Nepal which affects the lower course of river also causes overflowing
c) Sedimentation and shifting of river course lead to overflow of rain water and cause flash floods. Deforestation in the catchment area has led to increase in the silt content of the river flow

The present report concentrated on delineation of flood inundation and mapping of Bihar between 2009 and 2012. Generally, in Bihar, floods occur every year during July-October. Hence, multi-date mapping of floods during the peak period has been carried out. District level mapping of inundated areas, along with changes in land cover resulting due to floods, has been conducted using remote sensing and GIS. The precipitation data of TRMM has also been analysed to understand the major causes of flooding.

Satellite data used:

To analyse the flood situation in Bihar, radar data derived multi-date flood maps have been used. The published (http://www.dsc.nrsc.gov.in/DSC/Flood/index.jsp) flood map of National Remote Sensing Centre (NRSC) of peak flood period has been taken into consideration. The flood maps were derived based on Radarsat 2 data.

The *Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM)* has been considered to analyse the elevation of inundated areas. The spatial resolution of DEM is 30 m, while the improved vertical accuracy of ASTER GDEM version-2 is 8.86 m (ASTER GDEM V2 validation report). For this study, ASTER GDEM version-2 was freely downloaded from http://demex.cr.usgs.gov/DEMEX/.

The Tropical Rainfall Measuring Mission (TRMM) is a joint space mission between NASA and the Japan Aerospace Exploration Agency designed to monitor and study tropical rainfall. The data provides accurate measurements of rainfall from space. The TRMM Microwave Imager (TMI) is a passive microwave sensor designed to provide quantitative rainfall information over a wide swath under the TRMM satellite. Accumulated rain (3B43) product has been used in this project. The dataset currently contains monthly combined microwave-IR-gauge estimates of precipitation computed on quasi-global grids.

Other vector datasets such as river system and watershed administrative map are also created for analysis in GIS environment. Land cover information from MODIS data is also incorporated in this analysis. MODIS Surface Reflectance products (MOD09GA) provide an estimate of the surface spectral reflectance (Bands 1-7). The sensor provides daily gridded L2G product in the Sinusoidal projection, including 500 m reflectance values and 1 km observation (MODIS Product Information Table).

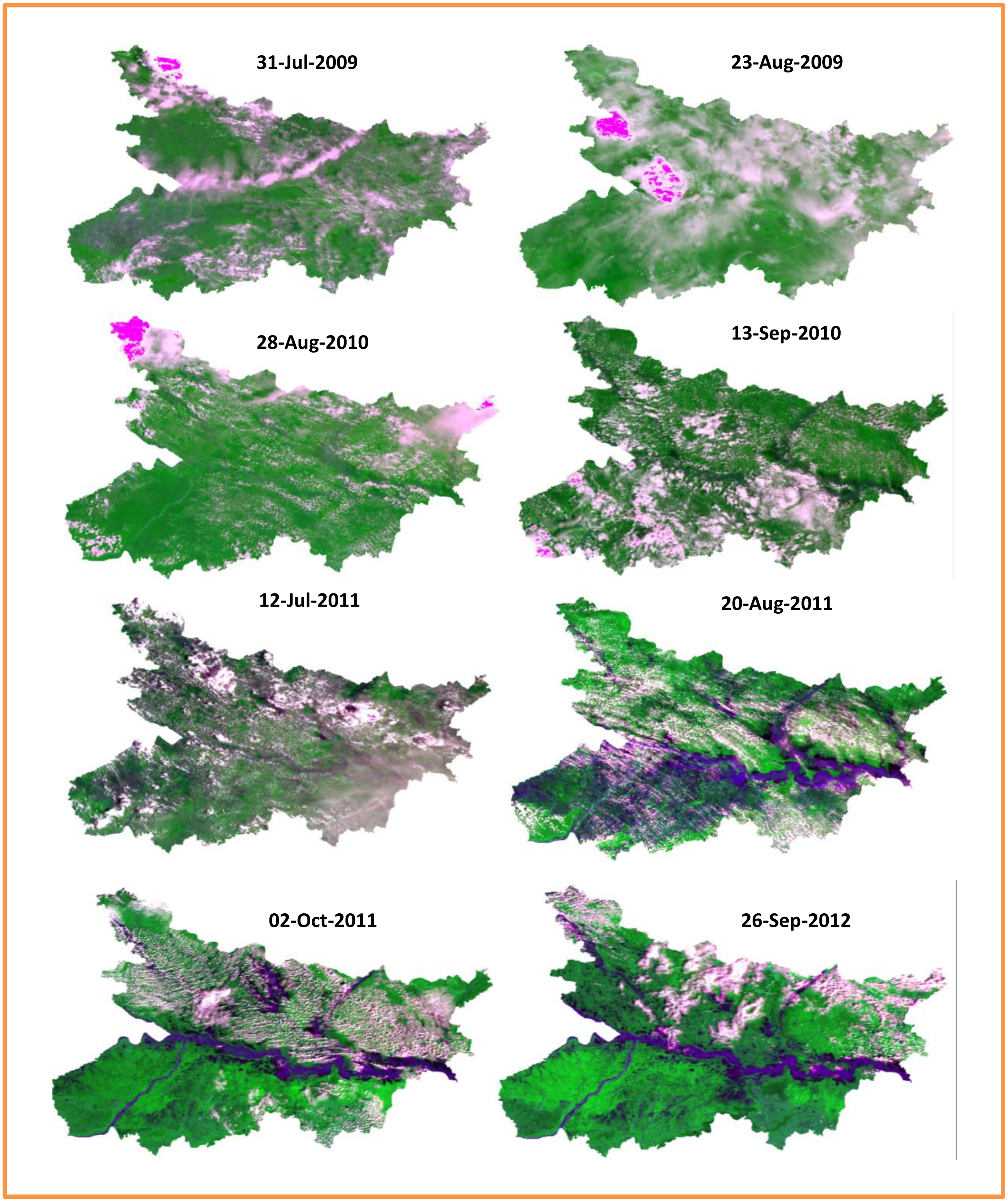


Figure 1A: Synoptic view of Bihar from MODIS Imageries during the study period

MODIS optical imagery of eight different dates during the flood period of 2009 to 2012 is shown. The flood inundation is seen in the imagery. But it is difficult to identify the flood inundation area from this imagery due to the presence of clouds during the period of floods. The optical wavelength cannot penetrate through cloud and it is not suitable for flood mapping (Figure 1A).

The land use/ land cover map of the study area has been created from 500 m resolution data using spectral signature based classification method. The map is shown in Figure 2.

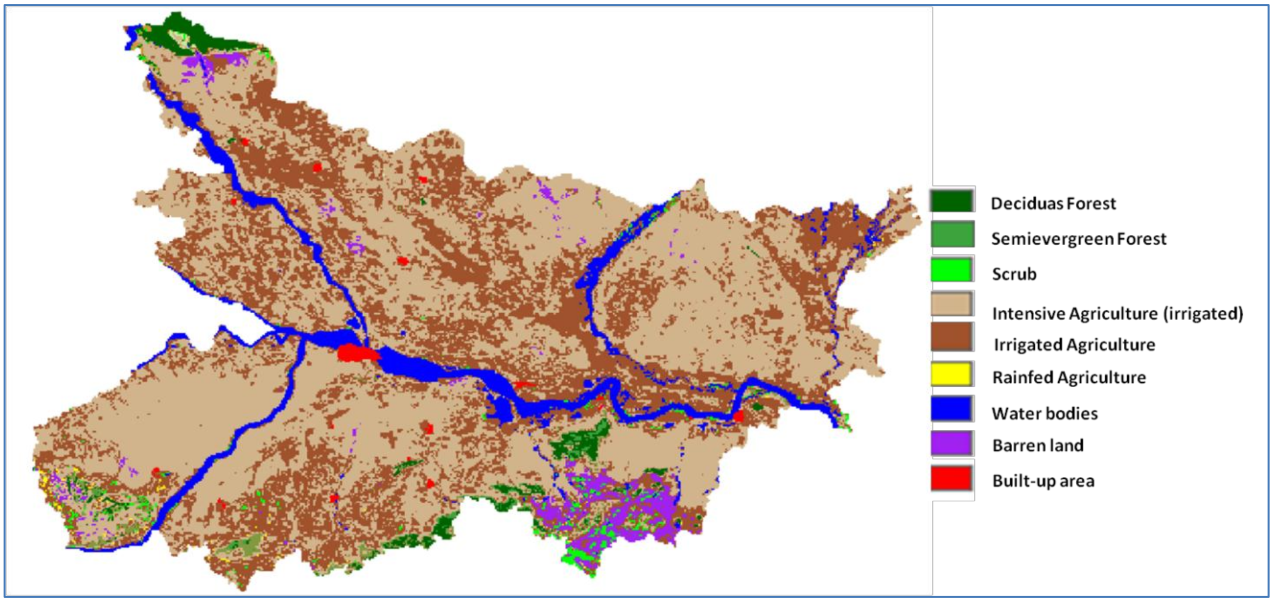


Figure 2: Land use/Land cover map of Bihar generated from MODIS data

Flood scenario in Bihar: Flood inundation mapping and analysis has been carried out on an annual basis. The flood scenario for years 2009 – 2012 has been shown below:

Year 2009: Flood inundated area has been delineated from the 29th July and 22nd August data. The flood extent maps are shown in Figure 3:

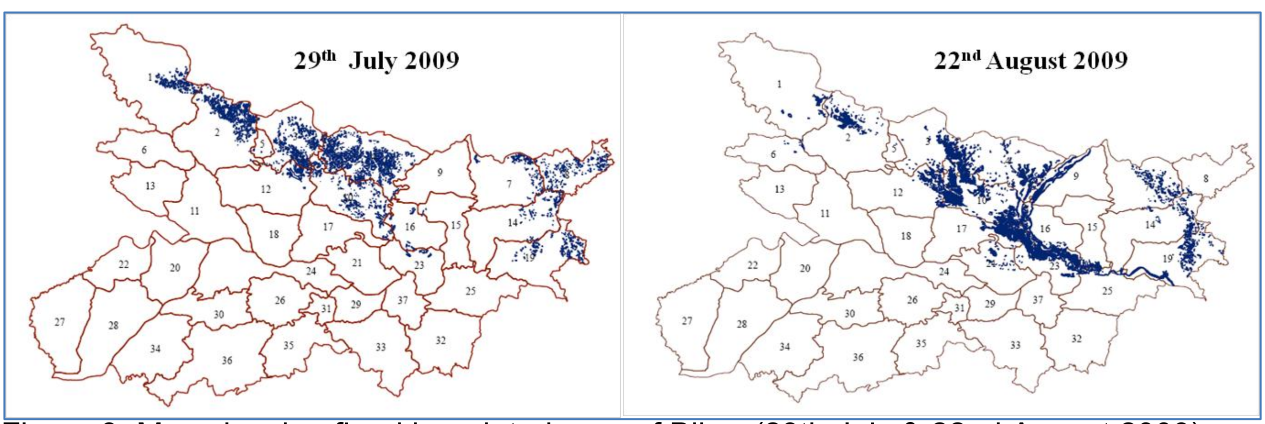


Figure 3: Map showing flood inundated area of Bihar (29th July & 22nd August 2009)

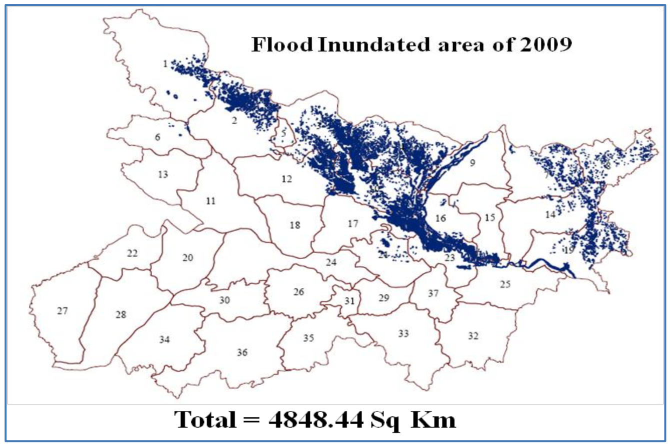


Figure 3A: Map showing flood inundated area of Bihar, 2009

The prime reason for floods was heavy rainfall in the catchment area of Kosi in Nepal during the last week of July (http://www.dsc.nrsc.gov.in/DSC/Flood). Floods also occurred in Bagmati, Mahananda, Kosi, Kamala Balan, Burhi-Gandak, and Adhwara river basins (figure 4). The elevation range of flood affected areas ranges from 25 m to 101 m. Specially, the northern part of Bihar was highly affected by floods whereas the eastern and northeastern parts of the state were moderately affected.

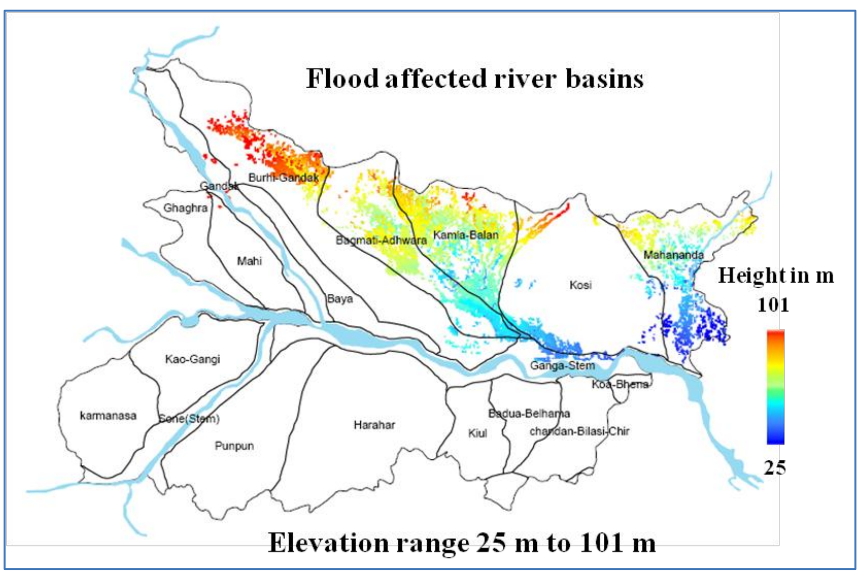


Figure 4: Flood affected river basin and elevation range

Another major reason for the floods was heavy rainfall during July (270 mm) and August (334 mm). The northern part of Bihar usually receives the maximum amount of rainfall (figure 5) during the monsoon season due to its foothill location, and in turn causes flood in north Bihar.

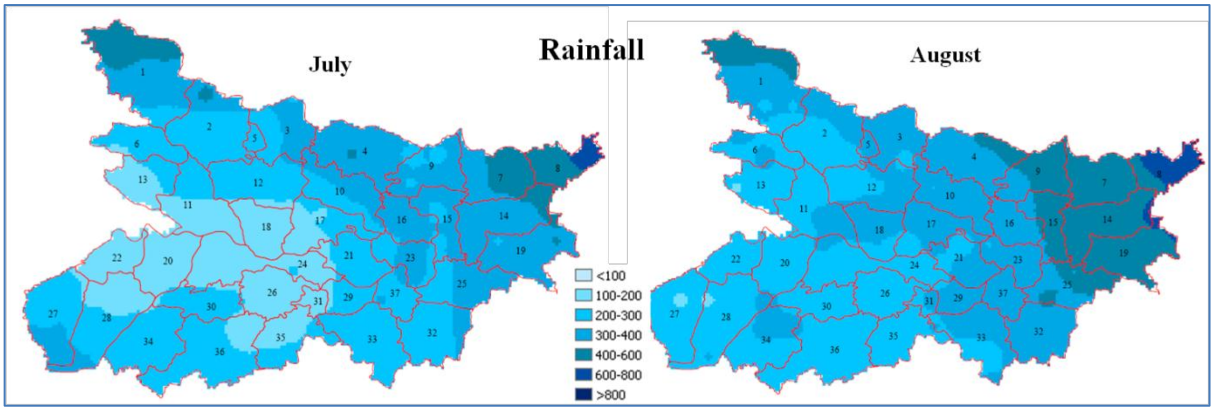


Figure 5: Rainfall distribution map of Bihar 2009

The flood affected districts and areas have been calculated as shown in Table 2 and Table 3. The rainfall on 29th July 2009 inundated 16 districts of Bihar (especially in the north). The aerial extent was about 1501.65 sq. km on 22nd August; floods spread over 19 districts (towards south and east) with an aerial extent of about 3613.22 sq. km

Table 2: Flood affected area of 29th July 2009

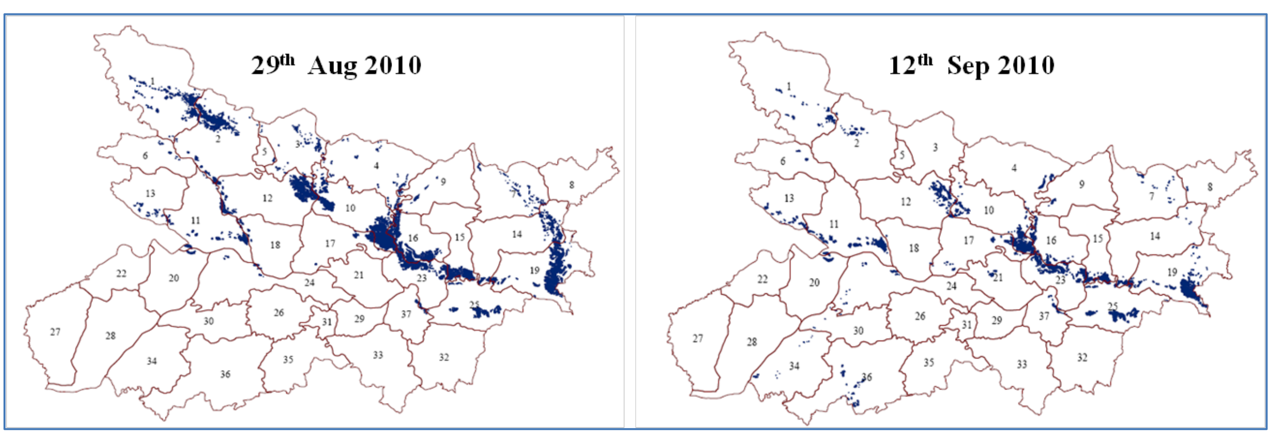
29th July 2009	
District	Inundated Area (Sq Km)
Araria	46.87
Darbhanga	121.16
Kashanganj	81.99
Kathihar	78.36
Khagaria	18.49
Madhepura	1.08
Madhubani	442.12
Muzaffarpur	71.75
West chamran	94.30
East champaran	304.25
Purnia	39.57
Saharsa	18.86
Samastipur	0.37
Sheohar	2.67
Sitamarhi	179.76
Supaul	0.05
Total	**1501.65**

Table 3: Flood affected area of 22nd August 2009

22nd August 2009	
District	Inundated Area (Sq Km)
Araria	122.97
Begusarai	45.95
Bhagalpur	76.10
Darbhanga	856.90
Gopalganj	8.20
Kashanganj	6.63
Kathihar	260.91
Khagaria	428.50
Madhepura	50.20
Madhubani	522.09
Muzaffarpur	182.62
West chamran	63.06
East champaran	193.49
Purnia	96.55
Saharsa	176.99
Samastipur	152.44
Sheohar	0.47
Sitamarhi	183.87
Supaul	185.30
Total	**3613.22**

Year 2010:

Flood inundated area has been delineated from the data of 29th August and 12th September. The flood extent maps are shown in Figure 6:



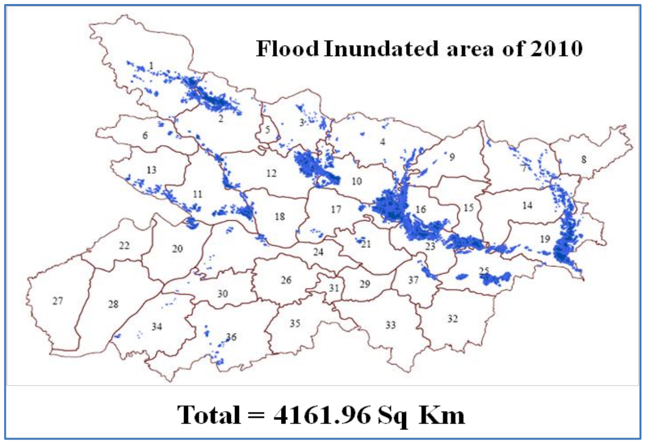


Figure 6: Map showing flood inundated area of Bihar 2010

During the year 2010, water level started rising in Bihar from second week of July. But due to the heavy rainfall in northern river basins, floods were reported during the last week of August 2010. According to CWC report of August 25, 2010, Kosi River at Basua was flowing above the danger level and the situation was categorized as 'unprecedented flood situation'. Flash floods due to heavy rains were reported during the second week of September 2010 and according to CWC report, Kosi River at Basua was in high flood situation (http://www.dsc.nrsc.gov.in/DSC/Flood). Some smaller patches at the southern bank of river Ganga were also affected in the same year.

Floods occured in Bagmati-Adhwara, Mahananda, Kosi, Kamala Balan and Burhi Gandak River basins (figure 7). The elevation range of flood affected area ranged from 26 m to 196 m. Northern part of Bihar was highly affected by floods. Eastern parts of the state were also affected. Though the intensity of the flooding was higher as compared to 2009, but the distribution of flood was more widespread.

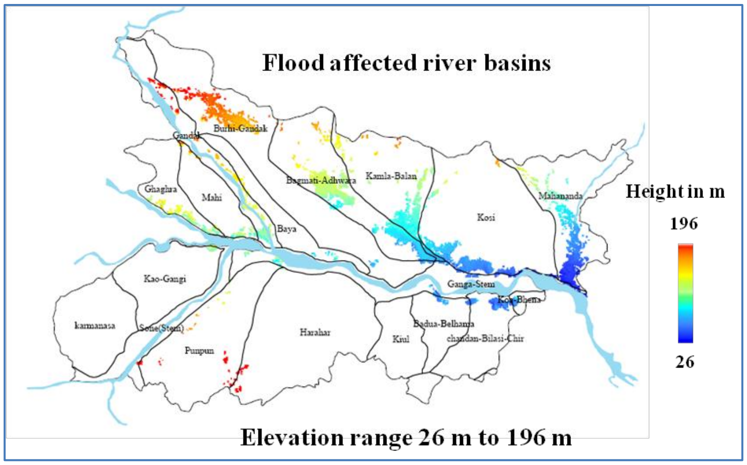


Figure 7: Flood affected river basin and elevation range 2010

Heavy rainfall occurred during August (284 mm) and September (210 mm) in the year 2010. Northern part of Bihar received the highest rainfall within the state (figure 8) during the monsoon season, but the amount was less in comparison to previous year.

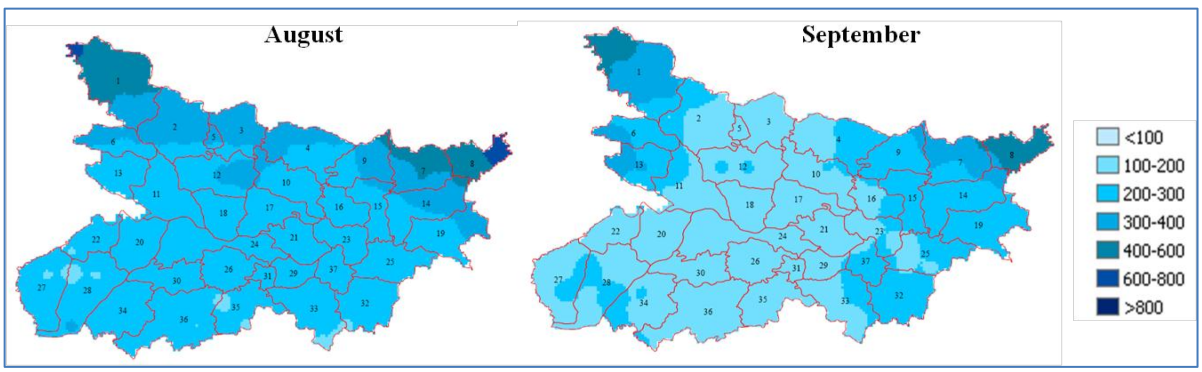


Figure 8: Rainfall distribution map of Bihar 2010

The identified flood affected districts and areas have been shown in Tables 4 and 5 respectively. On 29th August 2010, 23 districts of Bihar were flood affected with an aerial extent of about 3294.04 Sq. km. On 12th September 2010 flood affected 26 districts (more towards southern and eastern Bihar) with an aerial extent of about 1743.30 Sq. Km.

Table 4: Flood affected area of 29th July 2010

29th August 2010	
District	Inundated area (Sq Km)
Araria	50.78
Bhagalpur	123.03
Bhojpur	14.19
Darbhanga	512.21
Gopalganj	10.12
Kathihar	459.40
Khagaria	223.09
Madhepura	171.02
Madhubani	57.73
Monghyr	13.42
Muzaffarpur	325.84
West chamran	199.43
Patna	12.55
East champaran	293.33
Purnia	149.83
Saharsa	343.67
Samastipur	63.13
Saran	115.98
Sheohar	4.22
Sitamarhi	62.59
Siwan	29.25
Supaul	36.67
Vaishali	22.57
Total area	**3294.04**

Table 5: Flood affected area of 22nd August 2010

12th September 2010	
District	Inundated area (Sq Km)
Araria	20.42
Aurangabad	9.30
Begusarai	14.65
Bhagalpur	167.78
Bhojpur	19.01
Darbhanga	259.01
Gaya	39.83
Gopalganj	6.98
Jahanabad	2.61
Kashanganj	3.00
Kathihar	239.75
Khagaria	218.88
Madhepura	87.94
Madhubani	30.62
Monghyr	20.31
Muzaffarpur	113.93
West chamran	50.68
Patna	18.95
East champaran	29.39
Purnia	29.90
Saharsa	94.55
Samastipur	60.13
Saran	148.94
Siwan	43.32
Supaul	9.68
Vaishali	3.73
Total area	**1743.30**

Year 2011:

Due to heavy rains, devastating floods occurred in Bihar. Flood inundated area has been delineated from the 9th July, 17th August and 1st October data. The flood extent maps are shown in Figure 9:

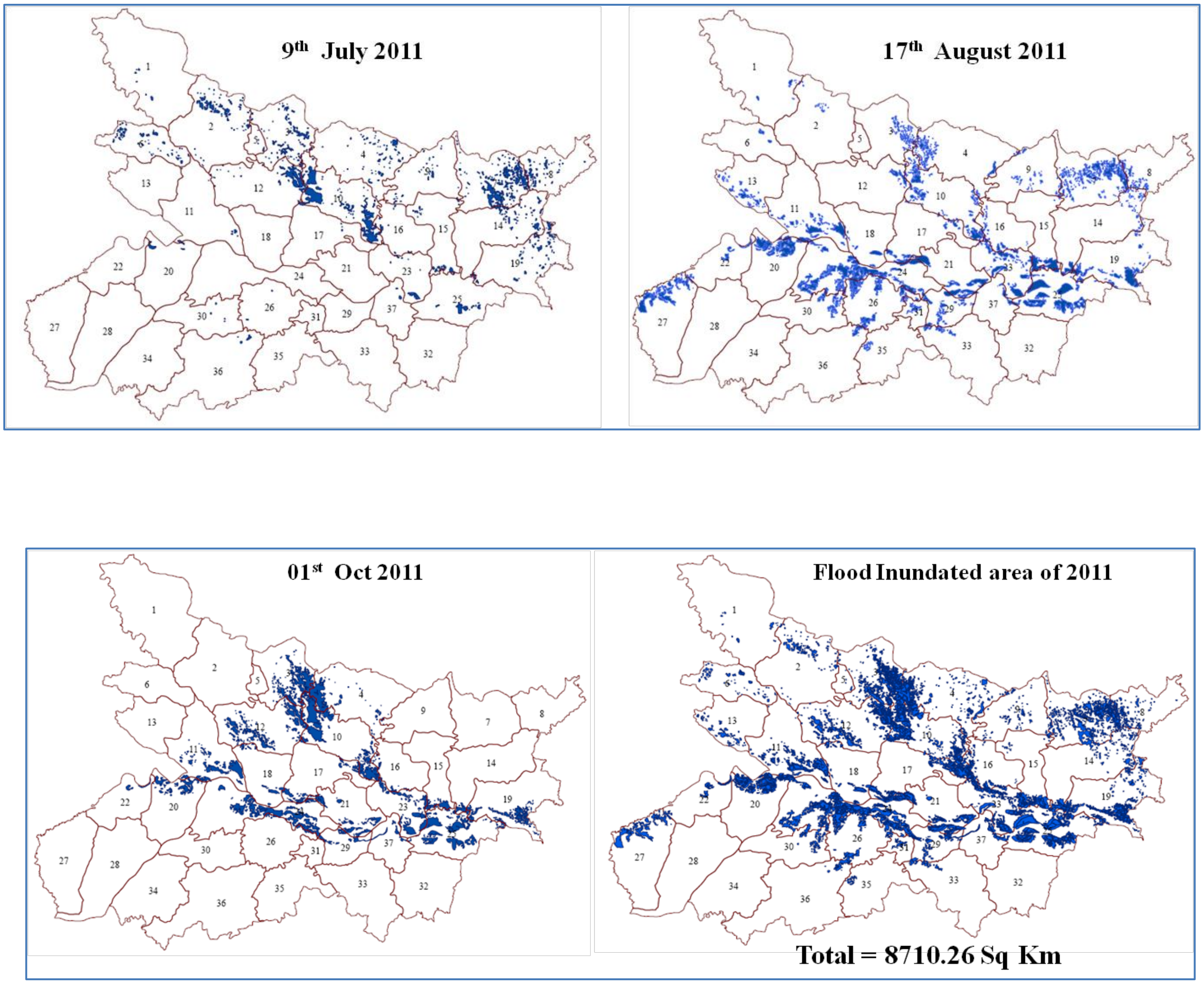


Figure 9: Map showing flood inundated area of Bihar, 2011

After two consecutive years of drought, floods were back in Bihar with incessant rain and heavy water discharge into the Kosi River from Nepal. Huge discharge of water in catchment areas of rivers flowing into Bihar was reported during the last week of June 2011. As a result, rivers like Kosi, Mahananda, Gandak, Bodhi, and Bagmati witnessed rapid increase in water levels. More than a hundred villages were inundated in the flood prone districts of Muzaffarpur, Gopalganj, Purnia, Araria, Saharsa, Madhepura, Bagaha, and East and West Champaran.

Flood situation was bad in the northern districts of Bihar during the first week of July 2011, affecting many parts of Darbhanga, West Champaran, Gopalganj, Muzaffarpur, Araria, and Saharsa districts. Torrential rainfall occurred in the Gandak River basin area during the first week of August. About 20 lakh people were affected. During 17th August floods, situation was worse and also spilled over southern part of Bihar. It was found that floods continued up to the second week of October (http://www.dsc.nrsc.gov.in/DSC/Flood and Media News).

Floods occurred in parts of Bagmati-Adhwara, Mahananda, Kosi, Kamala Balan, Burhi-Gandak, Punpun, Harhar, and Kao-Gangi River basins (Figure 10). The elevation range of flood affected area ranged from 26 m to 341 m. Along with northern and eastern parts of Bihar, southern areas were also affected. The intensity of the flood was higher in comparison to 2009 and 2010 with widespread distribution.

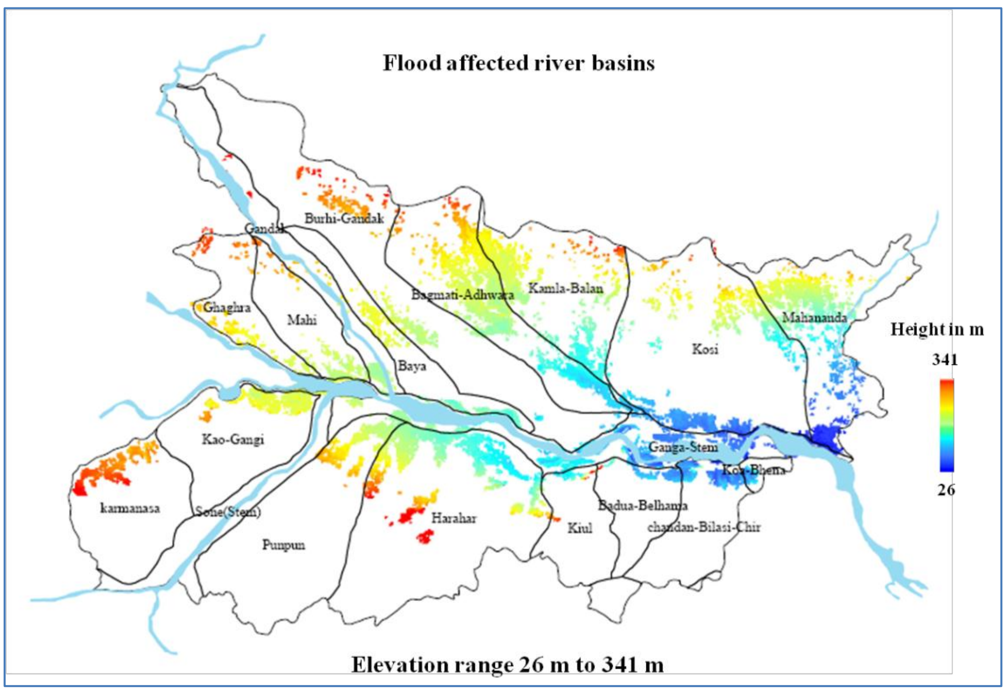


Figure 10: Flood affected river basin and elevation range 2011

Heavy rains occurred during July (307 mm), August (426 mm), and September (290 mm). The northern part of Bihar received maximum rainfall (Figure 11) during the monsoon season and the amount was higher than that of last two years.

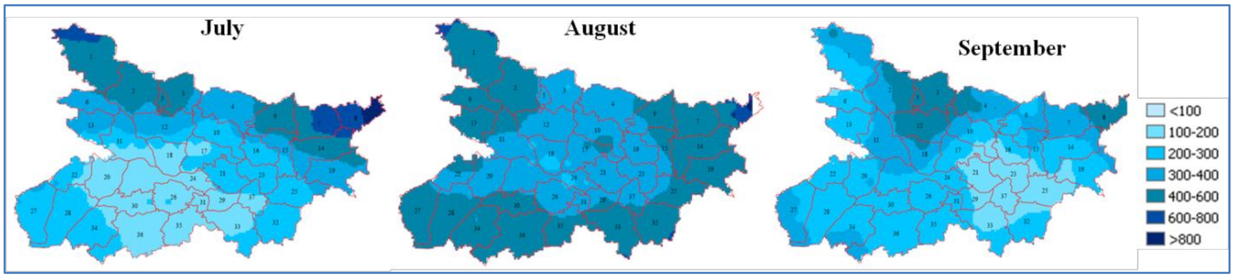


Figure 11: Rainfall distribution map of Bihar 2011

The flood affected districts and areas have been analysed and shown in Tables 6, 7, and 8. On 9th July 2011, 26 districts of Bihar were flood affected with an aerial extent of about 1957.78 Sq. km. On 17th August, flood spilled over towards southern Bihar and 33 districts were affected with an aerial extent of about 4939.12 Sq. km. On 01st October, 22 districts were affected with an aerial extent of about 4119.22 Sq. km.

Table 6 Flood Affected Area
9th July 2011

9th July 2011	
District	Inundated area (Sq Km)
Araria	373.24
Bhagalpur	64.04
Bhojpur	22.99
Buxar	1.18
Darbhanga	480.39
Gaya	11.13
Gopalganj	69.41
Jahanabad	4.08
Kashanganj	74.83
Kathihar	90.51
Khagaria	33.41
Madhepura	44.16
Madhubani	74.17
Monghyr	6.29
Muzaffarpur	166.60
Nalanda	2.84
West chamran	9.44
East champaran	125.38
Purnia	89.08
Saharsa	21.13
Samastipur	13.35
Saran	13.46
Sheohar	4.96
Sitamarhi	133.26
Siwan	0.05
Supaul	28.41
Total area	**1957.78**

Table 7 Flood Affected Area
17th August 2011

17th August 2011	
District	Inundated area (Sq Km)
Araria	376.18
Begusarai	226.04
Bhagalpur	505.50
Bhojpur	284.27
Buxar	50.94
Darbhanga	253.86
Gaya	30.09
Gopalganj	15.96
Jahanabad	82.99
Jamui	43.42
Kaimur	266.46
Kashanganj	60.69
Kathihar	257.03
Khagaria	254.97
Lakhisarai	119.93
Madhepura	149.79
Madhubani	139.29
Monghyr	32.84
Muzaffarpur	51.12
Nalanda	245.72
Nawada	17.72
West chamran	18.76
Patna	663.85
East champaran	11.81
Purnia	84.57
Saharsa	55.40
Samastipur	94.11
Saran	243.96
Sheikhpura	36.67
Sitamarhi	86.67
Siwan	80.65
Supaul	48.12
Vaishali	49.70
Total area	**4939.12**

Table 8 Flood Affected Area
1st October 2011

01st Oct 2011	
District	Inundated area (Sq Km)
Begusarai	157.85
Bhagalpur	451.59
Bhojpur	158.98
Buxar	22.12
Darbhanga	627.85
Kathihar	206.09
Khagaria	255.98
Lakhisarai	59.83
Madhepura	80.31
Madhubani	277.97
Monghyr	32.66
Muzaffarpur	377.69
Nalanda	30.71
Patna	520.93
Purnia	34.49
Saharsa	28.30
Samastipur	116.11
Saran	261.47
Sheikhpura	1.14
Sitamarhi	359.44
Supaul	2.84
Vaishali	54.74
Total area	**4119.215**

Year 2012 (Recent Flood):

Flood inundated area for the year 2012 has been delineated from the 18th July, 8th August and 25th September data. The flood extent maps are shown in Figure 12:

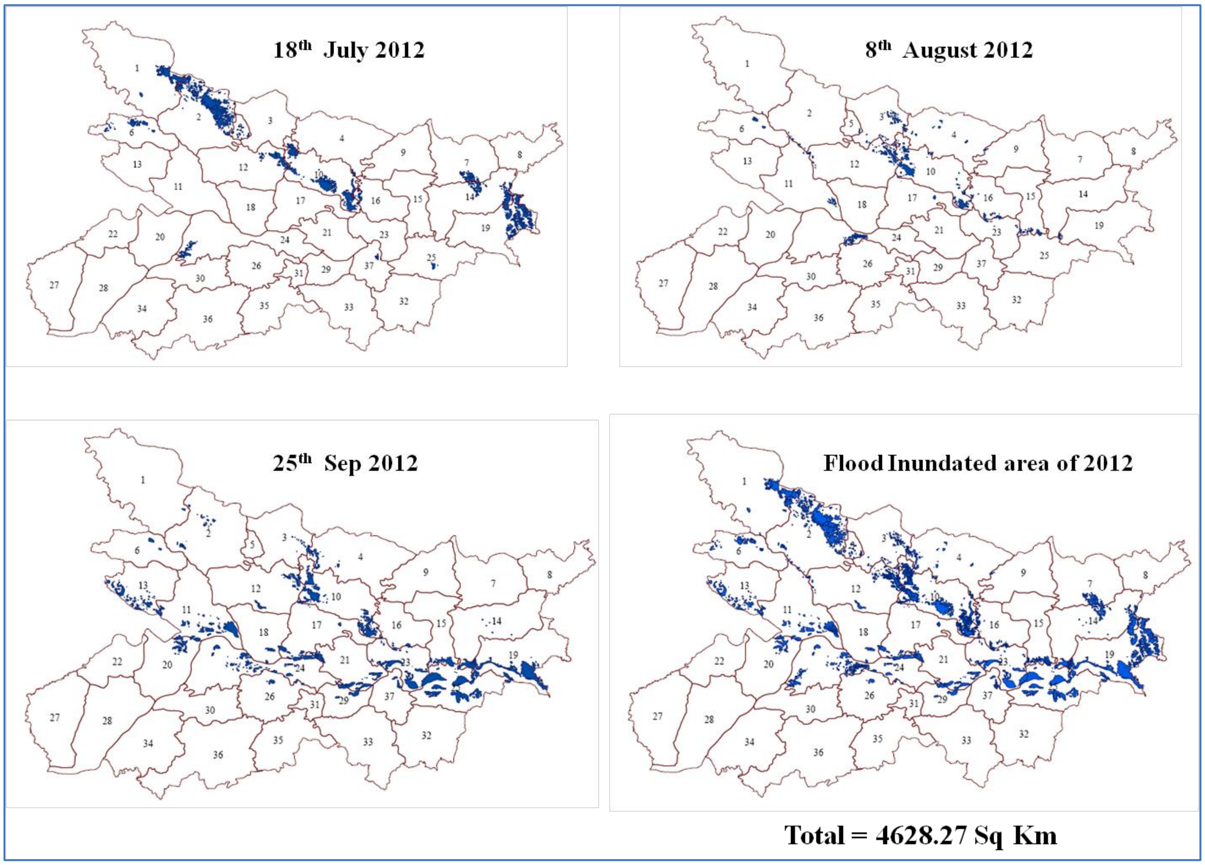


Figure 12: Map showing flood inundated area of Bihar 2012

After the devastating flood of 2011, low intensity flood situation occurred in 2012. In this year, flooding was reported in the second week of July in northern Bihar, and then the intensity reduced in August and again increased towards the end of September. The major affected districts were Darbhanga, Kathihar, Muzaffarpur, Purnia, Khagaria, Patna, and East and West Champaran.

Floods occurred in parts of Bagmati-Adhwara, Mahananda, Burhi-Gandak and Kamala-Balan River basins (Figure 13). The elevation range of flood affected area ranged from 26 m to 88 m. Along with the northern areas, north-western part of Bihar was also affected. The intensity of the flooding was much lower in comparison to 2011.

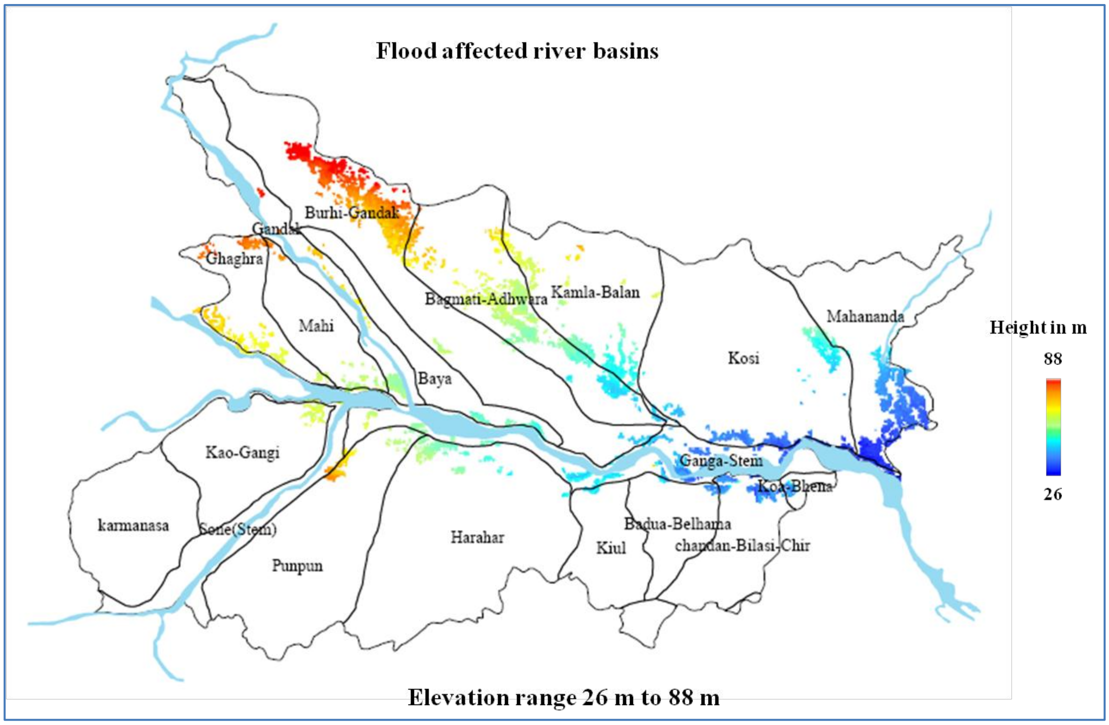


Figure 13: Flood affected river basin and elevation range 2012

Heavy rains occurred during July (380 mm). The analysis shows that the north and northwestern parts of Bihar received maximum rainfall (Figure 14) during the monsoon season.

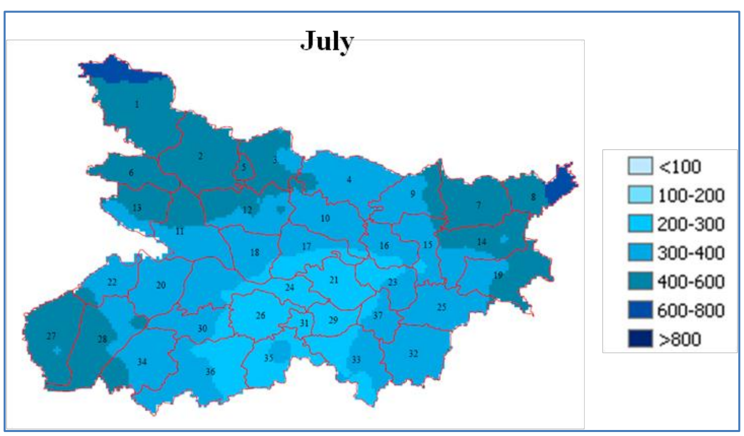


Figure 14: Rainfall distribution map of Bihar 2012

The flood affected districts and areas have been analysed and shown in Tables 9, 10, and 11. On 18th July 2012, 14 districts of Bihar were flood affected with an aerial extent of about 2054.18 Sq. km. On 8th August flood intensity decreased to 10 districts with an aerial extent of about 558.83 Sq. km. On 25th September, 23 districts were affected with an aerial extent of about 2361.06 Sq. km.

Table 9 Flood Affected Area 18th july2012

18th July 2012	
District	Inundated area (Sq Km)
Araria	67.96
Bhagalpur	14.20
Darbhanga	410.53
Gopalganj	70.38
Kathihar	352.63
Madhubani	9.77
Monghyr	8.41
Muzaffarpur	104.06
West chamran	158.94
Patna	57.46
East champaran	587.53
Purnia	154.73
Saharsa	35.63
Sheohar	21.87
Total area	**2054.18**

Table 10 Flood Affected Area 8th August 2012

08th August 2012	
District	Inundated aera (Sq Km)
Bhagalpur	9.40
Darbhanga	197.95
Gopalganj	18.22
Kathihar	2.04
Khagaria	13.86
Madhepura	23.41
Madhubani	17.64
Muzaffarpur	92.80
Patna	67.56
Purba champaran	5.67
Saharsa	24.78
Samastipur	6.74
Saran	19.23
Sheohar	2.73
Sitamarhi	51.48
Supaul	2.25
Total area	**558.83**

Table 11 Flood Affected Area 25th September 2012

25th September 2012	
District	Inundated area (Sq Km)
Begusarai	121.79
Bhagalpur	398.53
Bhojpur	61.43
Darbhanga	288.33
Gopalganj	16.26
Kathihar	328.28
Khagaria	219.48
Lakhisarai	47.92
Madhepura	53.39
Madhubani	45.80
Monghyr	19.59
Muzaffarpur	73.42
Nalanda	18.06
Pashchim chamran	3.57
Patna	145.99
Purba champaran	31.15
Purnia	38.33
Saharsa	11.64
Samastipur	65.80
Saran	207.49
Sitamarhi	14.92
Siwan	125.09
Vaishali	24.79
Total area	**2361.06**

Summary and conclusion:

Floods are a recurring catastrophe in Bihar. The major reason behind the flood could be the heavy rainfall in the upper catchment of rivers (Nepal area and Himalayan region) and increasing monsoon rains. Flood analysis in Bihar suggests that every year flood occurs in the state, though the intensity of flooding varies from year to year depending upon the variation in precipitation during monsoons. The northern of the state, along with some parts of the east, are particularly susceptible to flood. In general, Darbhanga, Kathihar, Muzaffarpur, Purnia, Khagaria, Patna, and Champaran districts get affected by floods during every year. Floods commence from July onwards and the peak period is August-September. The analysis for last four years has shown that the year 2011 experienced the highest flooding. Flood inundated areas since last 4 years were integrated and the flood prone areas of Bihar (Figure 15) have been delineated. The total flood prone area of Bihar is 14,950 sq km, which is 15.88% of its total geographical area. The land area affected since 2009 floods has been shown in Table 12 and Figure 16. It has been found that agricultural land, which is the lifeline of the economy of Bihar, is highly affected by the flood. The built-up (mainly urban) land also gets affected significantly with damage of infrastructure and disruption in services. Hence, it can be concluded that flood is the most significant hazard in Bihar, cause loss of life and property, and affect the economy in a recurring manner.

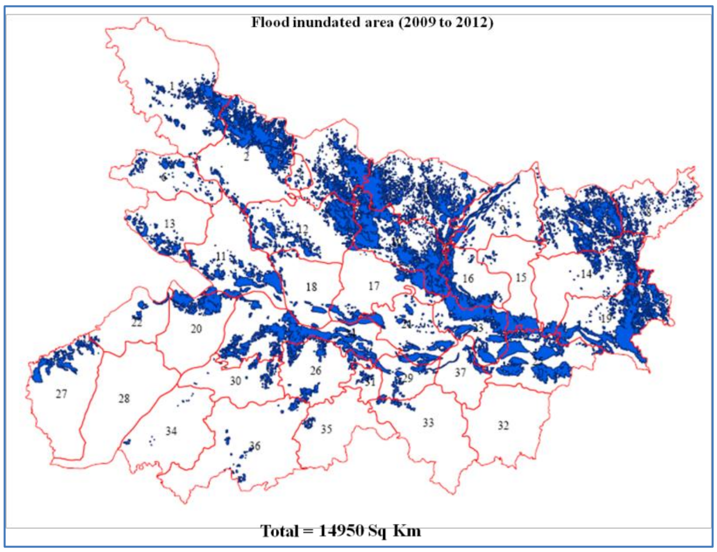


Figure 15: Flood prone area in Bihar (2009-2012)

Table 12: Land cover affected by flood (2009-2012)

Land cover class	**Area affected by flood (Sq Km)**
Forest	33.25
Scrub	55.68
Intensive Agriculture	6242.25
Irrigated Agriculture	5941.87
Rainfed Agriculture	0.87
Water Bodies	1130.37
Barren land	39.93
Built-up area	16.18

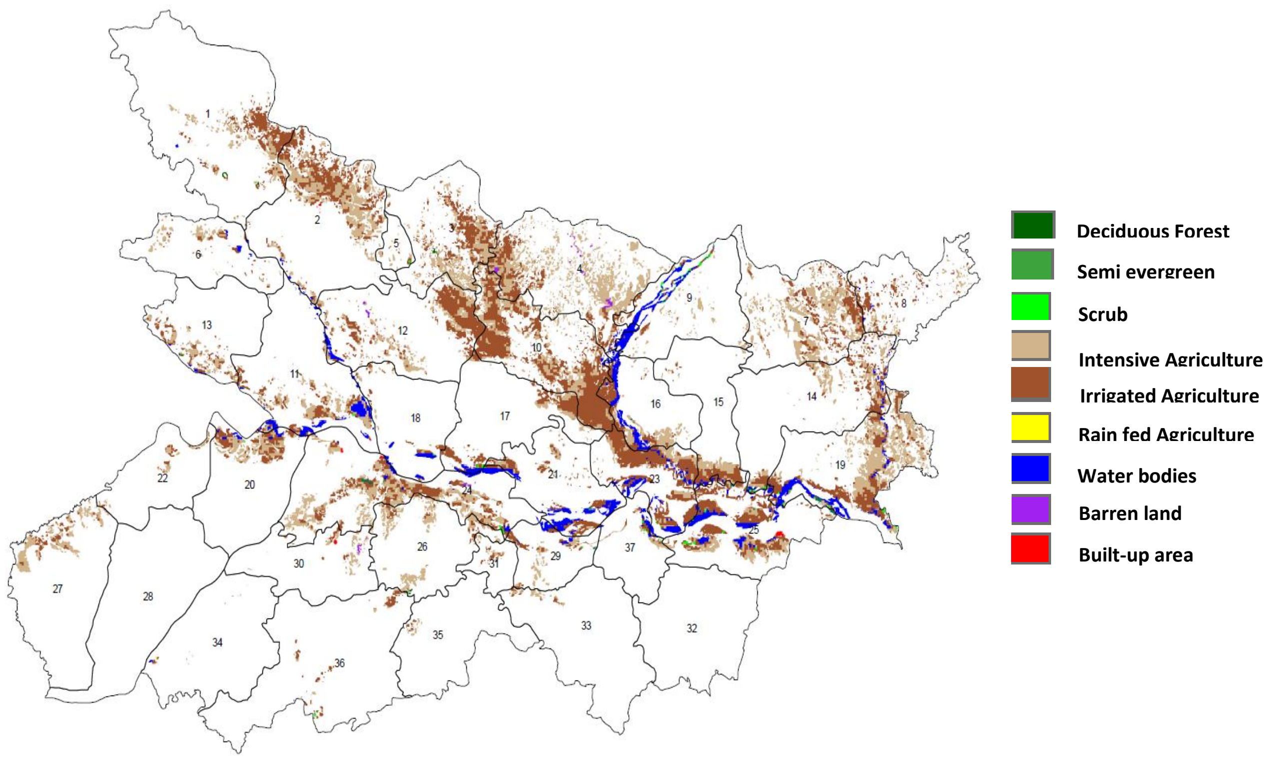


Figure 16: Flood affected land use / land cover area (2009-2012)

Chapter 2

Drought hazard in Bihar

Introduction:

Drought occurs when a region faces a deficiency in its water supply (either surface or underground) for an extended period of months or years, due to consistent low precipitation. Droughts are one of the major natural hazards affecting the environment and economy of regions worldwide. There are certain conflicts in defining drought. In a general sense, droughts originate from a deficiency of precipitation over an extended period of time, usually a season or more, resulting in a water shortage for some activity, group, or environmental sector. Its impacts result from the interplay between the natural event (less precipitation than expected) and the demand people place on water supply. Human activities can exacerbate the impacts of drought. In general, *a* drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield. No single operational definition of drought works in all circumstances, and this is a big reason why policy makers, resource planners, and others have more trouble recognizing and planning for drought than for other natural disasters. In fact, most drought planners now rely on mathematical indices to decide when to start implementing water conservation and other drought response measures.

Drought zonation is a difficult task as droughts the process of spreading of droughts is a slow one. Augmenting weather data with satellite images to identify the location and severity of droughts is a must for complete, up-to-date, and comprehensive coverage of current drought conditions. To monitor drought situation, the AVHRR-based Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) have been successfully used. Seiler et. al. (1998) proposed various indices to apply and validate drought detection and impact assessment. The VCI and TCI were useful to assess the spatial characteristics, the duration, and severity of drought, and were in a good agreement with the precipitation patterns. Normalized Difference Vegetation Index (NDVI) is also used to enhance drought-monitoring techniques (Peters et. al., 2002). Peters et al used Standardized Vegetation Index to describe the deviation of vegetation conditions from normal on the basis of calculations from weekly NDVI values. Bhuiyan et. al. (2006) worked on Aravalli region of Rajasthan province of India to quantify the agricultural drought using Vegetation Health Index (VHI). Prasad et. al. (2006) developed various indices such as normalized difference NDVI, VCI and TCI for mapping and monitoring of drought and assessment of vegetation health and productivity.

Bihar is the 12th largest state in India with an area of 94,163 sq. km. The topography of Bihar is a vast stretch of fertile alluvial plain occupying the Gangetic Valley. Bihar is a disaster prone state, especially with floods and droughts. Like floods, droughts are also a recurring phenomenon in Bihar. The area of north Bihar (north to river Ganga) is mainly flood prone while south Bihar (south of river Ganga) susceptible to droughts. Analysis shows that in recent years, the frequency of occurrence of these disasters has increased. Based on the observed IMD rainfall data for the period of 2009-2011 (Table 13) for the districts of Bihar, it is found that Kishanganj (-31%) and Katihar (-29%) districts of north Bihar experienced a remarkable deficit of summer monsoon rainfall in 2009. The southern part of Bihar, especially Bhojpur (-28%), Buxar (-12%), Gaya (-17%), Rohtas (-12%) and Kaimur show a remarkable deficit of rainfall in 2009-2011. The estimated rainfall of the state is 1,205 mm, considering an average of 53 rainy days each year.

Table 13: Occurrence of monsoon in Bihar during 2009 - 2011
(% deviation from normal)

Year	June	July	August	September	June-Sept
2009	-62	-32	8	-41	-29
2010	-32	-18	-22	-22	-22
2011	38	-25	1	19	3

In the present study, major emphasis was given on the comprehensive assessment and monitoring of agricultural drought situation in Bihar state of India, using satellite datasets during the Kharif season (June to October) for the years 2009 to 2012.

Satellite datasets for agricultural monitoring:

Space based remote sensing data has been used for monitoring the drought scenario of Bihar. NOAA AVHRR based Vegetation Health Index of 16 km resolution was used for assessment of drought. Vegetation Health Index, which was used by Kogan (2001), represents overall vegetation health. It is a combination of vegetation condition index and temperature condition index. Vegetation condition index indicates the short-term weather-related NDVI fluctuations from the long-term ecosystem changes (Kogan, 1995). NDVI depicts seasonal vegetation dynamics whereas VCI reflects relative changes in the vegetation condition from extremely bad to optimal. The range of VCI varies from 0 to 100. Temperature Condition Index reflects the relative change in thermal condition in terms of brightness temperature.

$$NDVI = 100\frac{Ch2 - Ch1}{Ch2 + Ch1}$$

$$VCI = 100\frac{NDVI_{Max} - NDVI}{NDVI_{Max} + NDVI_{Min}}$$

$$TCI = 100\frac{BT_{Max} - BT}{BT_{Max} + BT_{Min}}$$

$$VHI = 0.5(VCI) + 0.5(TCI)$$

MODIS global monthly vegetation index product (MOD13A3) at 1 km spatial resolution has been considered. Vegetation indices are widely used for monitoring of vegetation conditions, environmental monitoring, assessment of regional climate, monitoring hydrological process modeling; land use and land cover changes. In this study, vegetation growth is delineated using NDVI, which is also an important indicator of drought.

Tropical Rainfall Monitoring Mission (TRMM) data provides accurate measurements of rainfall from space. TRMM also provides improved estimate of precipitation in the tropics, where Earth's major rainfall occurs. TRMM started operating and recording data since December 1997 and is placed in a (46-day) processing orbit at a 35° inclination with a period of about 91.5 min. This orbit allows TRMM to build up a complete view of the climatological diurnal cycle. Accumulated rain (3B43) product has been applied in this project. The data set currently contains monthly combined microwave-IR-gauge estimates of precipitation computed on quasi-global grids.

Drought scenario in Bihar:

The study examines the agricultural drought scenario of Bihar. This occurs when the soil is devoid of enough moisture to support crop production. Though this generally happens during periods of low rainfall, it has a probability to recur even during periods of average precipitation when the soil conditions or agricultural practices require more water. Drought condition from the years 2009 to 2012 has been analysed and presented during June to October, considering the agricultural growing season (Kharif season). The analysis has been made considering the three major parameters:

a) Rainfall distribution
b) Vegetation vigor / growth
c) Vegetation health index

Rainfall distribution:

The average monthly rainfall (2009-2012) for entire Bihar has been calculated from TRMM accumulated rainfall data and has been shown in the Table 14. It has been found that the mean rainfall for the month of June is 160.65 mm and 67.93 mm for October. The difference in rainfall (maximum and minimum) and rainfall variation (standard deviation) is very large which signifies the uneven spatial distribution. July, August and September receive maximum rainfall due to the monsoons. Generally, monsoon rain commences in Bihar around mid of June to first or second week of July (depending on the time of onset of monsoon) and continues up to the last week of September.

Table 14: Rainfall statistics calculated from TRMM data (year 2009-2012)

	Rainfall statistics (in mm)			
Month	Min	Max	Mean	Standard deviation
June	89.41	461.34	160.65	50.54
July	138.78	602.29	239.69	71.82
August	254.92	758.98	347.56	68.37
September	135.77	414.36	219.33	43.86
October	28.71	179.19	67.93	29.01

The spatial distribution pattern of the rainfall has been shown in Figure 17, 17 A, B, C. This figure also shows that the occurrence of rainfall is not same for every year. The area that received less rainfall in 2009 has paradoxically got higher rainfall in 2011. It is also observed that the northern part of Bihar received higher rainfall due to its location on the foothills of the Himalayas. Moreover, the amount of rainfall that occurred was higher in the eastern part of Bihar. The occurrence of rainfall is the lowest in the southern and south-western parts of Bihar. The occurrence of low rainfall and its spatial variability is a major concern for the occurrence of droughts in Bihar.

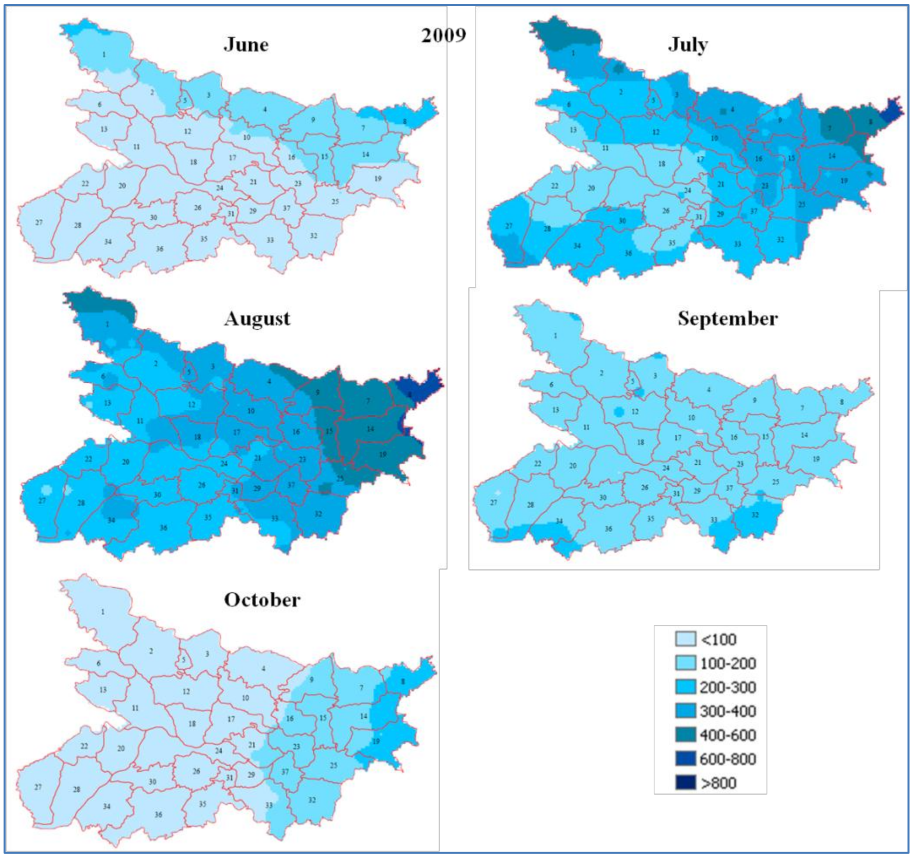


Figure 17: Spatial distribution of rainfall from TRMM data, 2009

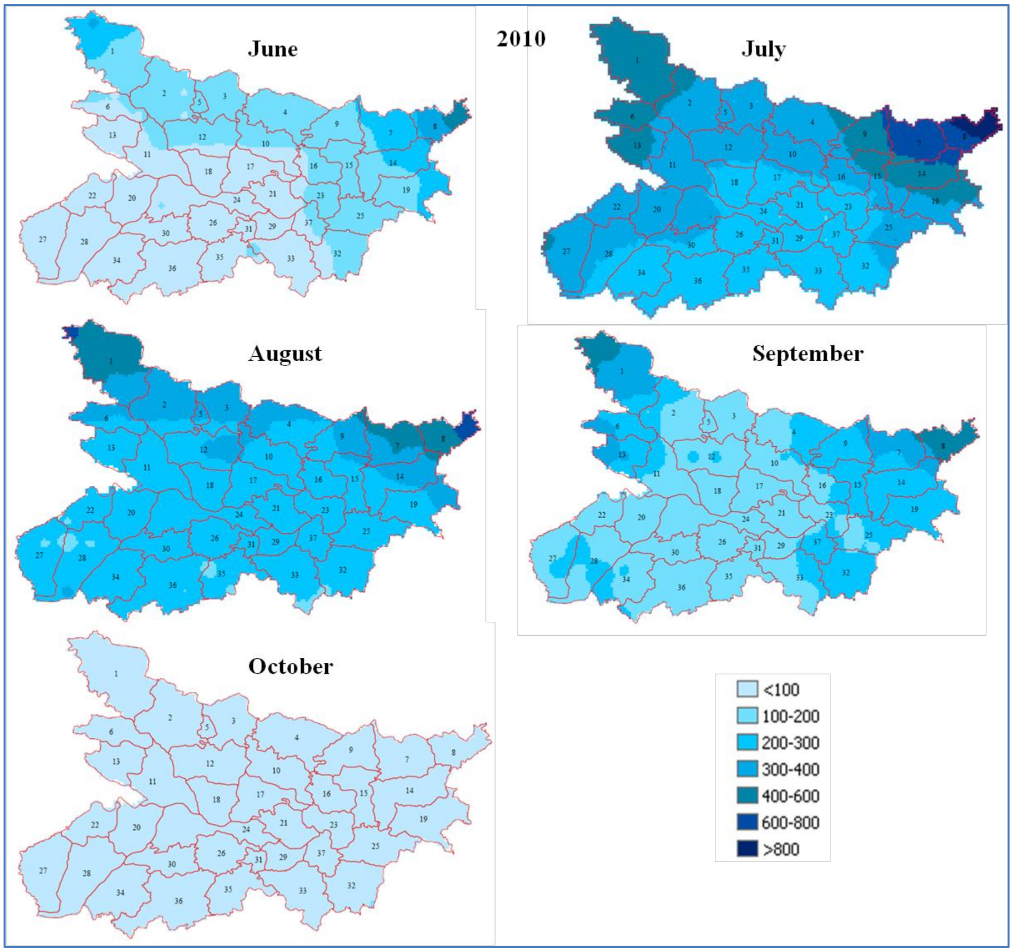


Figure 17A: Spatial distribution of rainfall from TRMM data, 2010

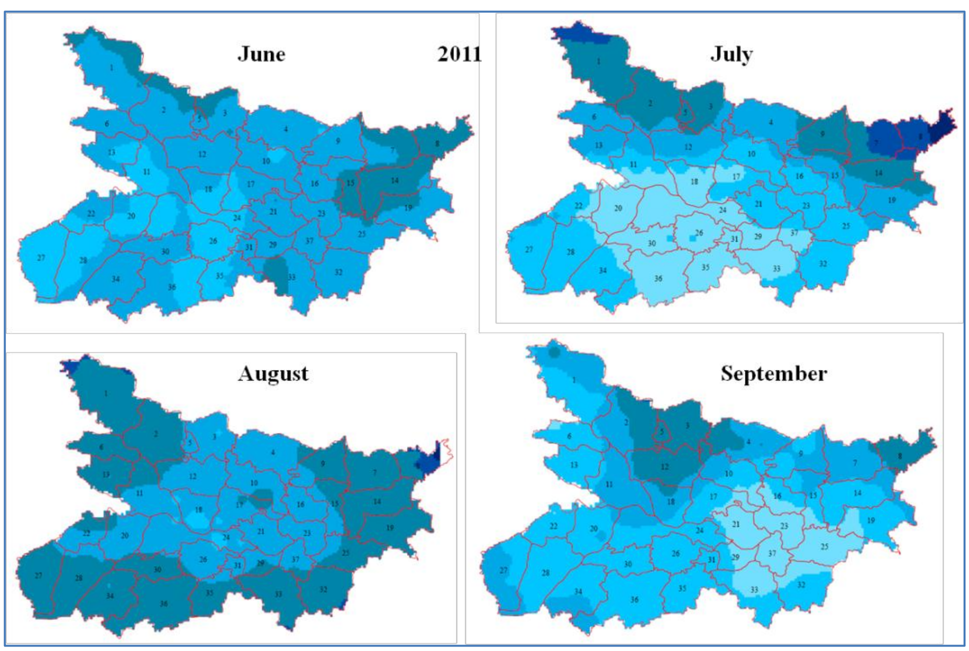


Figure 17B: Spatial distribution of rainfall from TRMM data, 2011

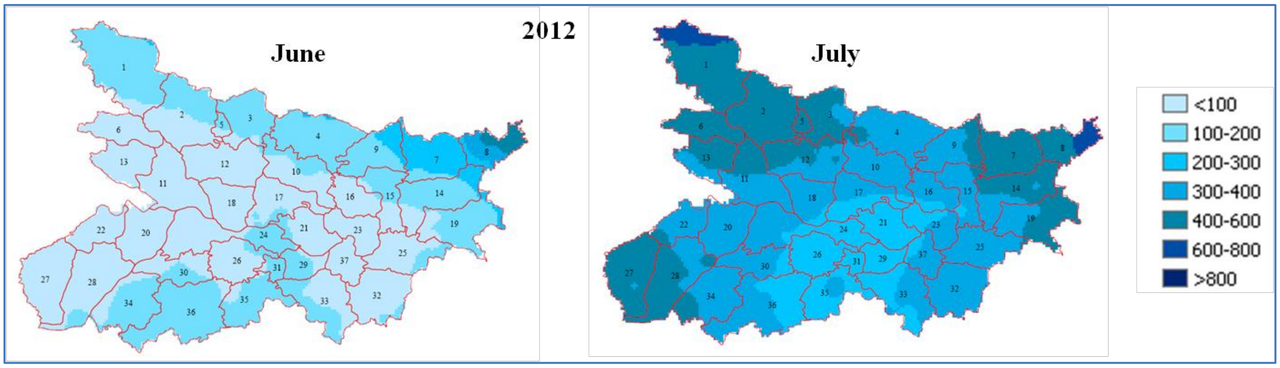


Figure 17C: Spatial distribution of rainfall from TRMM data, 2012

Vegetation vigor / growth:

Vegetation vigor is one of the important parameters to be considered for monitoring of droughts. The amount of soil moisture gets reduced due to the low occurrence of rainfall and it seriously affects vegetation growth. Vegetation vigor was estimated in terms of NDVI shown in Figure 18, 18A, B, C. Here, the NDVI value ranges from -0.2 to 0.99, while the usual range is between -1 and 1. NDVI value < 0.2 indicates poor growth of vegetation (more towards violet shade in map) and NDVI value >0.5 indicates higher growth of vegetation (more towards green shade in map). As the vegetation growth is directly linked with rainfall and temperature, a lower value of NDVI indicates a higher possibility of drought.

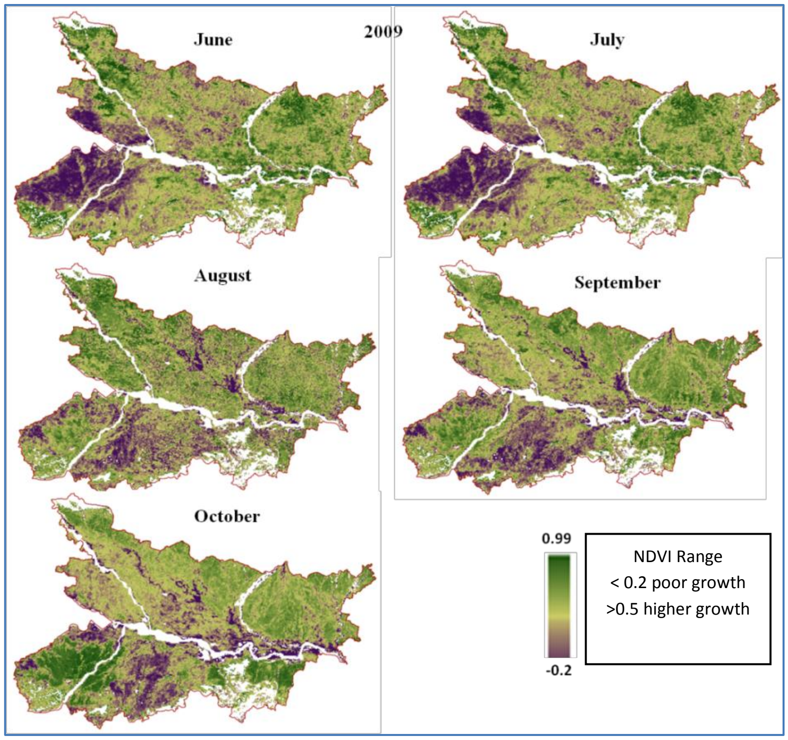


Figure 18: Normalized Difference Vegetation Index for the year 2009

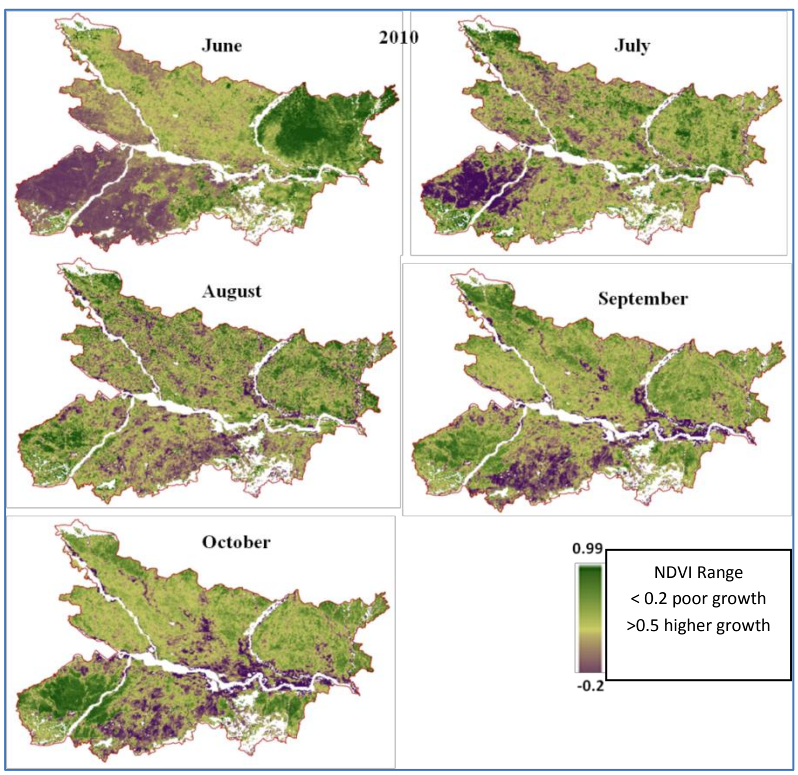


Figure 18A: Normalized Difference Vegetation Index for the year 2010

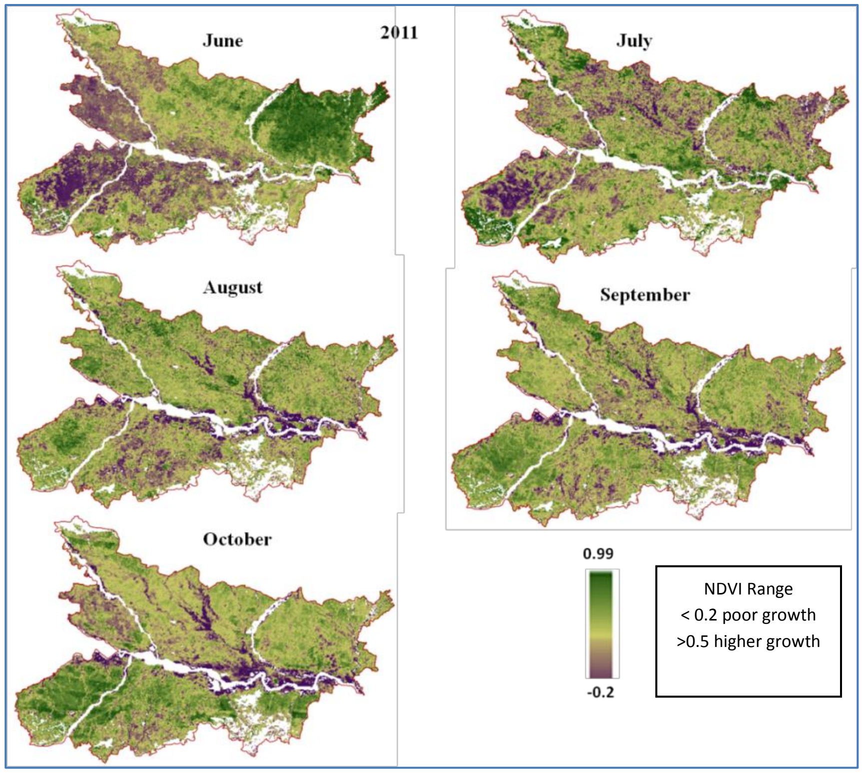


Figure 18B: Normalized Difference Vegetation Index for the year 2011

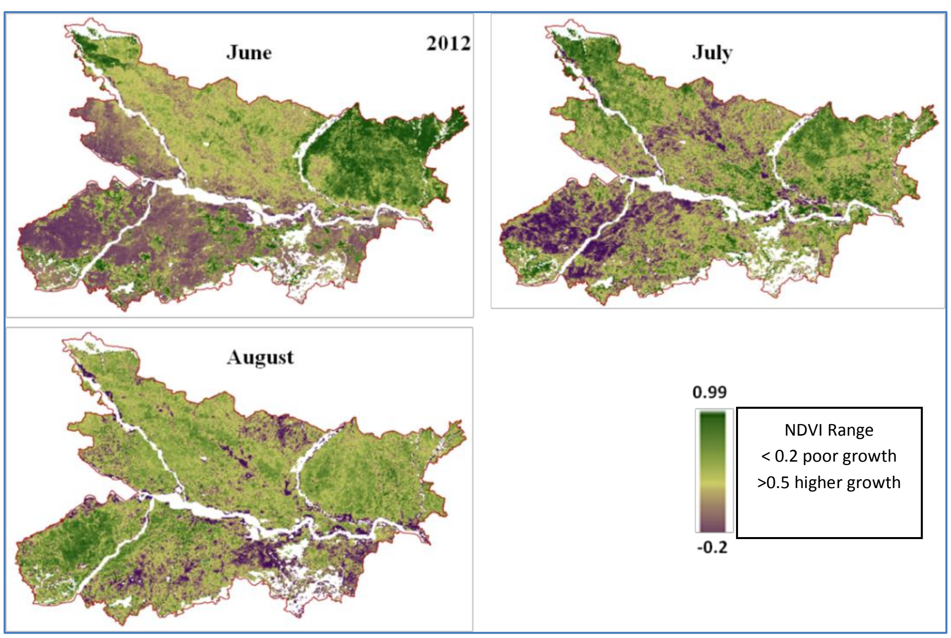


Figure 18C: Normalized Difference Vegetation Index for the year 2012

The analysis of the output presented in Figure 18, 18A, B, and C depicts that the vegetation growth is minimum in southern and southwestern parts of Bihar. Western part of Bihar was also affected in the month of June during the years 2009, 2010 and 2012. The northern and eastern parts of the state were not affected at all. This pattern matches with the spatial distribution pattern of rainfall, which supports the authenticity of the situation report.

Vegetation Health Index:

Vegetation Health Index (VHI) is widely used for drought monitoring and mapping, and it takes into account the vegetation and temperature conditions of a region considering the deviation over a substantial time horizon. The VHI value ranges from 0 to 100 and can be classified into 5 classes to delineate drought (Kogon, 2002; Bhuiyan*et al.,* 2006). The classification scheme is given below:

Drought class	VHI value
Extreme drought	**< 10**
Severe drought	**< 20**
Moderate drought	**< 30**
Mild drought	**< 40**
No drought	**> 40**

The VHI images for the entire state have been classified as per above-mentioned scheme and have been shown above. The economy of Bihar is exclusively dependent on the agricultural practice and in this study agricultural drought has been considered and assessed. So, for analysis of agricultural drought, only agricultural area is extracted from the generated land use/ land cover map. Figure 19, 19A, B, and C show that mainly southern, southwestern, and western parts of the state became drought affected in every year which also coincides with the rainfall and NDVI based analysis. The central and eastern parts of the state sometimes face mild drought. The intensity of drought is not the same for every month. June is the most drought-affected month, followed by July and October. A shifting pattern (towards east in October) has been observed in the pre-monsoon (June) and post monsoon (October) droughts. The drought condition also varies

year wise. June and July in the years 2009 and 2010 got highly drought affected. June 2012 was found to be extremely affected by drought due to extremely low rainfall. As per the Times of India on 5th June 2012, “The pre-monsoon rainfall in Bihar during this year has been the scantiest in the past six years”. According to the meteorological department, the state has recorded 46.5mm rainfall between March and May against the normal 77.5mm during the same period. It is a drop of 40 per cent from the normal pre-monsoon rainfall in the state. The situation has been worse in the state capital, which has received no rainfall for the past 57 days. To add to this, the maximum temperature in Patna that touched 44.1ºC on Monday is expected to soar even higher in the coming few days.” (Source:
http://www.telegraphindia.com/1120605/jsp/bihar/story_15569416.jsp#.ULkAiuSAAgE)

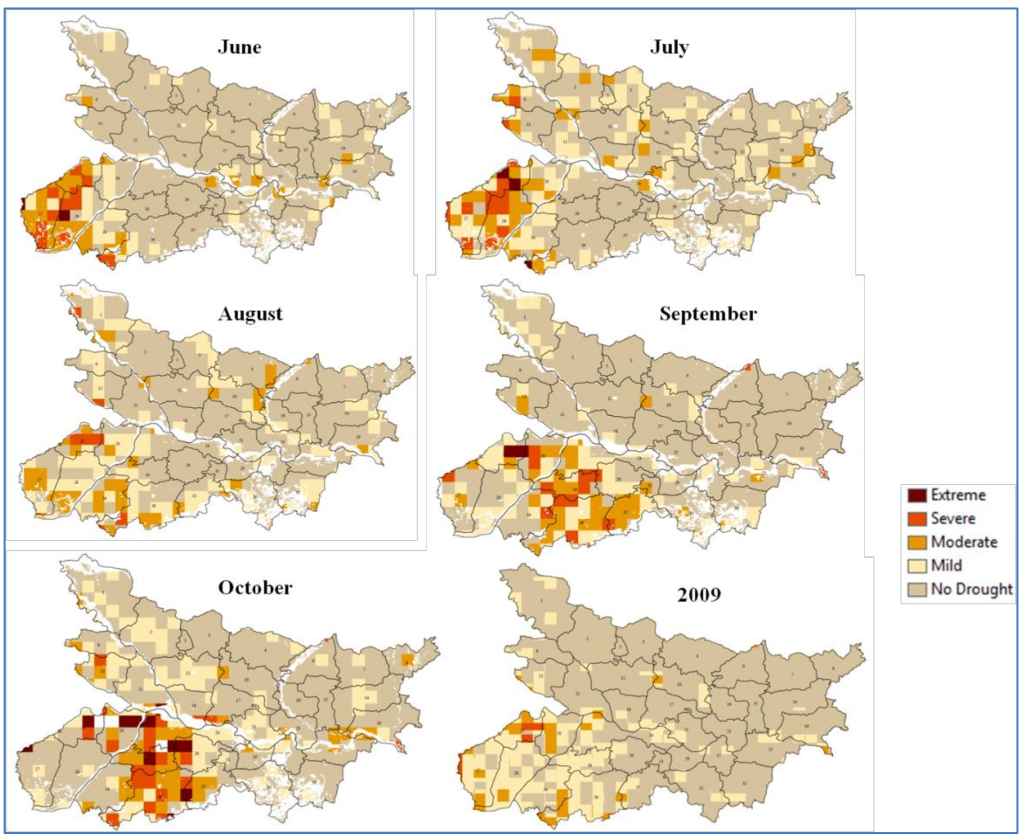


Figure 19: Vegetation Health Index (2009)

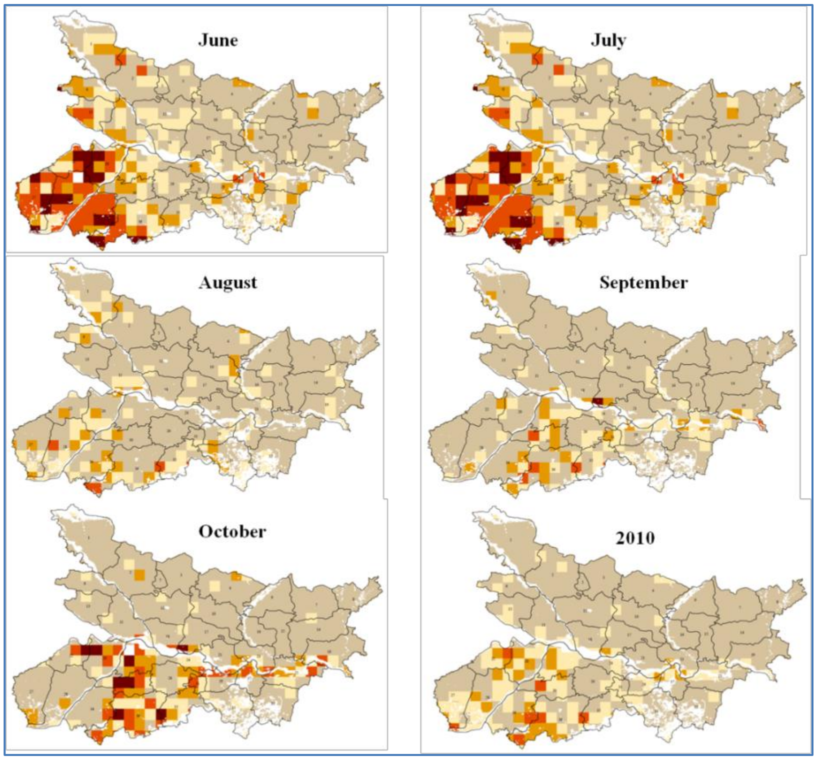


Figure 19A: Vegetation Health Index (2010)

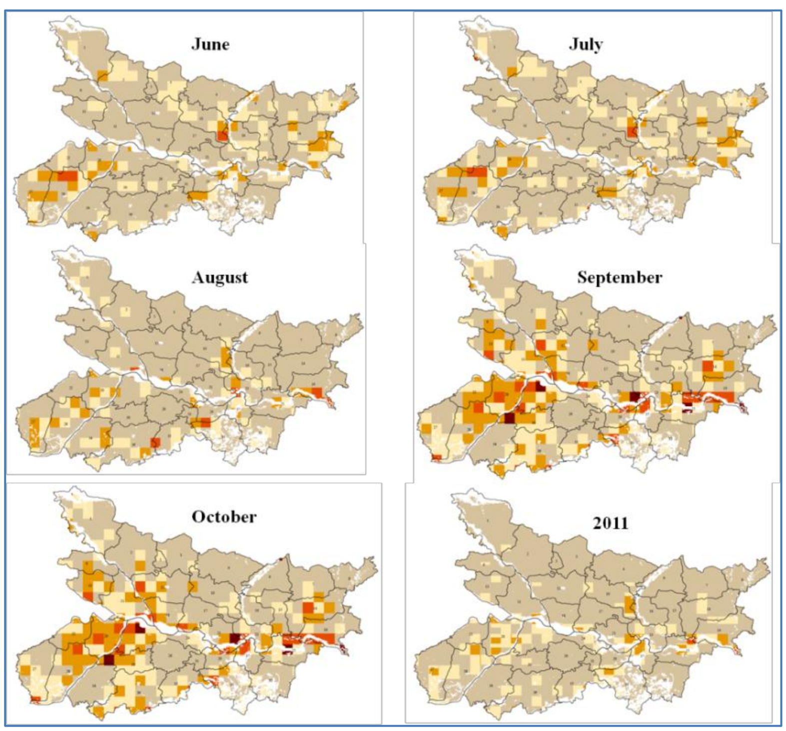


Figure 19B: Vegetation Health Index (2011)

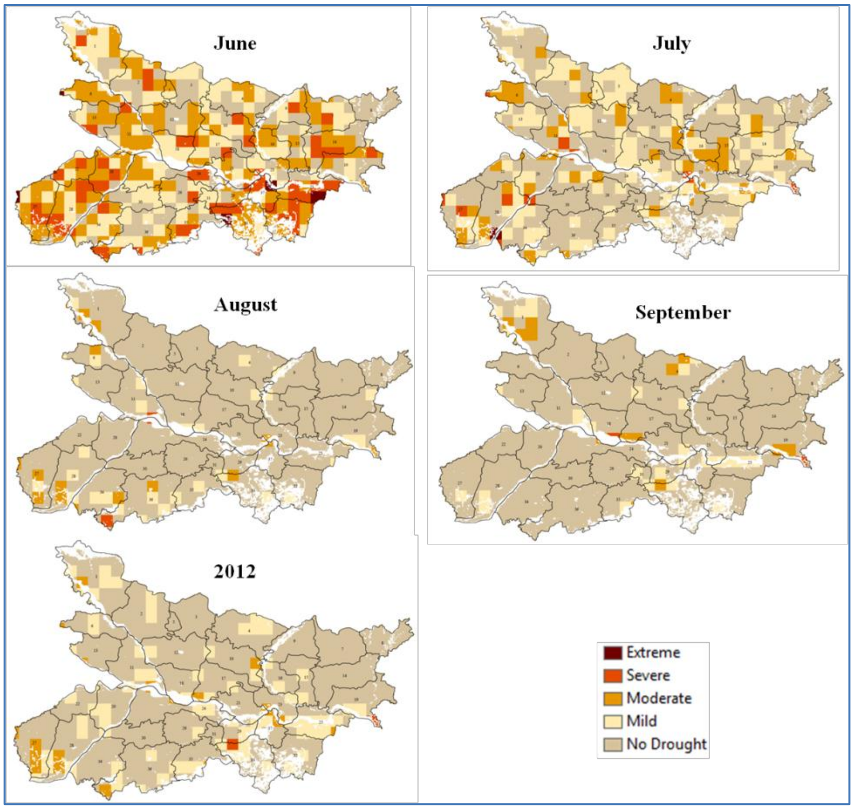


Figure 19C: Vegetation Health Index (2012)

The drought-affected areas of each year have been identified and shown in Table 15 as well as in Figure 20. They imply that drought intensity was higher in 2009 and 2010.

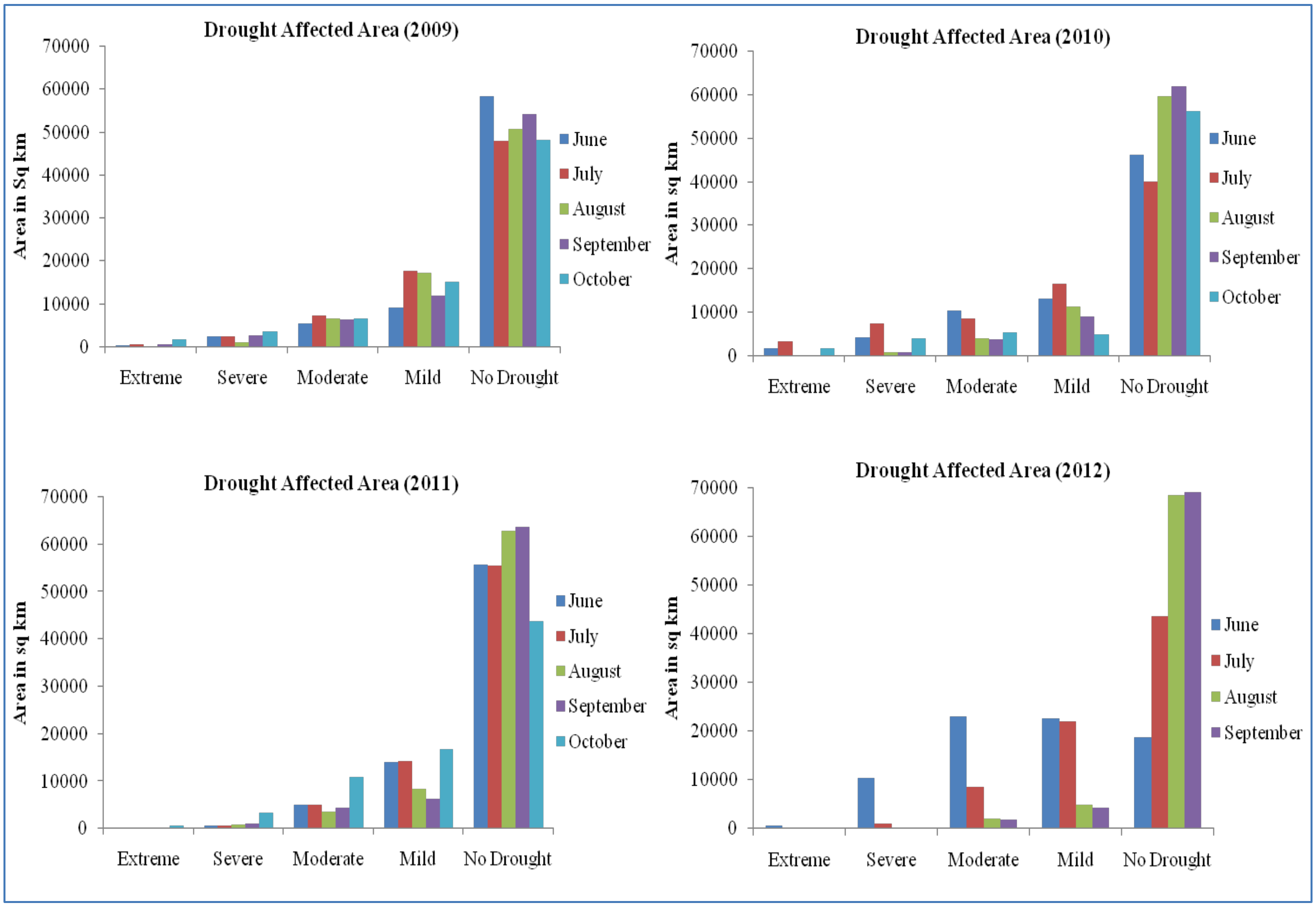


Figure 20: Drought Affected Area for the year 2009,2010,2011,2012

Table 15: Drought Affected Area for the year 2009 to 2012

	Drought Affected Area (Sq.Km)				
	2009				
	Extreme	**Severe**	**Moderate**	**Mild**	**No Drought**
June	257	2349	5409	9103	58389
July	435	2245	7077	17727	48023
August	0	1016	6477	17057	50825
September	406	2511	6266	11918	54274
October	1729	3558	6464	15048	48106
	2010				
June	1641	4173	10393	13149	46151
July	3153	7365	8474	16368	39951
August	0	657	3985	11256	59603
September	131	821	3687	8932	61936
October	1597	3780	5365	4818	5616
	2011				
June	0	647	5046	13967	55715
July	0	651	5001	14311	55544
August	0	792	3586	8287	62842
September	0	1077	4383	6380	63667
October	726	3254	10887	16852	43788
	2012				
June	574	10316	23105	22712	18800
July	118	1090	8494	22064	43741
August	0	251	1966	4812	68478
September	0	109	1908	4330	69160

Summary and conclusion:

Analysis of droughts in Bihar suggests that the southern part of river Ganga faces severe drought every year during Kharif season. The main reason for these droughts is the onset of monsoons and its uneven spatial distribution. The pre-monsoon droughts are more severe as compared to those in the post-monsoon season. A shifting pattern of pre-monsoon and post-monsoon droughts has been observed. June, July, and October are the most drought prone months. Ten districts of Bihar that are affected by drought the most are:

1) Kaimur
2) Rohtas
3) Aurangabad
4) Buxar
5) Bhojpur
6) Gaya
7) Jahanabad
8) Patna
9) Siwan
10) Gopalganj

Chapter 3

Earthquake hazard in Bihar

Introduction:

A devastating earthquake can cause widespread damage and destruction of life, property and economy. Extensive researches have been carried out for predicting earthquakes, with the long term aim to minimize the impacts. For example, thermal changes due to stress fields and radon emission just before the earthquake have also been studied. According to Tronin (2000), the advanced space-born equipment for remote sensing in the infra-red (IR) spectrum allows monitoring of the Earth's thermal field with a spatial resolution of 0.5-5 km along with a temperature resolution of 0.12 - 0.5 Co. Long time series of IR images along with seismic activity should be analysed to obtain conclusive finding. In north-east China, using NOAA (AVHRR) thermal IR images and Bekker's algorithm for ground temperature retrieval, something conclusive was tried. Lee (2005) made an evaluation on the hazard of landslides at Penang (Malaysia) using Landsat TM and SPOT images. He found that logistic regression model is more suitable for prediction than probabilistic model. Panda, Choudhury et. al. (2007) worked on Kashmir earthquake that occurred on 8 October 2005. They tried to find out Land Surface Temperature (LST) preceding the earthquake. They used Moderate Resolution Imaging Spectro-radiometer. They considered air temperature data from two meteorological stations (Islamabad and Srinagar) and found a correlation of thermal anomaly in LST to pre-seismic activity. After analysing MODIS, daytime LST data of September–October 2005 and air temperature data for the whole month of October 2005 they concluded that there was a distinct, robust and rapid rise in LST before the Kashmir earthquake. Saraf and Choudhury (2005) found that built-up pressure due to tectonic activities and associated subsurface degassing might create changes in thermal regime prior to an earthquake event. They used NOAA-AVHRR thermal datasets for studying the thermal changes before and after the earthquakes, of few major past earthquakes such as, Bhuj (India), Boumerdes (Algeria), Bam (Iran), etc. Their study was successful in detecting pre-earthquake thermal anomalies prior to these earthquakes. They also observed significant thermal anomalies with a rise in temperature of about 5-10°C in the vicinity of the epicenters. They also tried to use passive microwave SSM/I sensor datasets from DMSP satellites for few other earthquakes. Choudhury et. al. (2006) tried to detect the changes near ground temperature before earthquake in tectonically active regions. They concluded that thermal remote sensing can provide important clues about future earthquakes. They also analysed post-earthquake NOAA-AVHRR data and observed a rise in temperature (temperature variation curves were prepared from air temperature data collected from several meteorological stations) and short-term rise in LST prior to several earthquake around epicenter. They also observed that the thermal anomalies went away along with the earthquake events. Tronin (2000) evaluated the utility of thermal remote sensing while assessing the earthquake in China. NOAA/AVHRR thermal images indicated the presence of positive thermal anomalies that are associated with the large linear structures and fault systems of the Earth's crust. They found a relationship between thermal anomalies and seismic activity in Middle Asia on the basis of a 7-year series of thermal images. They found significant thermal anomaly near Beijing, at the border between mountains and plain, which was about 700 km long and 50 km wide. They observed that the anomaly appeared prior to about 6-24 days and continued about a week after an earthquake. Sahoo et al (2000) evaluated two major faults of India, in the Ganga and Yamuna tear faults along which the Ganga and Yamuna River emerge from Himalaya. These two major strike-slip faults (a high angle or vertical fault on which the movement is parallel to the strike of the fault.) transverse to the Siwalik range has been clearly identified in the satellite imagery of Dehradun area. They made an effort to study the tectonic evolution and neotectonic events of the Ganga and Yamuna tear faults. They performed spectral and spatial enhancement techniques in IRS-1B LISS-I data to delineate the lineaments and major faults of the area. Based on Mohr's theory, failure criteria and statistical analysis of remotely sensed lineament data, horizontal compressive stress values (SHmax) have been estimated at various sites within the study area and extracted active faults and lineaments from the images. To reconstruct a regional geodynamic model past earthquake data, depth to basement contour data has been applied in GIS platform. Bilham, Bodin and Jackson (1995) worked on a 500-800 km long segment of the Himalaya bordered by the rupture zones of the Great Bihar earthquake in 1934 and Kangra earthquake in 1905. They used historical records, GPS geodesy(The determination of the size and shape of the earth by mathematical means and surveys.) and GPS field work and also performed Great Trigonometrical Survey network to provide a vital test of existence of elastic strain in the region. Kocal et al (2004) carried out automatic lineament analysis using high resolution satellite imagery for the identification of rock discontinuities. In order to delineate rock discontinuities (A Rock discontinuity is a plane or surface that marks a change in physical or chemical characteristics between two rock layers), 8-bit Ikonos Precision Plus along with 1 meter resolution ortho-rectified image was used. Ramli et al (2009) proved remote sensing to be a useful tool in lineament identification and mapping. Their study demonstrated the use of multispectral Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) satellite data obtained over two acquisition dates in 1990 and 2002 for lineament interpretation in a Malaysian tropical environment. To improve the interpretability, they generated a digital elevation model (DEM) and successfully detected most of the major orientations in the field station from the remotely sensed imagery. The results from the study showed that the remote sensing technique is capable of extracting lineament trends in an inaccessible tropical forest. Saraf et. al. (2008) worked on the detection of earthquake thermal infrared precursors in Iran using satellite data and found Land Surface Temperature (LST) changes before an impending earthquake. This could have been detected with thermal infrared (TIR) sensors such as NOAA-AVHRR, Terra/Aqua-MODIS, etc. They studied TIR anomalies produced by 10 recent earthquakes in Iran during the period of Jun 2002–Jun 2006 in the tectonically active belt. They analysed pre- and post-earthquake NOAA-AVHRR datasets and observed a dual thermal peak instead of the single rise in case of moderate earthquakes (~ 6 magnitudes). They concluded that due to prevailing residual stresses, the epicenter (epicenter is the point on the earth’s surface that lies vertically above the focus of an earthquake.) and adjoining areas experience aftershocks and thus the disappearance of the IR anomaly might take a comparatively longer time. They showed a plausible relationship between surface deformations and appearance of the TIR anomaly. TIR temperature increment prior to an impending earthquake helped them to conclude that thermal anomaly is a ground-related phenomena not an atmospheric one. Tralli et. al. (2005) expressed that earthquake forecasting efforts are generally related to the understanding of the fundamental dynamics of major faults, with fault segment definition that would lead to a better description of the expected details of earthquake faulting and rupturing. They have used GPS and modern digital seismic data with satellite remote sensing, such as Interferometric Synthetic Aperture Radar (InSAR) data to provide spatially continuous deformation with sub-centimeter accuracy.

Scenario of Earthquake in Bihar

The state of Bihar lies in the Gangetic Plain. This is a fore deep, a down warp of the Himalayan foreland, of variable depth, converted into flat plains by long-vigorous sedimentation with complex tectonic setting (Figure 21 & 22). This is known as a geosyncline and the Gangetic Plain is the Indo-Gangetic Geosyncline. This has shown considerable amounts of flexure and dislocation at the northern end and is bounded on the north by the Himalayan Frontal Thrust. The floor of the Gangetic trough is not an even surface; it rather shows corrugated inequalities and buried ridges (shelf faults). Western Bihar sits on the sub-surface Faizabad ridge while the eastern sections sit on the Munger-Saharsa Ridge. The areas near the border with West Bengal lie on the Kosi Graben (Purnea-KasganjGraben). The central sections of Bihar lie atop the Gandak depression and East Uttar Pradesh shelf. The Himalayan Frontal Thrust does not run in Bihar, though, it runs across the border of Nepal. Several faults have been identified in the region and some have shown evidences of movement during the Holocene epoch. The West Patna Fault runs in a NE-SW direction from near Arrah in the south to the Nepalese border near Madhubani in the north. Running almost parallel to it, is the East Patna Fault which extends from the south-east of Patna in the south to the Nepal border to the east of Madhubani. Another fault (also lying parallel to the previous two), is the Munger-Saharsa Ridge Fault which runs from Bihar Sharif to near Morang in eastern

Nepal. Apart from these there is east-west running tear faults in the region that control the courses of the main rivers. However, it must be stated that proximity to faults does not necessarily translate into a higher hazard as compared to areas located further away, as damage from earthquakes depends on numerous factors such as subsurface geology as well as adherence to the building codes.

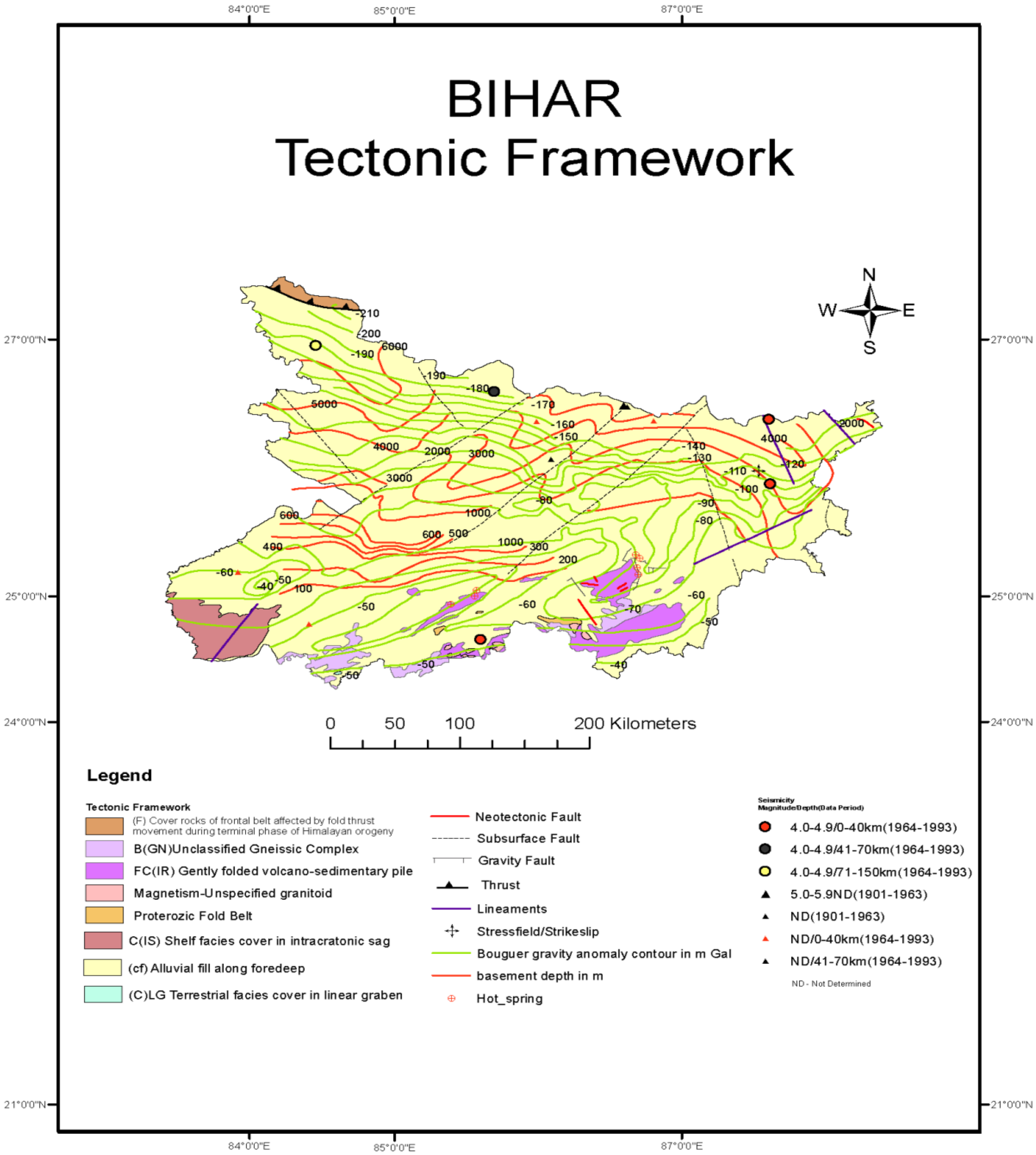


Figure 21: Bihar Tectonic Framework

The seismic hazard map of India was updated in 2000 by the Bureau of Indian Standards (BIS). There are no major changes in the zones in Bihar. Districts such as Araria, Darbhanga, Madhubani, Sitamarhi and Supaul lie in Zone V. The south-western districts of Aurangabad, Bhojpur, Buxar, Gaya, Jahanabad, Kaimur, Nawada and Rohtas lie in Zone III. The remaining districts of Bihar, including the capital city of Patna lie in Zone IV. Since the earthquake database in India is still incomplete, especially with regards to earthquakes prior to the historical period (before 1800 A.D.), these zones offer a rough guideline of the earthquake hazard in any particular region and need to be regularly updated.

Just after the 2009 Bhutan earthquake, earth scientists tried to predict the probability of a devastating earthquake in the eastern region within a couple of years. The 2010 Sikkim earthquake, which rocked major parts of the country, proved the prediction was right. Seismologically the entire region is sitting on a time bomb. Bihar has a history of moderate to severe earthquake occurrences and its area is covered in seismic zones IV and V with possible maximum intensity up to 8.4 on the Richter scale, while the northern part of the state, adjacent to Nepal, lies in the highest risk zone and densely populated Patna with its adjoining areas fall in zone IV (high risk zone).

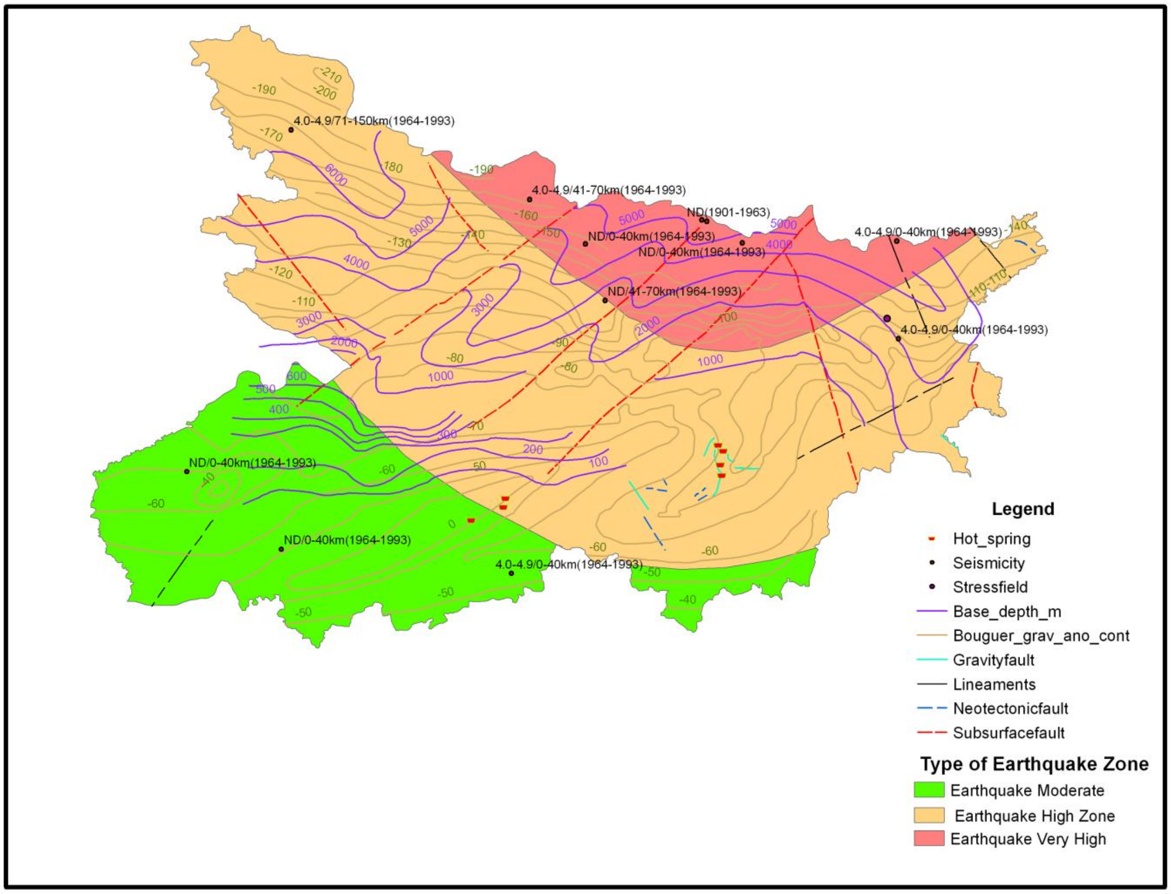


Figure 22: Earthquake Hazard map

Chapter 4

Thermal Heat Island effect in Bihar

Introduction:

Most of the time, the air and surface temperatures of cities are a few degrees higher than their surrounding areas. This temperature discrepancy is the result of an unexpected phenomenon known as the urban heat island (UHI) effect. UHI refers to a metropolitan area with a significantly higher temperature in comparison to surrounding rural areas due to human activities. By default, through the process of urbanization, the cities are converted into islands of heat. Burning of fossil fuel, increasing the impervious surface area, high density of population, and deforestation are the driving forces of heat island formation. Building materials are usually very good at insulating, or holding in heat. This insulation makes the areas around buildings warmer. 'Waste heat' also contributes towards the UHI effect. To accommodate the increasing population density in urban areas, the places become densely constructed and expand upward. Night-time temperatures in UHIs remain high as the heat is trapped on lower levels leading to the urban area being warmer. Several studies have been carried out to identify the UHI effect from ground truth data and also using remote sensing techniques. Effects of different degrees of urbanization on land surface temperature have been analysed by Guo et al (2012). The study builds a quantitative assessment of the relationship between urbanization and land surface temperature, simulated by an urbanization index, which integrates the coverage ratio of built-up land cover type and the vegetation index. Imhoff et. al. (2010) worked on thirty eight of the most populous cities in the continental United States considering the impervious surface area and land surface temperature over three annual cycles to analyse UHI skin temperature amplitude and its relationship with development intensity, size, and ecological setting. Pongracz et al (2006) studied about UHI in the ten most populated cities of Hungary considering day and nighttime surface temperature to determine UHI intensities. They defined UHI intensity as the difference in spatially averaged surface temperatures between urban and surrounding rural pixels. Hung et al (2006) focused on comparative assessment of surface urban heat island in 18 mega cities in both temperate and tropical climate regions to examine the spatial patterns of UHIs for each city over its diurnal cycle and seasonal variations. Peng et. al. (2011) also studied the surface urban heat island intensity taking 419 global cities using 1 km resolution 8 day composite MODIS land surface temperature data.

The present study focuses on the urban heat island issue of Bihar state considering two different years 2004 and 2012 using night time land surface temperature datasets. The study delineated the UHI and attempted to analyse the relationship with the urban extent.

Data used:

MODIS land surface temperature products (MOD11A2) were used in this study. It is a level-3 MODIS global LST and emissivity data product of 8-day composite generated from MODIS daily one kilometer resolution LST data. It provides average values of clear-sky LSTs for a period of 8 days (MODIS product information table).

The Global Rural-Urban Mapping Project (GRUMP) version 1 data of 1 km resolution has been used to estimate the urban extent. The urban extent data distinguishes urban and rural area based contiguous lighted cells from the nighttime Lights.

(Source: http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents). Vector data of 59 major cities of Bihar state were also used.

Urban Heat Island scenario of 2011:

The UHI has been identified from the nighttime 8-day LST composite data shown in Figures 23, 23A, B, & 24. The nighttime temperature of the urban areas is much higher than the surroundings including rural areas. It has also been found that the major cities have higher temperature as compared to the smaller cities.

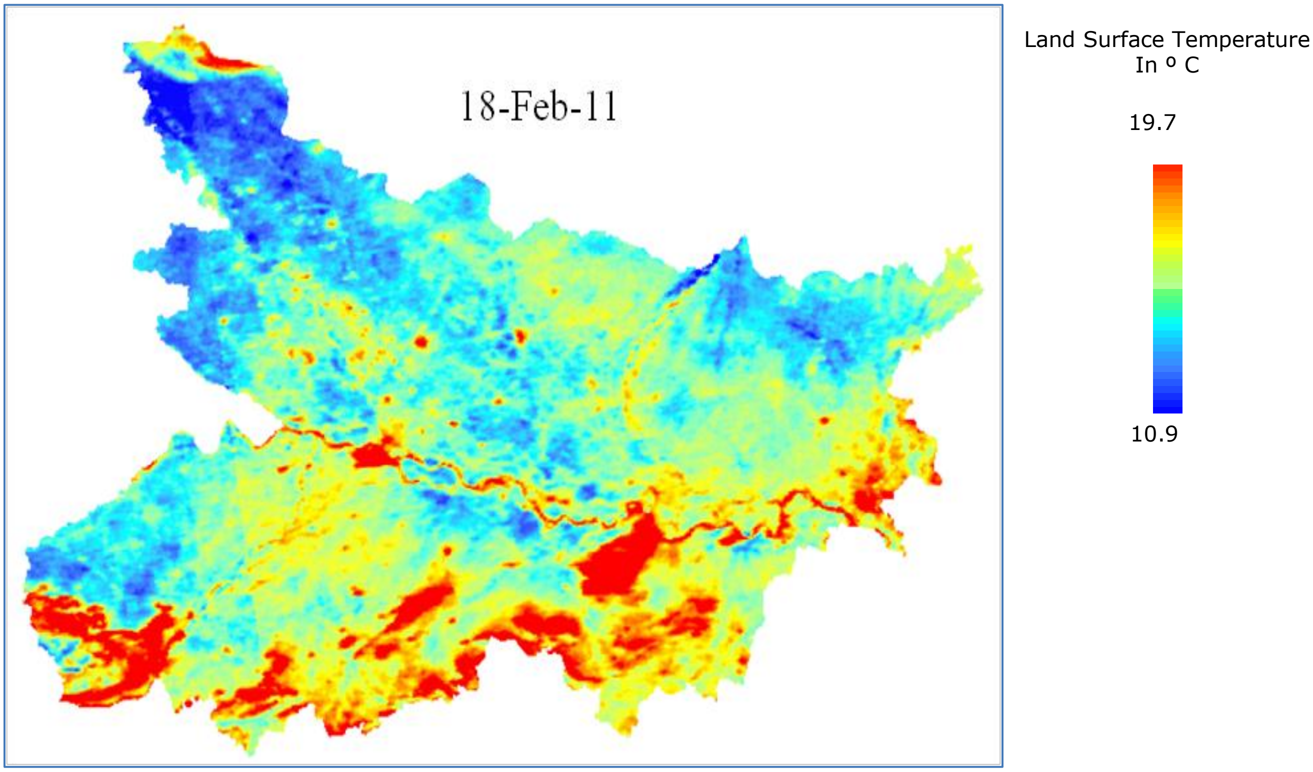


Figure 23: MODIS night time LST showing the UHI 18 Feb11

The figure is showing the land surface temperature (night) of Bihar. The major cities showing high temperatures are compared to surrounding rural areas. The cities appear as bright red points in the nighttime thermal imagery. In the southern parts, some hilly areas also have high temperatures. The high city temperature indicates the UHI effect.

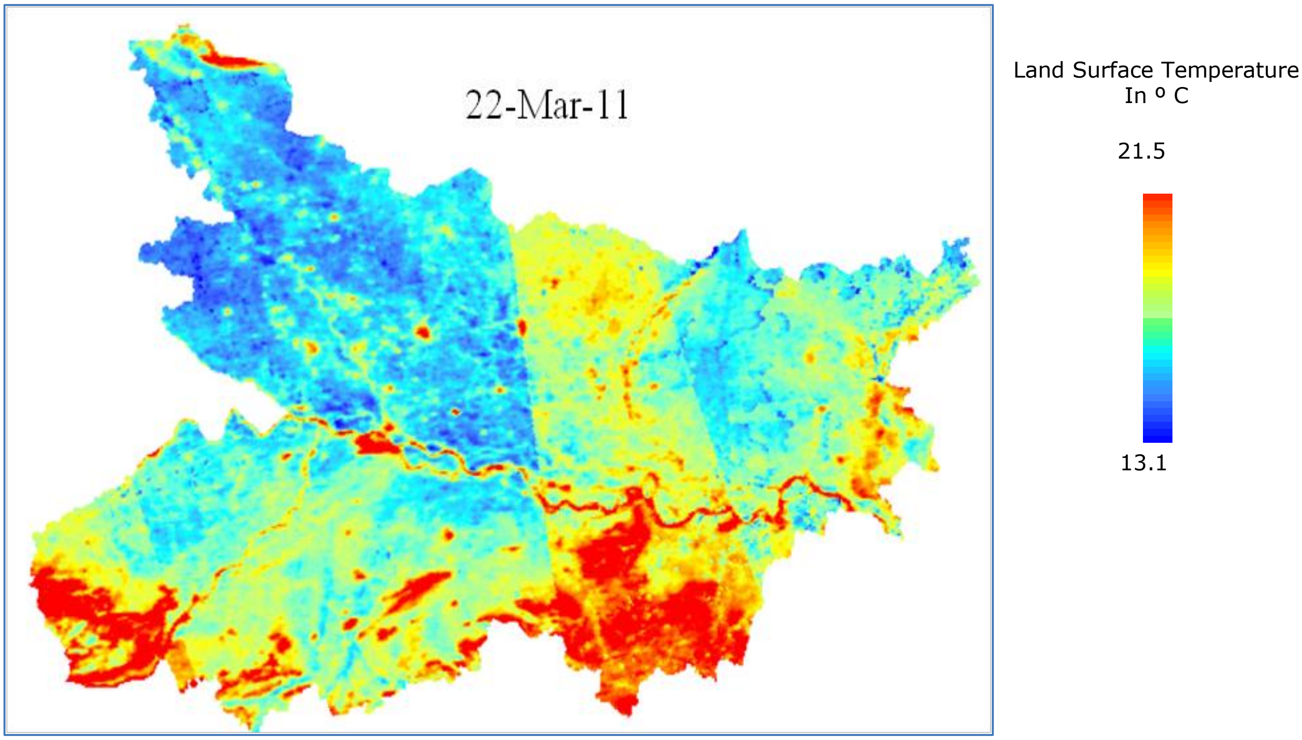


Figure 23A: MODIS night time LST showing the UHI 22 Mar 11

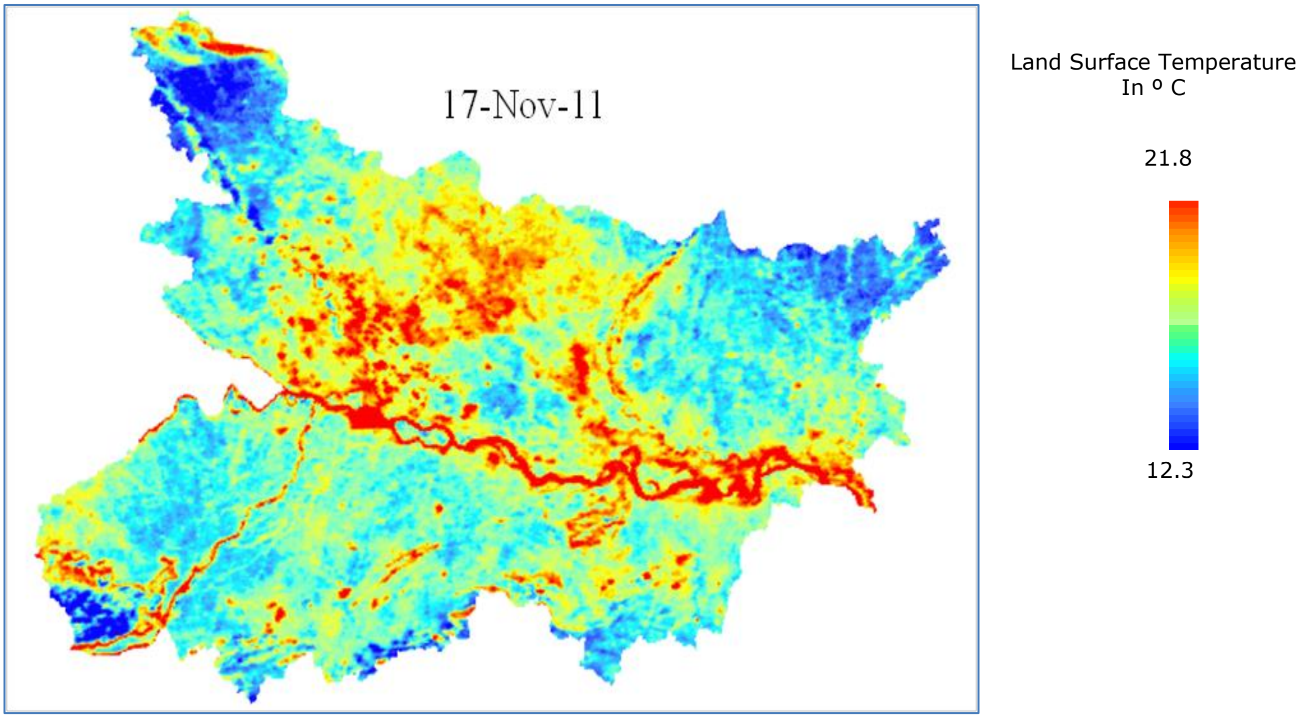


Figure 23B: MODIS night time LST showing the UHI 17Nov11

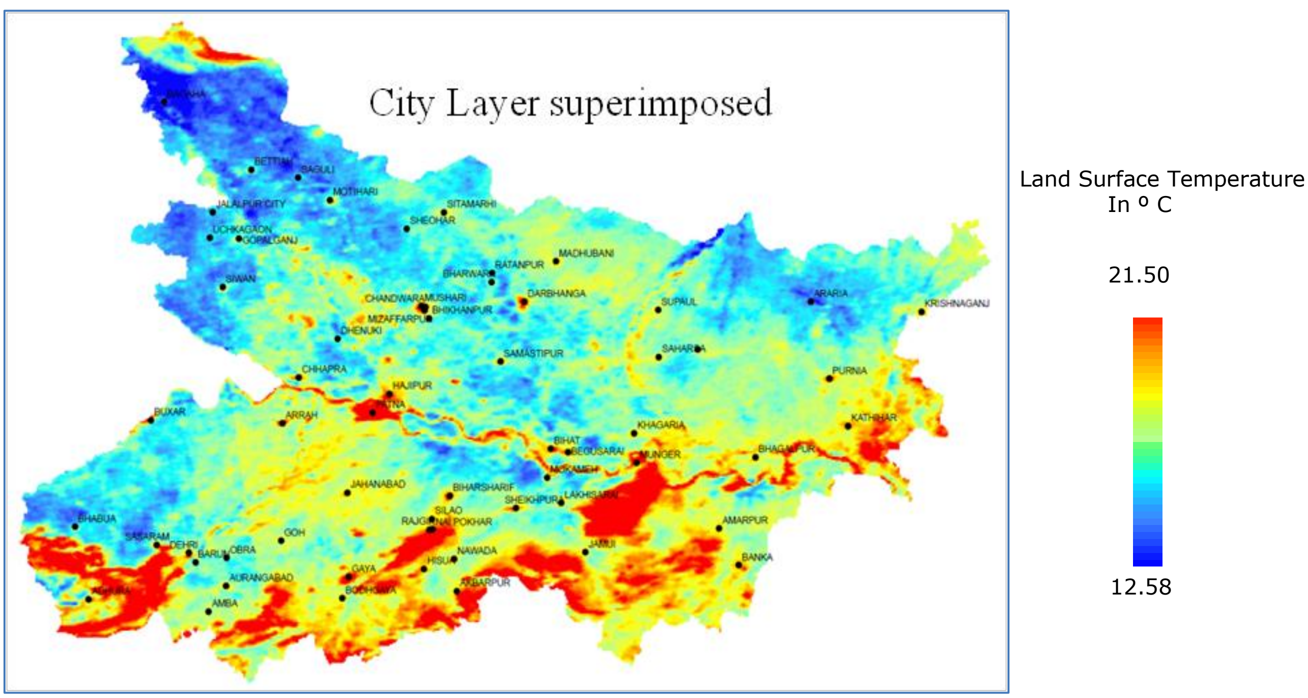


Figure 24: MODIS night time LST showing the UHI City layer superimposed

Efforts have been made to identify the relationship between the urban size and UHI intensity. The temperatures of 59 cities/major towns have been presented in Figure 25, 25A, and 25B

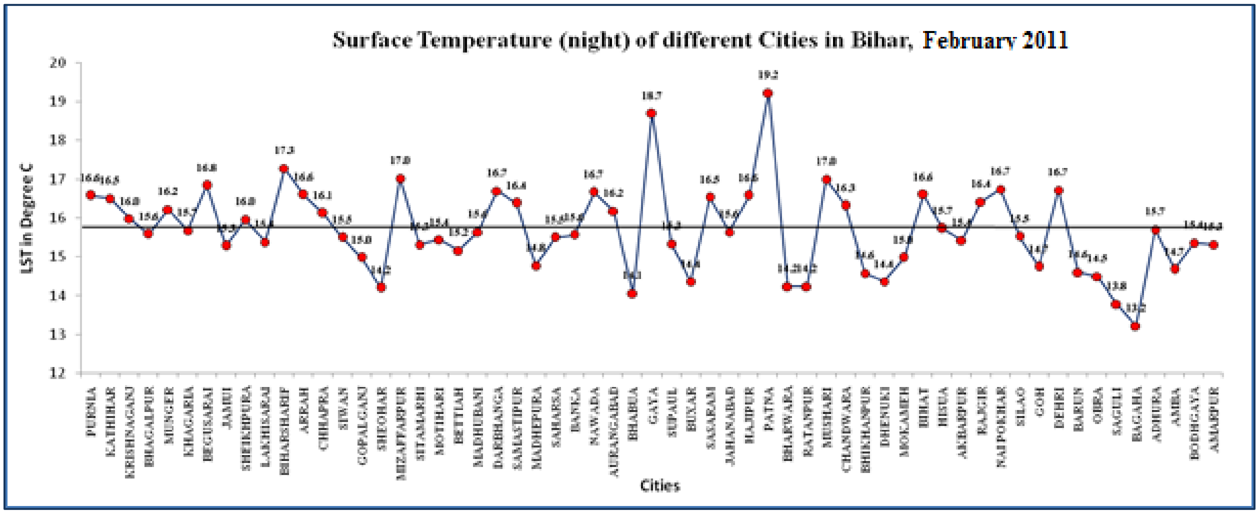


Figure 25: Night time LST of 59 major cities of Bihar showing the UHI in 18th February 2011

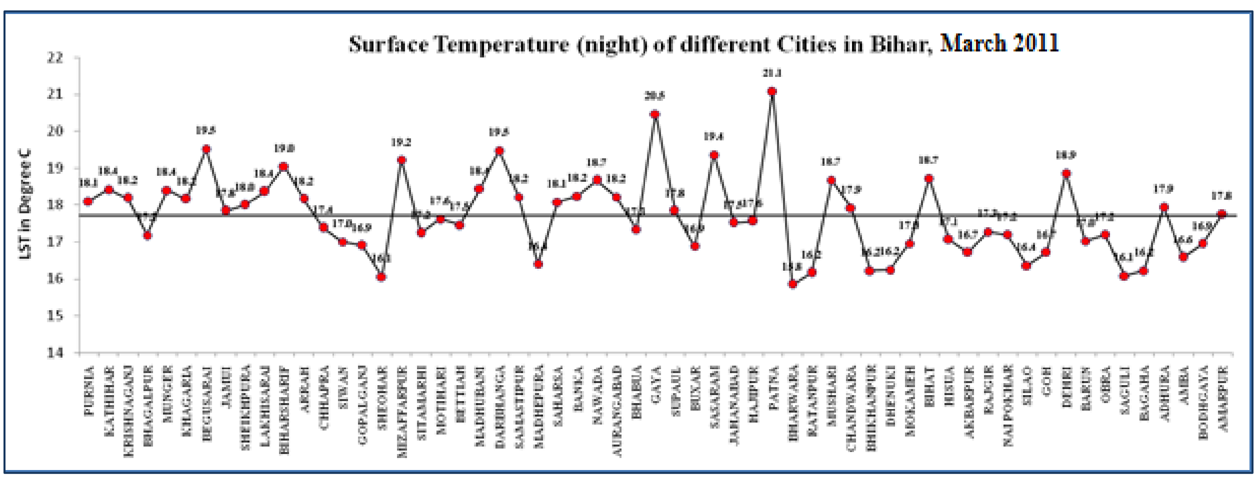


Figure 25A: Nighttime LST of 59 major cities of Bihar showing the UHI in 22nd March 2011

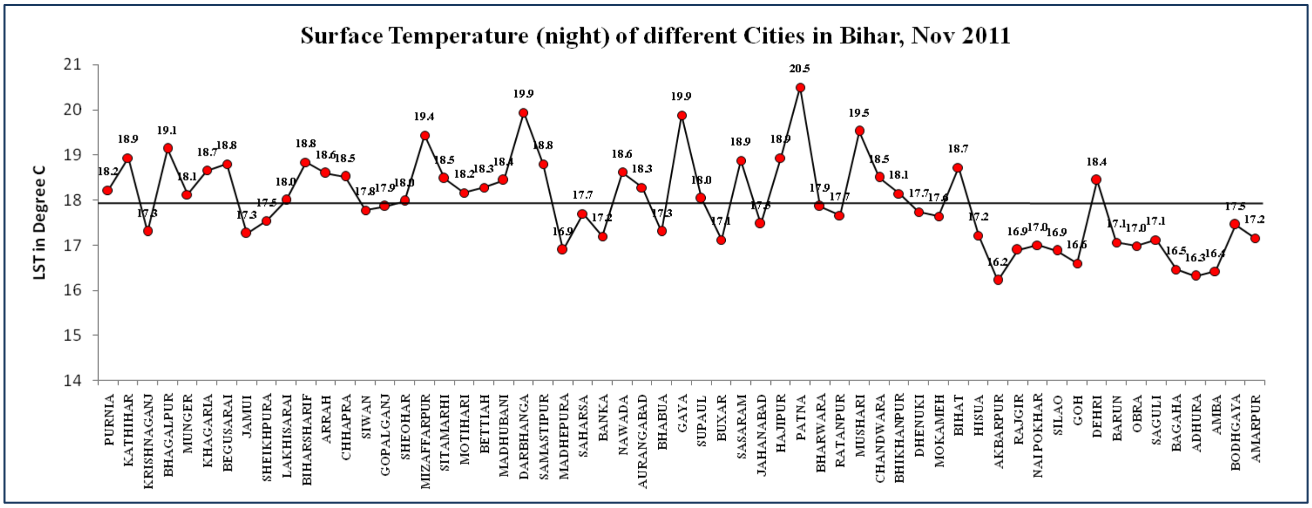


Figure 25B: Nighttime LST of 59 major cities of Bihar showing the UHI in 17th November 2011

Figures 25, 25A, and 25B show that temperatures of major cities are much above the mean temperature of all cities plotted (straight line in the plot). The capital city, Patna, shows the highest temperature of all. The result signifies that urban extent or impervious surface area is an important factor causing UHI.

Urban Heat Island scenario of 2004:

Similar kind of scenario generated from the 2004 datasets has been presented in Figures 26, 26A, and 26B. The LST plots in Figure 27 for major cities also support the same scenario.

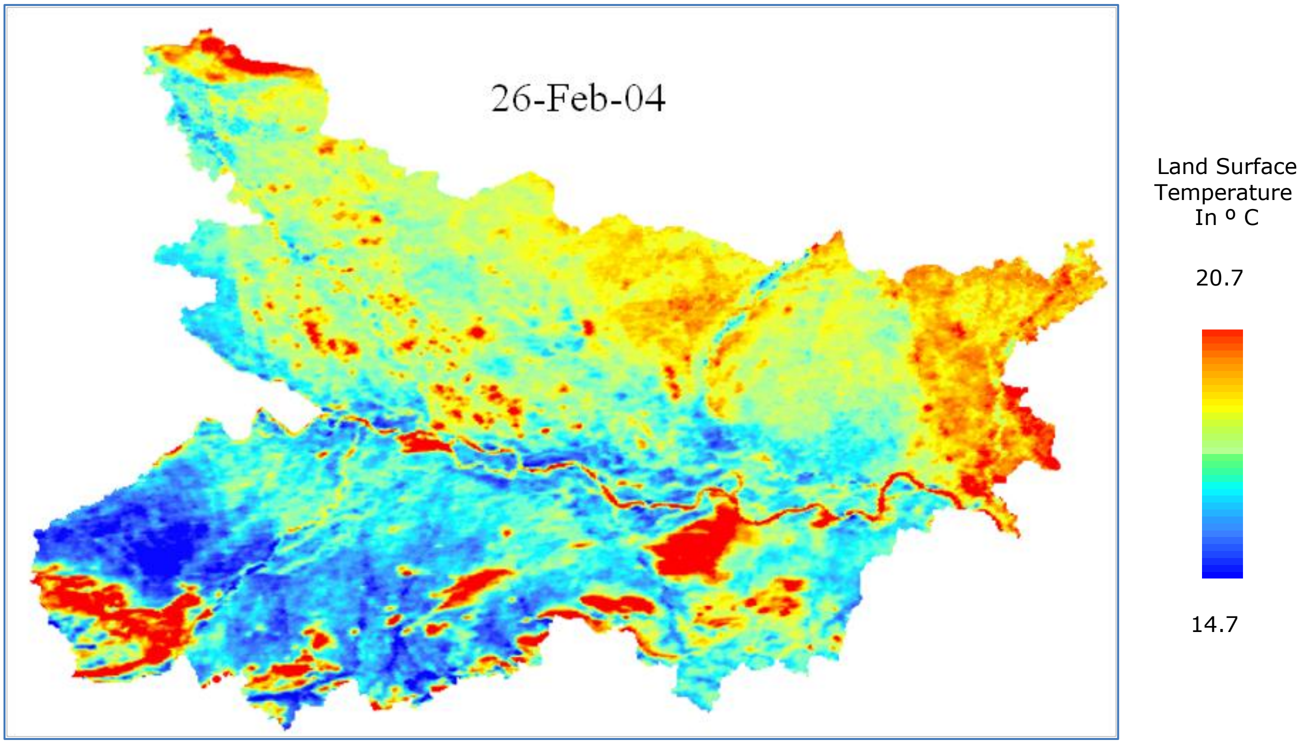


Figure 26: MODIS night time LST showing the UHI 26th February 2004

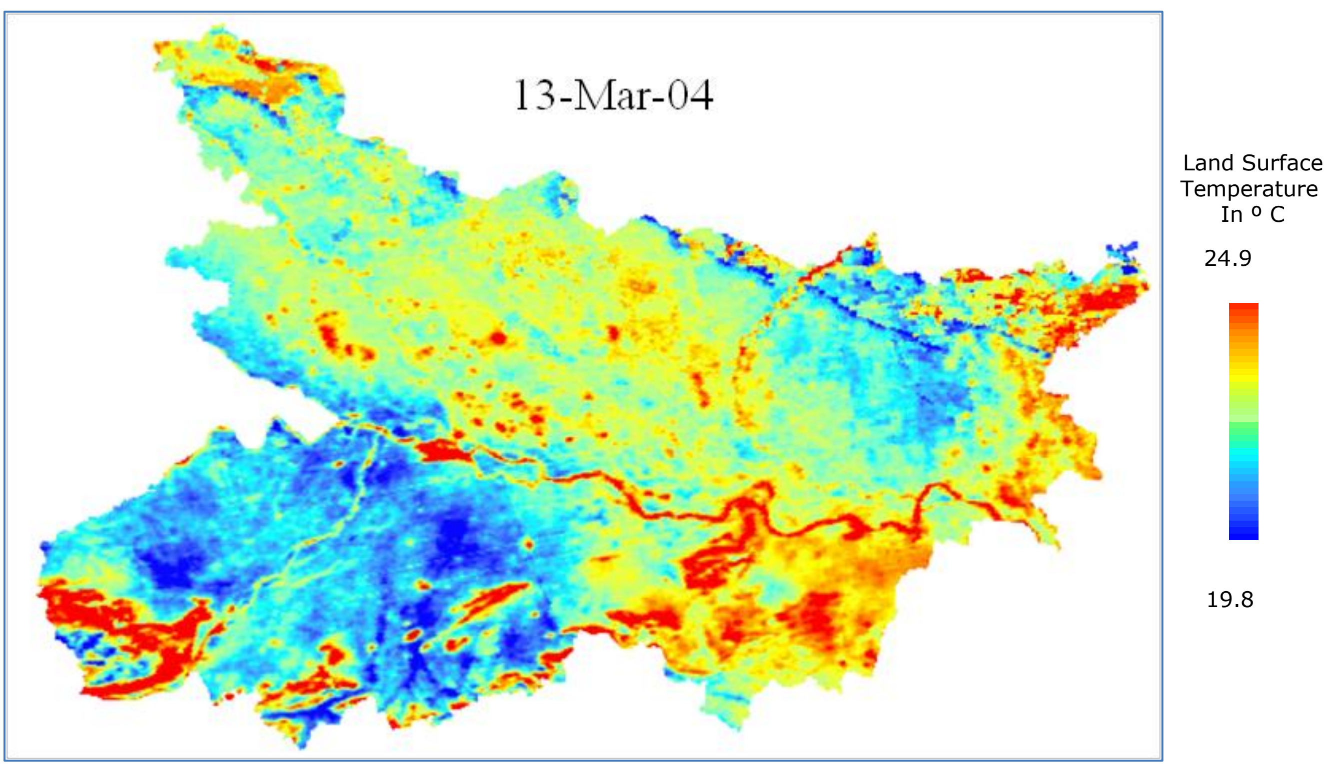


Figure 26A: MODIS night time LST showing the UHI 13th March 2004

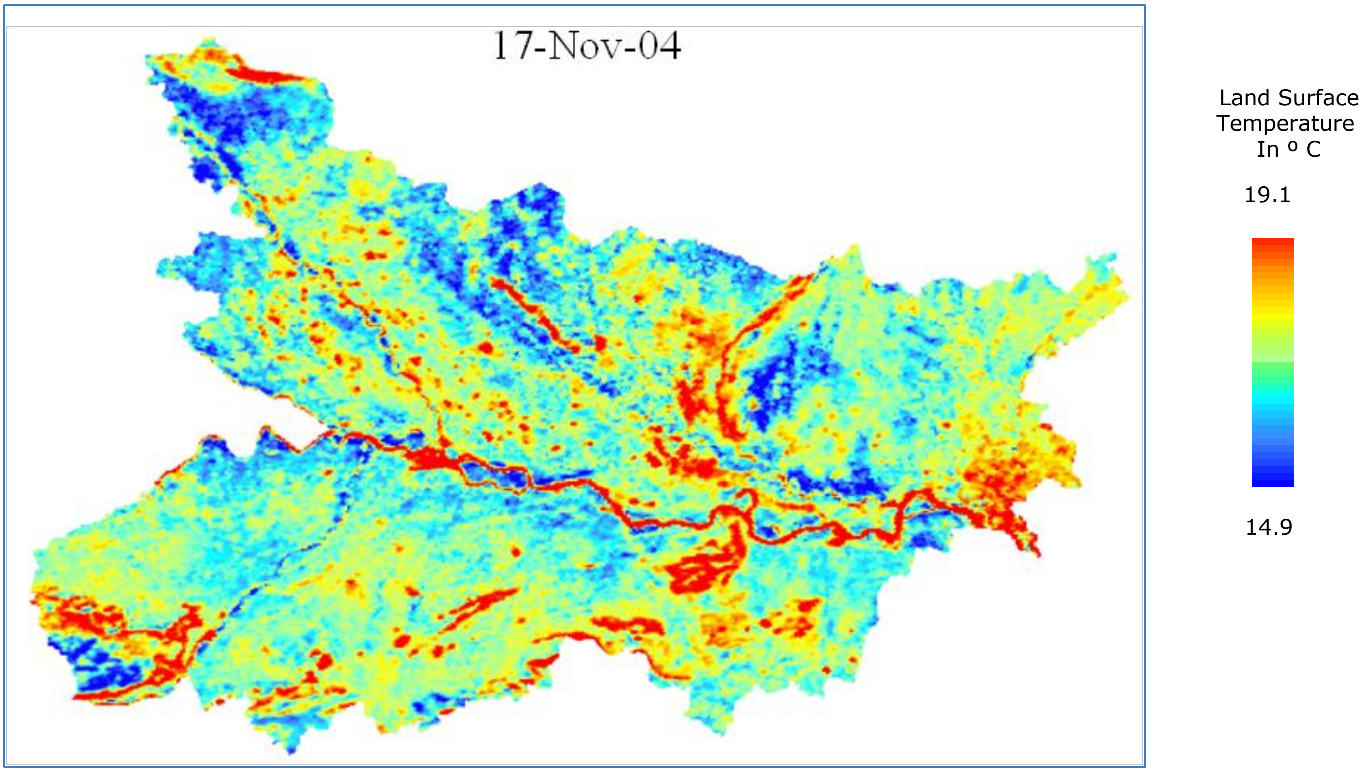


Figure 26B: MODIS night time LST showing the UHI 17th November 2004

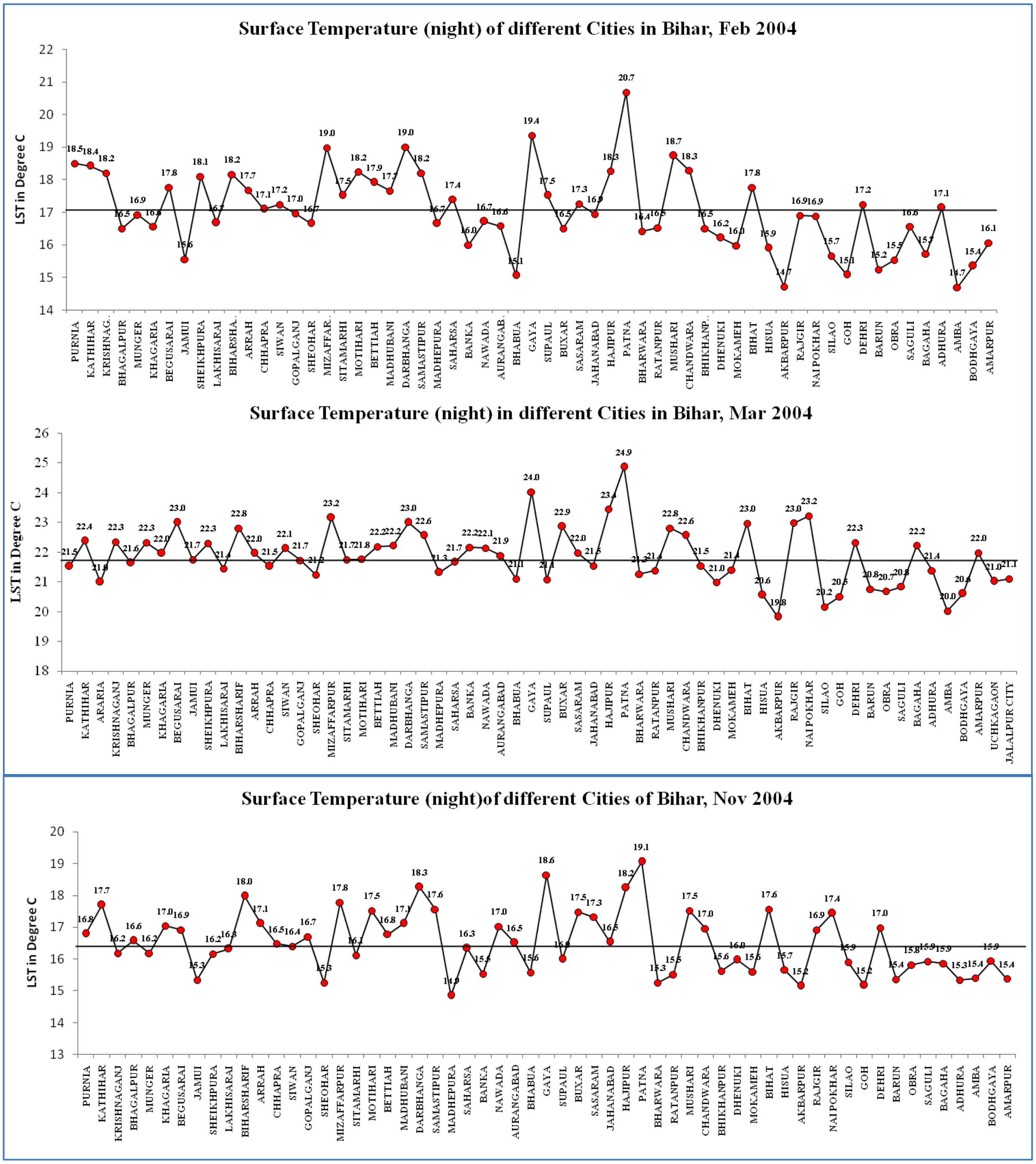


Figure 27: Composite Night time LST of 59 cities/major towns of Bihar showing the UHI in February 2004, March 2004 and November 2004

The statistics generated from the LST data (Table 16) show that the mean temperature of the city is 1.5 to 2 degree centigrade higher than the overall LST mean as well as rural mean for all six dates. The result signifies that the urban areas are getting warmer as compared to their surrounding areas, which is a significant issue for the environment.

Table 16: LST statistics of UHI

Date	Min	Max	Mean	Standard Deviation	City Mean	Rural Mean
18-Feb-2011	**10.97**	**19.72**	**14.47**	**0.97**	**15.7**	**14**
22-Mar-2011	**13.12**	**21.5**	**16.5**	**0.94**	**17.71**	**15.5**
17-Nov-2011	**14**	**23.34**	**16.99**	**0.76**	**17.97**	**16.5**
26-Feb-2004	**12.58**	**21.5**	**15.99**	**1.07**	**17.03**	**15.3**
13-Mar-2004	**5.09**	**25.47**	**20.92**	**0.76**	**21.85**	**20**
17-Nov-2004	**12.33**	**21.88**	**15.32**	**0.75**	**16.5**	**14.9**

The urban extent map for the year 2000 taken from GRUMPS data has been analysed and presented in Figure 28. It is observed that the urban extent has a positive relationship with the temperature due to rapid growth of urbanization. The temperatures of Patna, Bihat, Muzaffarpur, and Gaya are 1º-2.5ºC warmer than other minor townships and more than the temperature of the rural areas.

Figure 28 shows the geographical extent of urban area. It indicates the physical extent of the various cities of Bihar estimated from DMSP night light data sets.

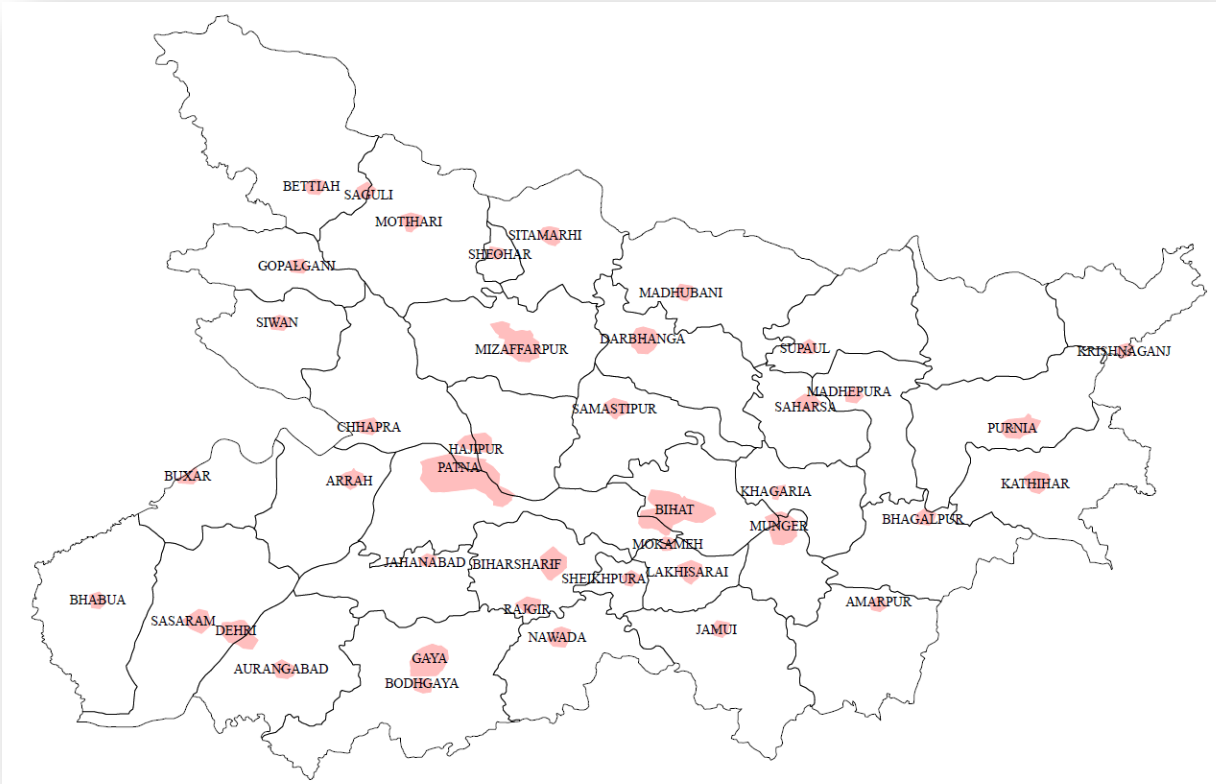


Figure 28: Extent of Urban areas of Bihar

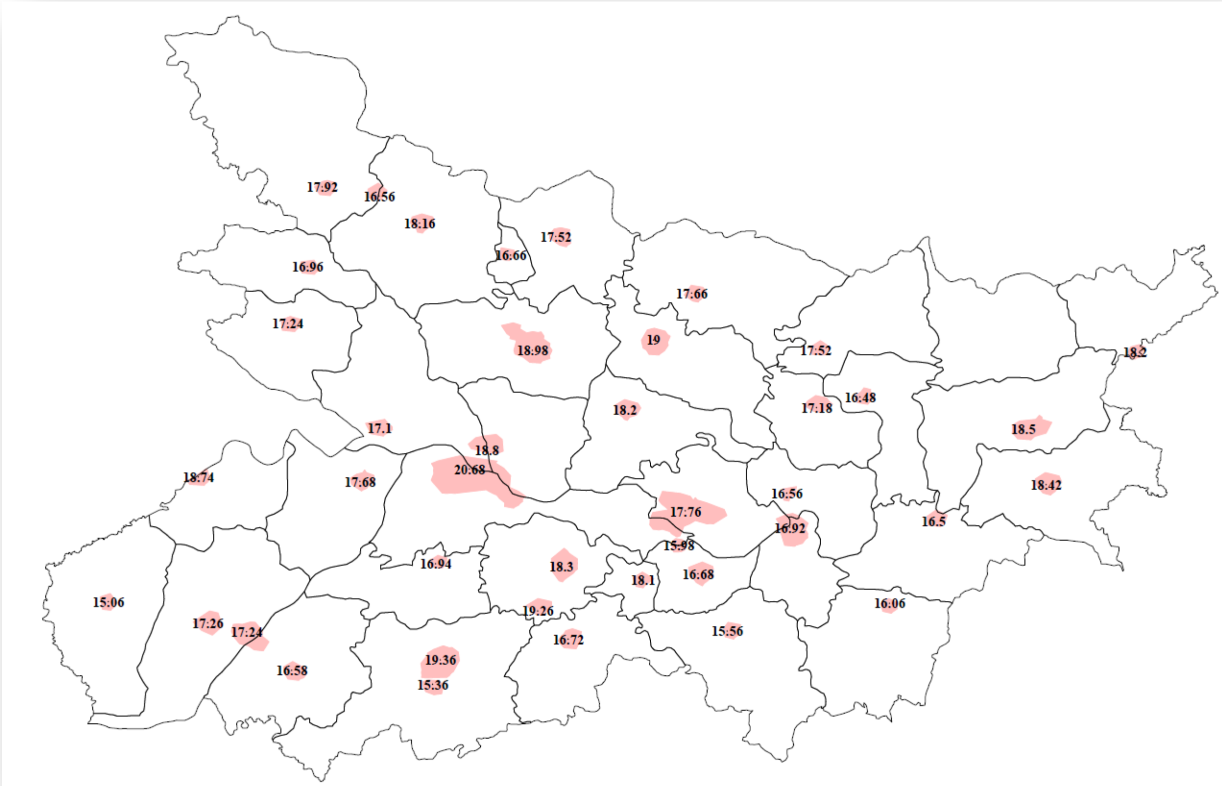


Figure 28A: Urban extent and UHI 18th February 2011

Figure 28A shows urban extent with night land-surface temperature. It indicates that temperature is higher in urban extent. It signifies that urban extent is a significant factor for UHI (**18-Feb-11**).

Conclusion:

The results achieved from the satellite data indicate that Bihar is suffering from urban heat island (UHI) effect. The nighttime LST is higher in urban areas than in rural areas. With rapid urbanization and growth of population density, the impervious surface area is increasing in the cities (Figure 28 & 28A). Finally, all these factors are leading towards the formation of heat islands. The climate change scenario and release of greenhouse gases (GHGs) are also responsible for the formation of UHI. It is an accumulated effect of human activity level and climate change. Hence, the identification of different driving forces, responsible for UHI and analysis of air temperature data in relation with climate change scenario are necessary to assess the environmental monitoring in the context of climate-change.

Chapter 5

Conclusions and Recommendations

The major emphasis to tackle impacts of natural hazards in Bihar has been on preparedness. As disasters occur only when hazards meet vulnerable people, it indicates that minimizing the vulnerability of people is the best way to reduce the impact of natural disasters on the population. The modern concept of managing a disaster is to manage the root causes of the disaster much before it appears in front of us. This is the insight of preparedness. The more we are prepared, the lesser is the impact of disasters and consequently, the lesser the requirements of emergency operations (the 3Rs-Rescue, Relief and Rehabilitation). So, how efficiently and effectively we manage a disaster depends on how meticulously we are prepared. Risk and hazard mapping along with multi-hazard zonation can lead towards the formulation of a detailed and comprehensive preparedness plan.

Schematic Hazards Zonation

In the present study three natural hazard phenomena are analysed separately: Floods (*Fl*), Droughts (*Drt*), and Earthquakes (*Eq)*. Three different types of hazard maps have been superimposed and shown in Figure 29. In order to combine these three maps to create a multi-hazard zone map, spatial decision support system (SDSS) technique has been applied. Three natural hazards have been considered as criteria for the assessment and multi-criteria approach has been adopted. This approach allows the variation in criteria to be ranked according to their computed weights. The higher the weightage, the more important is the criterion, i.e., the chance of that area being affected by one of these hazards is higher. The schematic hazard zone can be calculated as:

$$S_{HZ} = f \int_{i=1-10}^{w_i} (Fl, Drt, E_q)$$

Where;

S_{HZ}= Schematic Hazard Zonation, F*l*=Flood, D*rt*=Drought, Eq= Earthquake

Each class within the criteria has been assigned a score, and a score has been formulated. As per the importance / intensity, a weightage is given to each criterion. The weighted score has been calculated and summed up. The weighted sum has been classified into the following three classes: (a) Highly hazard prone zone, (b) Moderately hazard prone zone, and (c) Low hazard prone zone. The final schematic hazard map has been shown in the Figure 30.

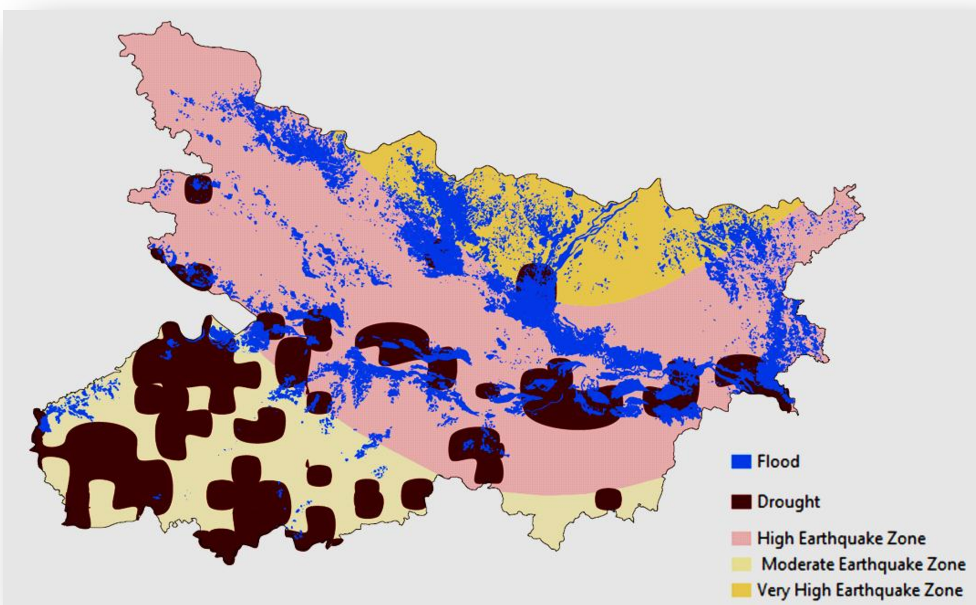


Figure 29: Map showing superimposition of three hazards

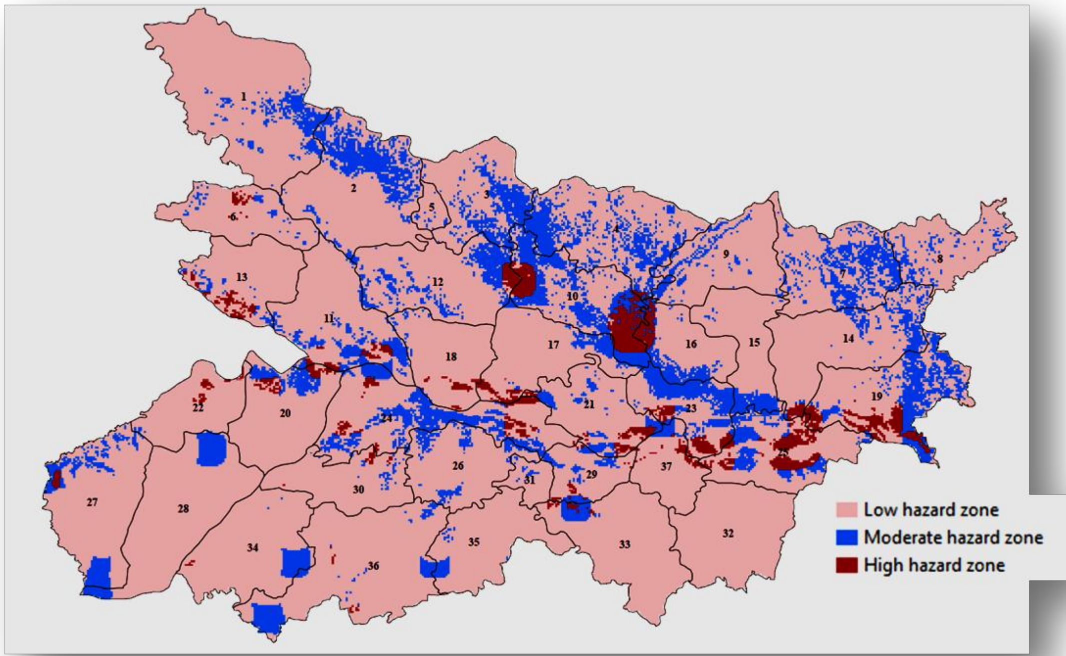


Figure 30: Schematic hazard zonation map of Bihar

Validation and Updating of Existing Hazard Maps

In this project, various natural hazard maps such as those of floods, droughts, and earthquakes affecting Bihar have been derived using remote sensing and GIS techniques. This analysis has been carried out for the time period between 2009 and 2012 to generate different kinds of such maps. Various environmental and mapping agencies have provided similar kind of hazards zonation maps for Bihar. An effort was also made to validate and update the maps produced with the existing maps (Figure 31-36).

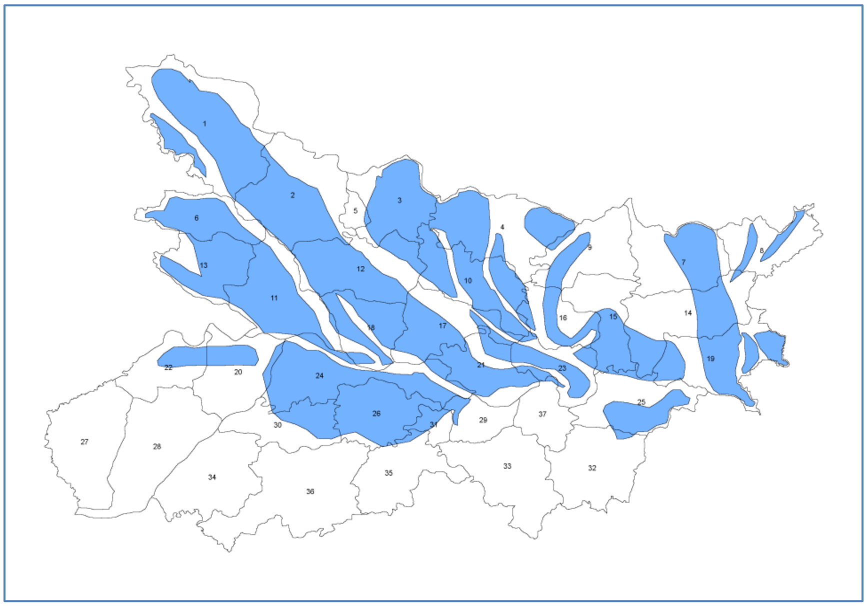


Figure 31: UNDP Flood hazard zonation map

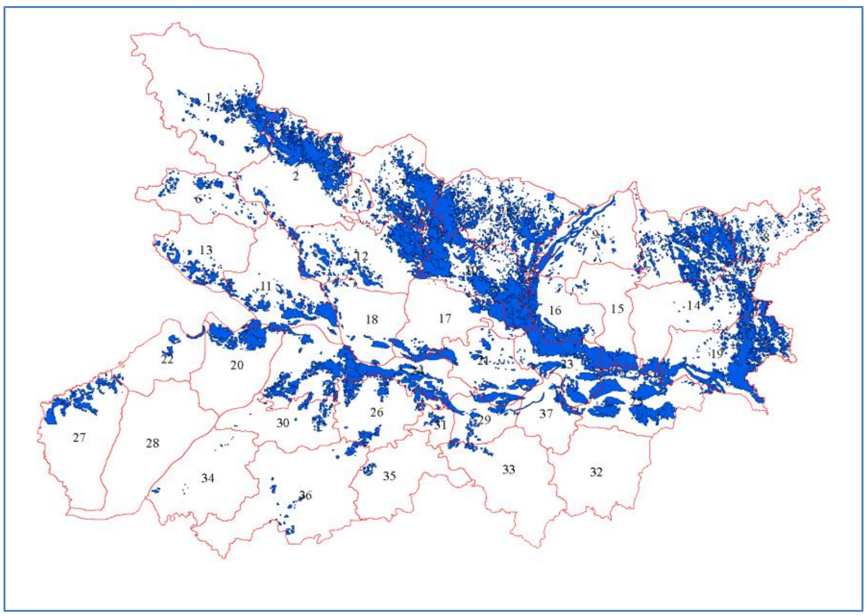


Figure 32: Updated Flood hazard zonation map

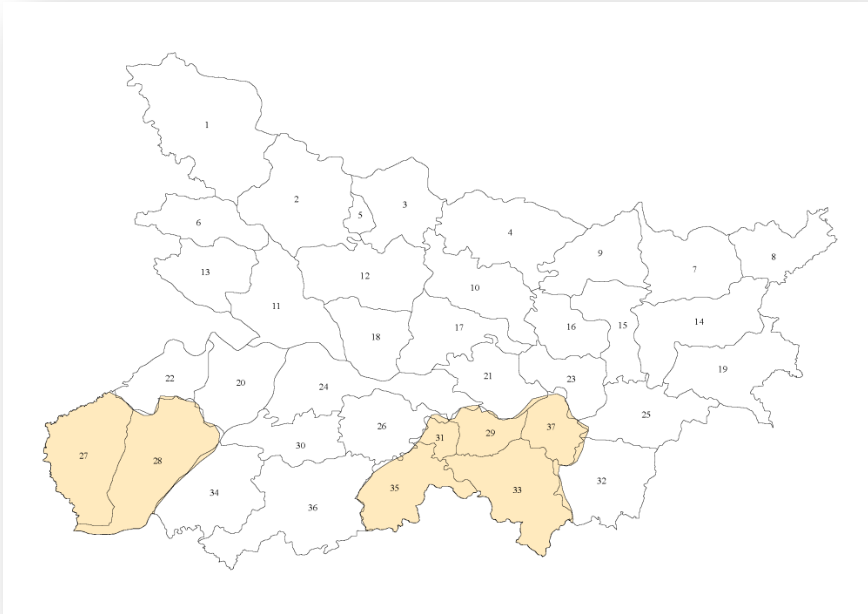


Figure 33: NATMO drought hazard zonation map

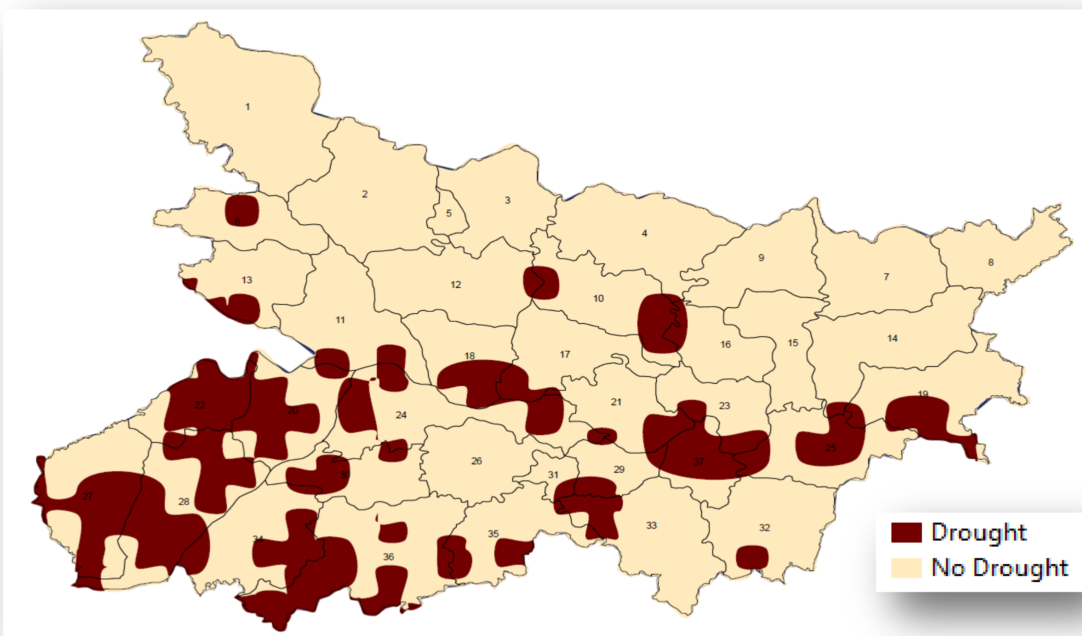


Figure 34: Updated drought hazard zonation map

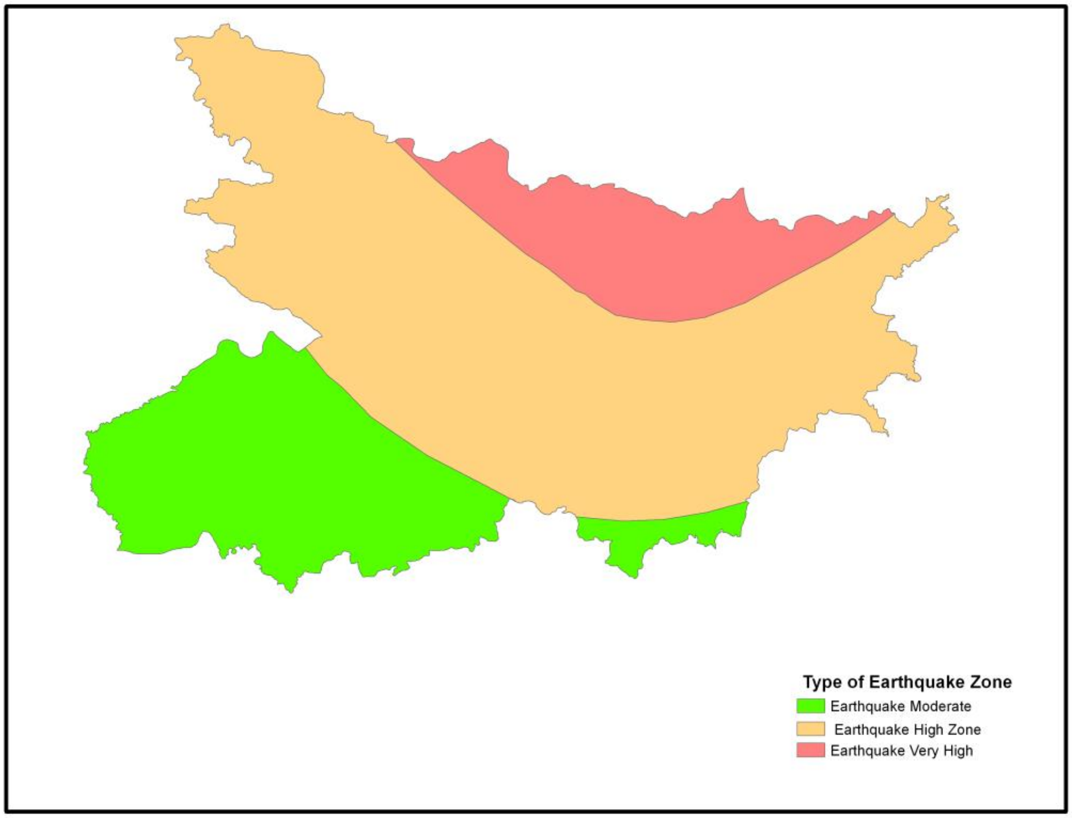


Figure 35: UNDP Earthquake hazard zonation map

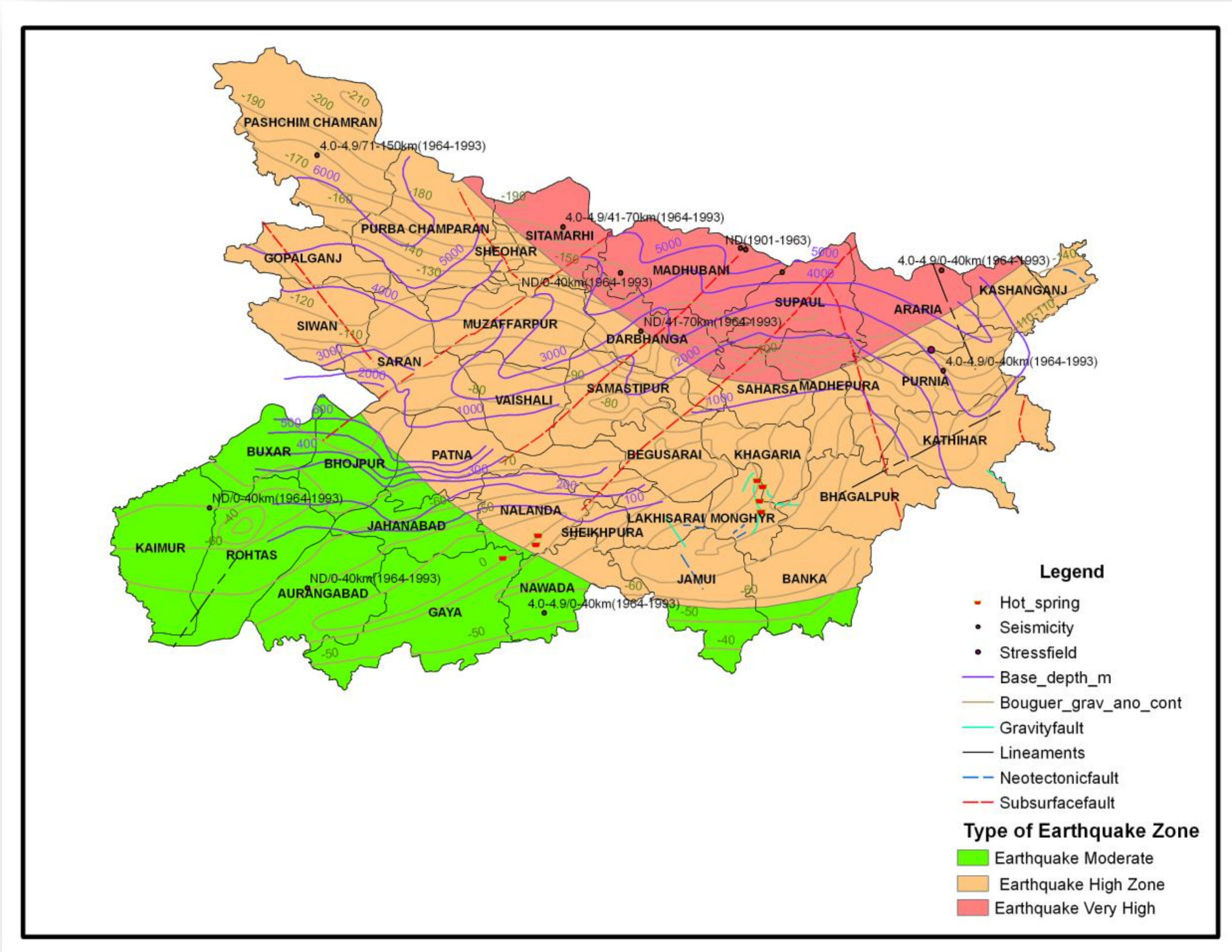


Figure 36: Updated Earthquake hazard zonation map

Recommendations:

The overall study of the schematic zonation of natural hazards in Bihar has been carried out with rigorous satellite data analysis and limited field verification. The output of the entire study not only puts forward new challenges in disaster management strategies to be adopted in Bihar, but also comes up with a lot of possibilities. These recommendations of good practices to minimize the impact of natural hazards in Bihar can, if adopted, also aid the overall growth of Bihar.

Bihar is an agriculture-based state and a major hindrance for sustainable agricultural growth is flood and/or drought. Changing climate mostly indicates that the change of pattern in monsoon is contributing towards aggravated natural hazards, with increase in their frequency and impacts. A thorough climate analysis, dealing with temperature, rainfall, soil moisture, forest cover, and land-use cover change is necessary for understanding the real time scenario. Estimation of changes in the course of rivers is also an important factor.

This study reveals the actual zonation of different natural hazards, on the basis of which policymakers can formulate future plans. The necessity of detailed population studies has been felt to substantiate this process of planning. The zonation of different kinds of natural hazards should be carried out in detail up to the block level. The block level population maps should also to be prepared. These maps in combination can also be utilized to formulate the strategic effort of minimization of the damage on environment, population and property. There is an urgent need to formulate a comprehensive preparedness plan for each district along with the implementation of incident response system along with setting up of Emergency Operation Centre (EOC). The formulation of Standard Operating Systems (SOPs) and capacity building efforts are also mandatory in this process. The comprehensive preparedness plan will come up with pre/syn/post-disaster recommendations and strategies to minimize the level of impact.

Based on the above discussion the overall recommendations have been listed below:

Category-I	Action needed	Remarks
Stress on more activities	• Block level natural hazards zonation • Analysis of frequency, magnitude and scope of the historical events to estimate the expected damage that may occur from such events • Perform Risk Analysis and Hazard Analysis procedures • Combine climate map and population map with all possible analysis • Formulation of comprehensive preparedness plan for damage minimization • Effective functioning of EOC and formulated SOPs • Awareness and capacity building for the community • Ensure growth in every possible policy formulations	Serious effort must be put in to address the characterization, minimization and, policy formulation for disaster management strategies with clear linkages to climate change scenario

Category-II	Actions needed	Remarks
Allow paradigm shift in thought process	Formulate the procedures to/for - • Deal with the rural and urban disasters in different ways • Actual assessment of the damages • Reaching out to the cut off villages • Evacuation of the local community and tourists • Restoration of communication with the villages and transportation of essential commodities • Protection of crops, livestock, etc. • Tackle the added situation of VVIP visits, media management, political opportunism and keeping up employees working in relief operations along with the morale of public at large Indulge the processes of - • Mobilizing villagers to remove silt from water ponds and check dams, and for strengthening embankments. • Harvesting of rainwater and recharging of wells • Implementing a properly planned watershed programme integrating farm ponds, village ponds and check dams • Encouraging cultivation of low water using, drought-resistant crops and crop varieties; • Introducing a higher productivity fodder crop like hybrid Napier and the practice of sowing tree crops in the peripheral areas. • Ensuring the sustainability and flourishing capacity of the society	Mindset and attitude towards disaster management should be shifted from emergency response to preparedness effort for minimizing the damage

Category-III	Actions needed	Remarks
Use modern Techniques with knowledge and objective	• 'Do fantastic science' • Delineate properly the catchments and exact basin capacity to retain water • Detect change in river courses through time • Match these with the amount of rainfall based on microclimatic study • Measure rainfall and surface water availability in comparison to threshold value for minimum needs for agriculture, domestic and industrial need • Pre and post monsoon ground water level fluctuations • Minimize potential loss from total water availability after monsoon • Optimize soil moisture along with the crop and field irrigation demand • Check the vegetation growth • Take special care for dam safety and embankment stability • Installing reliable early warning systems • Constructing reservoirs with large storage in upland or interlinking of river basins • Deeper introspection with the traditional housing construction and design new building codes for the earthquake prone areas for seismic strengthening and proper retrofitting	Make maximum use of Remote Sensing and GIS techniques for fast, actual, and conclusive assessment blended with ground reality and perception.

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APPENDIX

Rationale of this study

Natural hazards are potent problems for every stakeholder within a community. Geoinformatics is a useful tool to assess the types and extent of various natural hazards that befall a particular area. Use of Geoinformatics minimizes both cost and time. Bihar, a landlocked state in eastern India, is also prone to such hazards, which include flooding, soil erosion, landslide and earthquake. Therefore, an assessment of these natural events and their probable extent is important for the planners and policy makers.

Our earth is constituted of different components of nature and various natural elements. Each of these components has definite role in our earth system and every element has its own shape, form and properties. Each element or a group of elements interact with one another and create various natural events and situations.

The components of our nature are sun and sunshine, temperature, cloud, rainfall, rivers, lakes, springs, ocean, tides & ebbs and wind. The natural elements are of two major types, non-living and living. The Non-living elements are Mountains, Valleys & other landforms, different types of soils, tectonics, plate movements, etc. while the living elements are human beings, animals & other species, trees, plants, forests & other botanical species.

The natural events in combination with various natural elements can create some important natural disasters, like cloud & heavy rain can create flood, while cloud, heavy rain & mountains may produce flash flood. Likewise, cloud and heavy rain in combination with high wind can produce flood & cyclone, typhoon and hurricane. Earthquakes, submarine landslides and volcanic eruptions below the ocean can create tsunami, and less cloud, while less rain with high sunshine may produce drought, heat wave and water scarcity. Tectonic events, plate movements can also create hazards like earthquakes and volcanic eruptions.

It is interesting to note that except in earthquake and volcanic eruptions, rainfall (excess or shortages) and wind velocities play very crucial roles in all other types of natural hazards.

Natural Events, Calamities and Disasters

Natural Events like flood, cyclone, tsunami, avalanches, landslides, volcanic eruptions, earth shakes (earthquakes), droughts, desertification, locust invasion, etc. are normally referred to as natural calamities or natural hazards, though in reality, they are all natural events. Human beings are hardly responsible for creating these natural hazards or calamities. However, some of our actions, may accelerate, trigger or advance some of these natural events to a certain extent. The impact of these natural events on the human beings is largely functions of our alertness to respond, preparedness to face and precautions undertaken to safeguard. Natural events or natural hazards or natural calamities often become natural disasters in the absence of adequate preparation. So, we may conclude that

NATURAL DISASTERS = Natural Events or Natural Calamity
(Bigger events are known as Calamities)
+
Absence of Preparedness

Natural Hazards can also be defined as ***rapid onset hazards***, such as Volcanic Eruptions, Earthquakes, Floods, Landslides, Severe thunderstorms, Lightning, and wildfires, which develop with little warning and strike rapidly, and also ***slow onset hazards***, like drought, insect infestations, and disease epidemics that take a considerably long time to develop. In addition, there are manmade hazards that may generate from bad governance and policy, hoarding, disparity, absence of equity, etc.

Table 17: List of natural and manmade disasters

Category of Disasters	Common events
Natural	**Drought, Earthquake, Epidemic, Extreme Temperature Famine, Insect infestation, Flood, Landslide, Volcano, Wave / Surge, Wild fire, Wind storm, Locust, Pest**
Technological	**Industrial accident, Miscellaneous accidents, Transport accident**
Conflict	**Civil disturbance, Civil strife, Displaced/Refuge International conflict**

Types of Natural Hazards:

Natural Hazards and natural disasters can be divided into several different categories:

- **Geologic Hazards -**These are the main subject of this study and include earthquake, volcanic eruption, tsunami, landslide, flood, subsidence and impact with space objects.
- **Atmospheric Hazards -**These are also natural hazards but processes operating in the atmosphere are mainly responsible. They will also be considered in this course, and include hurricane, tornado, drought, severe thunderstorm, lightening, etc.

Other Natural Hazards are those that may occur naturally, but don't fall into either of the categories mentioned above. They will not be considered to any great extent in this course. They include insect infestation, disease, and wildfire/forest fire.

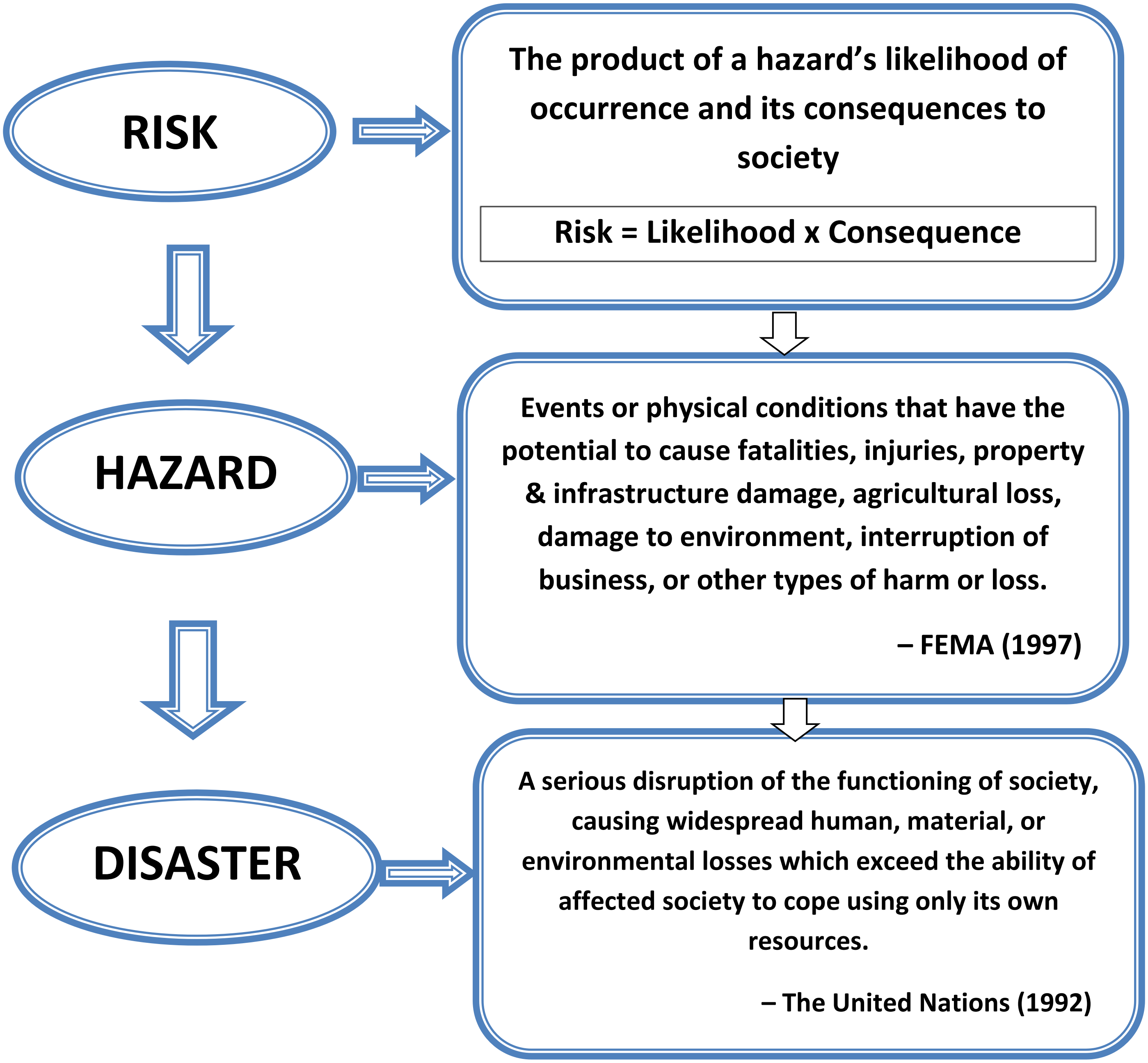
Natural Hazards can also be divided into ***catastrophic hazards***, which have devastating consequences to huge number of people, or have a worldwide effect, such as impacts with large space objects, huge volcanic eruptions, world-wide disease epidemics, and world-wide droughts. Such catastrophic hazards only have a small chance of occurring, but can have devastating results if they do occur.

Normally, a simplistic linear taxonomy of event terminology is maintained to understand the minute conceptual differences between the following terms –

- **An Incident is considered to be minor situation**
- **An Emergency is a more serious situation**
- **A Disaster is yet a more serious situation**
- **A Catastrophe is the most serious situation of all**

\- (Pearce, 2000)

The perception of people regarding natural events originates from the concept of risk and hazards, which may disrupt their usual activities and livelihood. The schematic flow chart has been shown below.



The prime objective of this project is to identify the area affected by various geo-hazards taking place in Bihar along with their spatial distribution within the state.

The Linkage between Natural Hazards and Growth

> *There were earthquakes and floods of extraordinary violence, and in a single dreadful day and night all your fighting men were swallowed up by the earth and the islands of Atlantis was similarly swallowed up by the sea and vanished (Plato)*

The Earth's population is increasing and as the existing cities become completely occupied, people keep searching for new place to live in, and they are forced to enter into areas that are prone to hazards. For example, today around 50% of the >6 billion inhabitants on Earth live in cities. Current trends suggest that by 2025 there will be 8 billion people on Earth and 66% of them will be living in cities. Of all the cities, 40% lie on the coast and therefore are prone to severe storm and tsunami damage. Historically, there have been so many incidences of hazards, which have ruined some remarkable civilizations and places (Figure: 37).

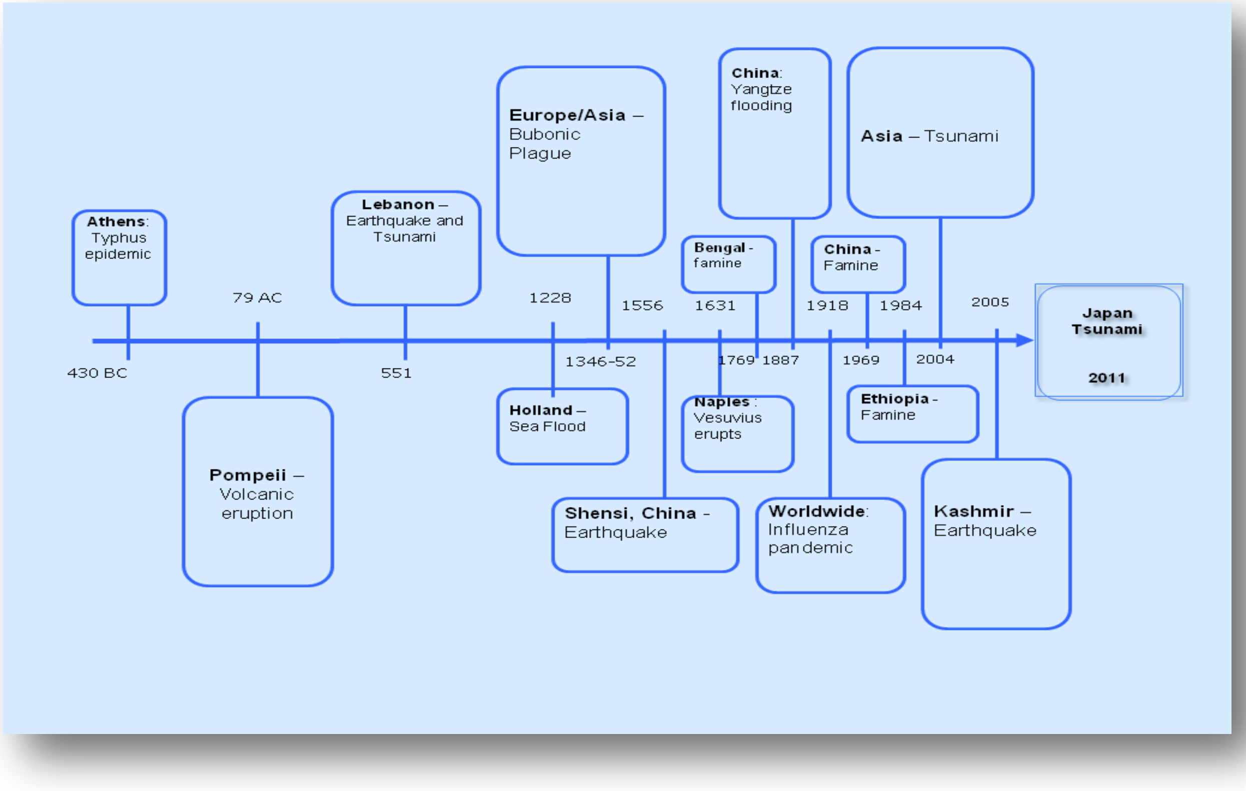


Figure 37: Chronology of remarkable disaster

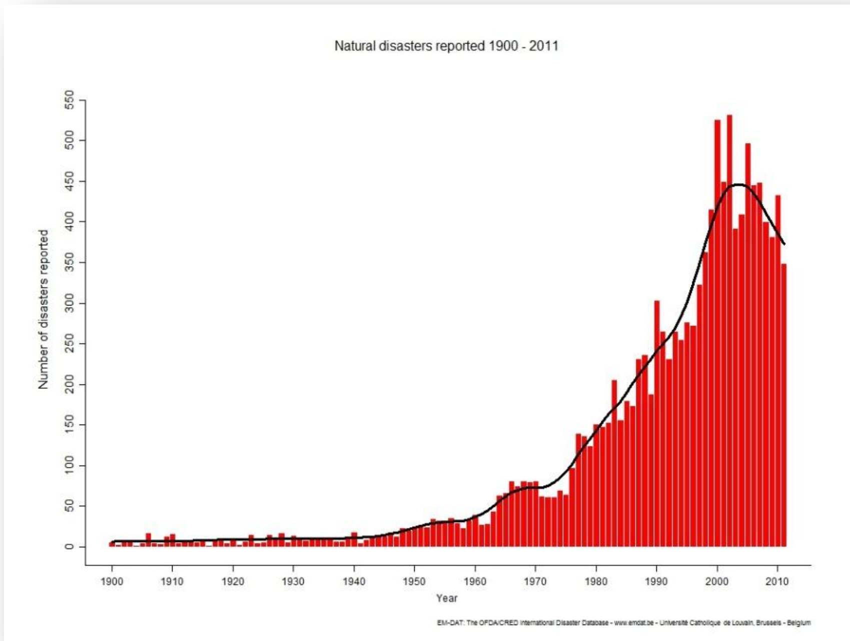
Natural disasters such as earthquakes, tsunamis, cyclones, and floods generate destruction at large scale. Recent events such as the Indian Ocean Tsunami in 2004, hurricane Katrina in 2005, and the Haitian and Chilean earthquakes in 2010, Japan Tsunami in 2011 have received worldwide media coverage, and there is an increasing sense of awareness among the general public about the destructive nature of such disasters. Much research, in both the social and natural sciences, has been devoted to enhance our ability to predict disasters; while the economic research on natural disasters and their consequences is fairly limited. In particular, very little is known about the recovery of the output losses in the aftermath of natural disasters. This is an important question for the development literature. In two recent papers, Barro (2006, 2009) has shown that the infrequent occurrence of economic disasters has much larger welfare costs than continuous economic fluctuations of lesser amplitude. However, at the empirical level, we still do not know much about the aggregate effects of natural disasters.

Abadie et al. (2010) pursued a comparative event study approach, taking advantage of the fact that the timing of a large sudden natural disaster is an exogenous event. The idea is to construct an appropriate counterfactual. i.e., what would have happened to the path of gross domestic product (GDP) of the affected country in the absence of the natural disaster and to assess the disaster's impact by comparing the counterfactual to the actual path observed. Importantly, the counterfactuals are not constructed by extrapolating pre-event trends from the treated countries. According to Abadie and Gardeazabal (2003), by building a synthetic control group. i.e., using as a control group of other 'untreated' countries that are optimally weighted, the missing counterfactual of interest can be estimated. Given the macro nature of the question, this methodology provides the best feasible identification strategy of the parameter of interest. Probably, this is the pioneer work that applies this quasi-experimental design to a topic within the economic growth literature.

Effects of Natural Hazards on Economic Development

The historical assessment (1900-2011) by EM-DAT regarding the natural disasters worldwide, specifically their occurrence and extent of economic damage (Fig: 2), clearly show that natural hazards have very strong influence on the economy. Following natural disasters, governmental sources and media publish estimates on the economic losses that society has suffered. In general, disasters affect economic stocks (direct effects) as well as economic flows (indirect effects). Damage on a company's production facilities is a decline in capital stock. The succeeding business interruption leads to a reduction of output and service flows. Although the majority of loss reports focus on direct losses to stocks, flows tend to be a preferable measure for damage estimates (Rose, 2004). Firstly, flows give a wider picture of the effects of natural disasters.

Machines in a factory may not be directly struck by a flood but production can still decrease or slow down because of shortages in intermediate goods, energy or natural resources due to the disaster. Secondly, losses to stocks might exaggerate damages due to natural disasters as only a fraction of the asset value gets translated into actual services and thus increases utility at a given point in time. Thirdly, flows incorporate indirect effects of natural disasters in a more comprehensive manner.



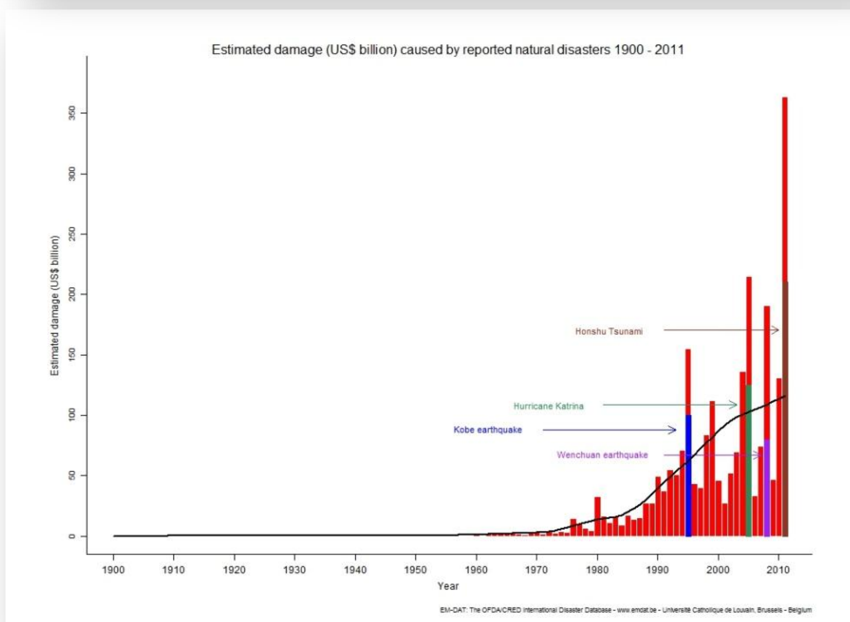


Figure 38: Increasing frequency and damage potential of natural disasters (1900-2011)

(Source: EM-DAT)

The immediate effect of a natural disaster is the sudden reduction of the amount of human and physical capital. Natural catastrophes can have a direct impact on a nation's mortality rate (e.g. Anbarci, Escaleras and Register 2005, Kahn 2005) or can increase the outward migration flows to other countries (Halliday 2006).The pioneering work by Albala- Bertrand (1993) tried to estimate the direct capital losses through natural disasters. This direct destruction of input factors is followed by disruptions in production and output. The cross-country analysis by Tavares (2004) depicts that natural disasters have a small, but negative effect on economic growth. Several studies concentrating on the macro-economic impacts of natural disasters of developing countries provided similar results. Rasmussen (2004) presents a comprehensive study of natural disasters in the Eastern Caribbean Currency Union. He concludes that disaster damages in this area amount to about 0.5 % of GDP. The panel study by Auffret (2003) also finds a decline in output due to natural disasters in Latin American and Caribbean economies.

The possible decline in the national output in the aftermath of a disaster can lead to an increase in imports and a decrease in exports resulting in deterioration of the balance of trade (Auffret 2003). The panel-econometric study by Gassebner, Keck & Teh (2006), however shows a general negative impact on trade (0.3 % in imports and 0.1 % in exports). The assumed effect of any deterioration in the balance of trade only applies for small exporting countries. Another macro-economic effect of disasters is related to the level of investment. The impact on national investment levels is ambiguous. It mainly depends on the reconstruction effort and the efficiency of the risk-transfer regime in place. Private investment tends to decrease while governments tend to initiate more public spending. This might then lead to a higher budget deficit. The reduction in output and investment can also lead to a decrease in private consumption. The study by Auffret (2003) finds that natural disasters have a rather large negative impact on investment growth, as well as a negative effect on public and private consumption. Regarding international investment flows, Yang (2005) shows that following a major disaster, the national level of foreign lending, inward foreign direct investment as well as migrant's remittances increase. In the short run, a major flood event in a European region reduces the regional GDP by 0.4-0.6 %-points; an average flood event in the USA reduces the personal income by 0.3-0.4 %-points (Raschky, 2008).

Thus, the evidenced link between natural disasters and long run growth identified some specific macro-economic variables, where certain level of negative impacts has been felt, such as –

A. **Institutional:**

Since institutions and the economy are closely intertwined, the relation between these two is symbiotic. Better institutions allow growth, while the latter again allows better institutions.

B. **Natural Resources:**

Natural disasters always affect the natural resource stock of any country or society. Several natural disasters have the ability to decrease the soil fertility, which definitely affect the agricultural yields. On the other hand, tourism, which earns good revenue, is usually impacted.

C. **Physical Capital Accumulation:**

Physical capital provokes workers for more productions and has a vital role in achieving economic growth through higher level of per capita income. The change in the situation after any natural disaster changes the physical capital stock and depends on the change in the amount of investment. The natural disasters have a negative effect on physical capital accumulation (Skidmore and Toya, 2002).

D. **Human Capital Accumulation:**

Natural disasters affect human capital accumulation substantially when there is a considerable loss of life. The 2004 Indian Ocean Tsunami caused the loss of life of about 1,30,000 people. During the time lag between any disaster and completion of reconstruction, the people suffer a lot on social and cultural level, including education. It has some positive effect only when serious effort for capacity building of the common people is implemented.

E. **Impact on Technology:**

The natural disasters destroy physical and human capital along with the infrastructure of an economy, the only option for a country is to rebuild with new applied technology. This requires more physical capital and skilled human capital.

Considering all the above mentioned natural disaster impacts on economy, there are possibilities of inflation, increased debt for recovery and loss of revenue (Akigary et al, 2004). There is a certain possibility of black markets in regional scale, especially in rural areas where surveillance is less (Skoufias, 2003). This can put extra burden on the society and reduce their buying capacity. This may, in turn, produce a crippled society in the long run, with less resilience, and definitely with more vulnerability.

Impacts of disasters on human beings and environment:

The impact of all major disasters are basically three folded and they affect all the primary resources like water, land and biomass, cause damage to forest & greeneries, livestock & wildlife, life loss of the population (with specific impacts on gender, aged people, children and disabled), property, and negatively impact the economy, education, infrastructure, health & sanitation and employment (Figure: 39). As a consequence, all the development processes get impeded.

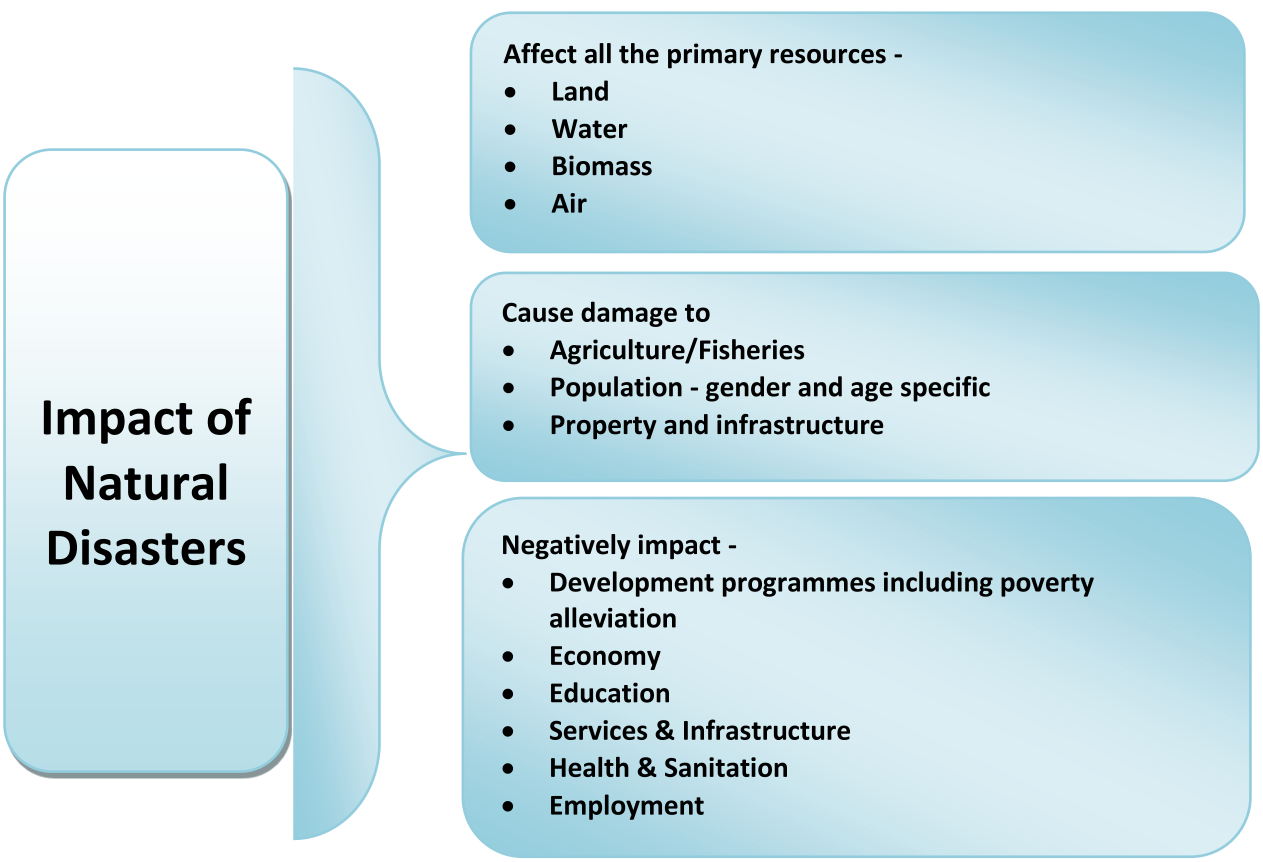


Figure 39: Impact of disaster on society and environment

Table 18: Consequences, Measures and Tangible/Intangible losses of Natural Disasters

Consequences & their Measures		Losses, both Tangible and Intangible	
Types	**Measures**	**Tangible**	**Intangible**
Deaths	Number of People	Loss of Economically Active Individuals	Social and Psychological Effects on Remaining Community
Injuries	Number and Injury Severity	Medical Treatment Needs, Temporary Loss of Economic Activity by Productive Individuals	Social and Psychological Pain and Recovery
Physical Damage	Inventory of damaged elements, by number and damage level	Replacement and Repair Cost	Cultural Losses
Emergency Operations	Volume of Labour, Workdays Employed, Equipment and Resources	Mobilization Costs, Investment in Preparedness Capability	Stress and Overwork in Relief Participants
Disruption to Economy	Number of Working Days Lost and Product (ion) Lost	Value of Lost Product (ion)	Opportunities, Competitiveness and Reputation
Social Disruption	Number of Displaced persons, homeless	Temporary Housing, Relief, Economic Production	Psychological, Social Contacts, Cohesion and Community Morale
Environmental Impact	Scale and Severity	Clean-up Costs, Repair Cost	Consequences of Poorer Environment, Health Risks, Risk of Future Disaster

A natural hazard turns into a natural disaster when the people become exposed to the hazard with less resilience and high level of vulnerability. These natural disaster impacts are multi-fold and several sectors and sub-sectors of the society suffer. The sectors are always constant with more or less impacts, while the population and infrastructure varies spatially in parity with the socio-economic conditions and social dynamics.

In Bihar, several natural hazards create specific impacts on all the sectors at different scales depending on their proximity and resilience/vulnerability. The activity level and background of the people concerned are only suggestive to the extent of impact (Figure: 40). This is referring to an overall degradation of the situation and points towards the need for minimization of loss. It hampers the trend of growth of the society, while the disaster recovery funds are siphoned from the development fund itself.

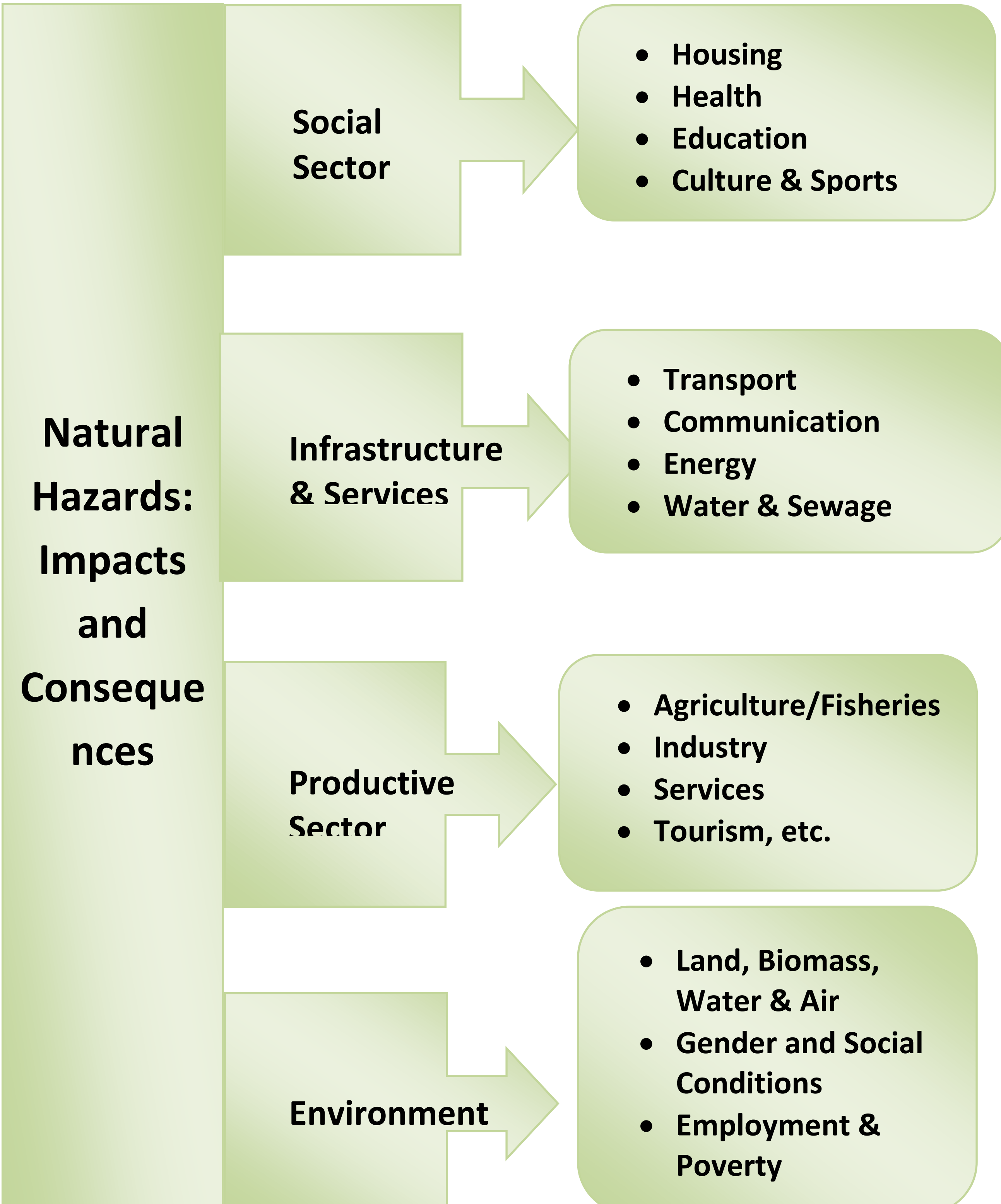


Figure 40: The range of sectors where disaster impacts are felt

After all kinds of analysis and assessment, a number of strategies and interventions will be formulated to minimize the impacts of natural hazards and to cope up with the worst scenario. They directly or indirectly contribute to the futuristic growth of the environment, livelihood and overall economy. The possible areas of growth have been shown in Fig. 5

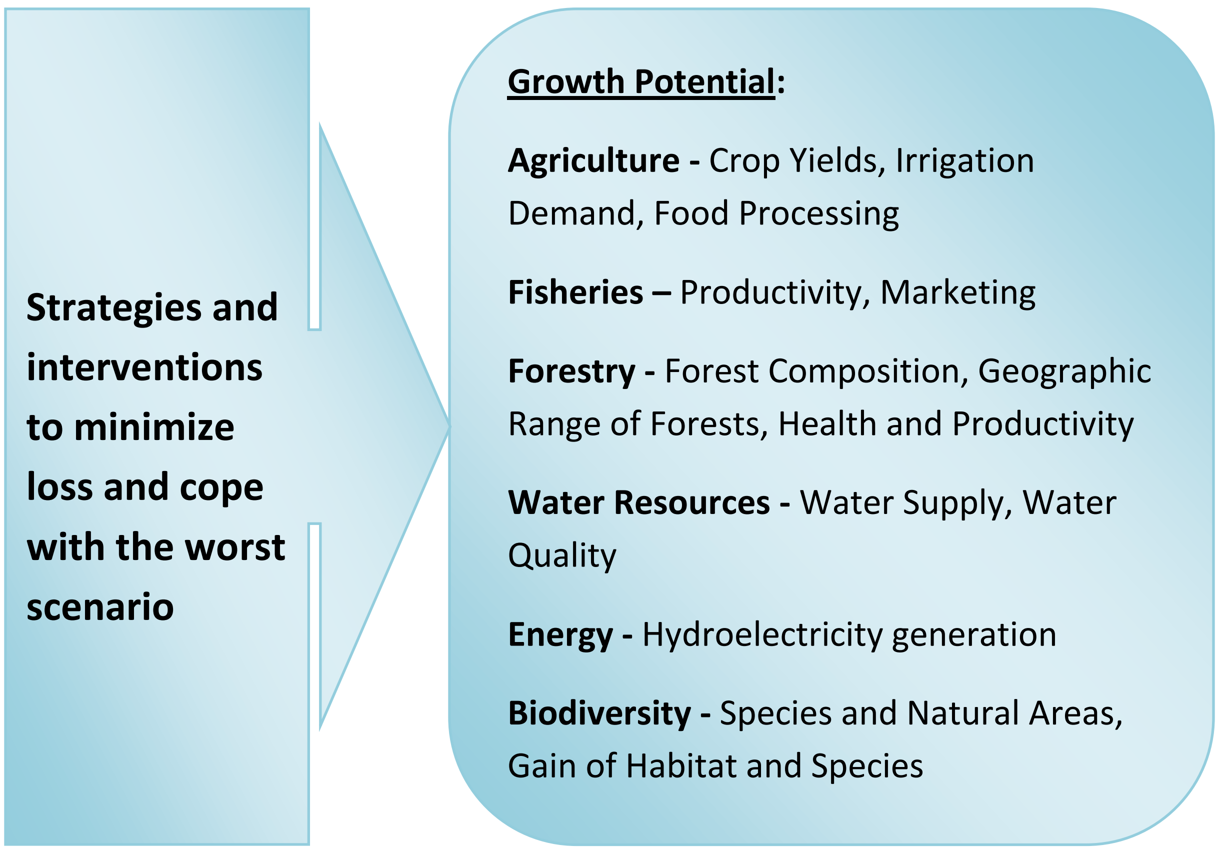


Figure 41: Growth potential out of disaster management practices

Bihar At A glance:

The name of the state Bihar is derived from the Sanskrit and Pali word Vihara which means 'abode'. Ancient Bihar, known as Magadha, was the center of power, learning, and culture in India for 1000 years. India's first empire, the Maurya Empire, one of the world's greatest pacifist religions, Buddhism arose from the region that now makes modern Bihar. The Mauryan Empire, originated from Magadha in 325 BC, was started by Chandragupta Maurya, who was born in Magadha, and had its capital at Pataliputra (modern Patna). The tenth and last GURU of Sikhism, Guru Govind Singh was born in Patna. Bihar was a part of Bengal Presidency of British India till 1912, when the province of Bihar and Orissa was carved out as a separate province. In 1935, certain portions of Bihar were reorganized into the separate province of Orissa. The state of Jharkhand was also carved out of Bihar on 15th November 2000.

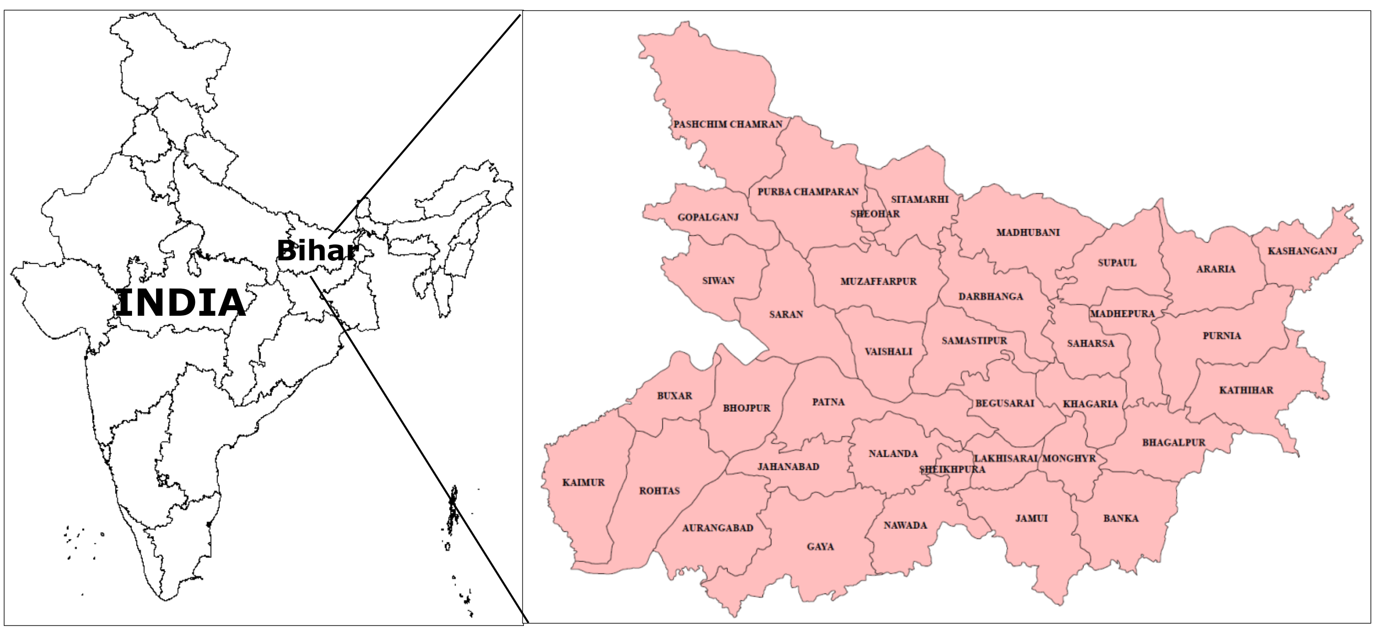


Figure 42: Location map of Bihar

Location:

Bihar is located on the Indo-Gangetic plain and it is rich in natural fertile soil. Plain of Bihar is divided in two parts by the river Ganges that flows in the central part of the state from West to East. The plain of Ganges plays a crucial role for Bihar as it contributes the most to the agricultural and industrial development for the state. Bihar has mainly a vast stretch

of very fertile flat land, which makes it an agricultural rich state. Northern part of Bihar consists of plain land whereas hills constitute the central part of the state. The physical location of northern Bihar is attached with Nepal where Himalayan mountain ranges are situated. Chhotanagpur plateau is the part of South Bihar. The state is positioned between $24^0$20'10" North to $27^0$31'15"North latitude and $83^0$30' East to $88^0$00' East longitude. In the North, Bihar shares international boundary with Nepal. Uttar Pradesh, West Bengal and Jharkhand are encompassing this state in the West, East and Southern parts respectively. Bihar has its approximate length (North to South) of 345 km and width (East to West) of 483 km. It is an entirely landlocked state having a total area of 98,940 sq. km. Its average elevation above sea level is 173 ft.

Climate:

Bihar is largely subject to four seasons: winter (December to February), summer (March to May), a southwest monsoon season (June to September) and a post-monsoon period or retreating southwest monsoon (October to December). Its temperature varies from a maximum of 44^0C in summer to a minimum of around 5^0C in the winters. It is too hot during summer and too cold during winter. Its average temperature is 27^0 C (81^0 F). Its average temperature in summer is 34^0 C (93^0 F) and in winter is 10^0 C (50^0 F). In summer, the temperature varies between 35^0C to 40^0C (95-104^0C). In winter season the temperature ranges from 4^0C to 10^0C (39-50^0F). Annual precipitation is 1200 mm (47 in). Average numbers of rainy days are 52.5 in a year. Most of the rainfall takes place during monsoon. The onset of the rainy season takes place when a storm from the Bay of Bengal passes through Bihar. However, the monsoon may set in as early as the last week of May or as late as the first or second week of July. The rainiest months are July and August. In particular zones, rainfall surpasses 1800 mm. Similar to most of northern India, Bihar experience thunder storms and dusty winds in summer. The hot winds (loo) of Bihar plains blow in April and May averaging a speed of 8-16 kilometers per hour.

The factors regulating the climate of Bihar are - (a) The state is lying between 22-degree to 27-degree latitude within a tropical to sub-tropical zone, (b) The Himalayan Mountains in the north determine the monsoon rainfall and (c) Its connection with the Ganga delta and Assam.

Topography:

The topography of Bihar can be easily described as a fertile alluvial plain occupying the north Gangetic plain. It is drained by the river Ganges as it flows through the state from west to east. The Ganges has divided Bihar into two unequal halves, the north Ganga plain or north Bihar extends from the base of the Terrai in the north to the Ganga in the south covering an area of about 53.3 thousand square km, and the south Bihar dotted with some craggy hills rising up to 488 meters having an area of 40.9 thousand square km.

The Kosi and Gandak are two important tributaries of Ganges, drain through one of the most flood prone areas of India. The Kosi originating in Nepal Hiamlaya emerges on the great plain of northern India in Bihar on its way to the Ganges River. Because of its great out flushing of debris, the Kosi (River of Sorrow) has no permanent channel in its course through the great plain of northern India. It has long been notorious for its devastating floods. It may rise as much as 30 feet (9m) in 24 hours and can make vast tracts of northern Bihar unsafe for habitation or cultivation. Bagmati and Budi Gandak are two important tributaries of Kosi. The Gandak, originated from Nepal Himalaya, with its entry point at the Indo-Nepal border, is a confluence called Triveni with rivers Pachnad and Sonha descending from Nepal. The Gandak flows southeast 300 km across the Gangetic plain of Bihar through Champaran, Gopalganj, Saran and Muzaffarpur districts. In the North Western Bihar's Middle Gangetic Plain, mega fan (large fan shaped deposit of sediments built by a stream near mountain consisting of sediments eroded from the rapidly-uplifting Himalaya) can be seen. Other Ganges tributaries are Son, Chandan, Falgu etc. Son River plays major role in Bihar for creating flood.

In the central part of Bihar, Rajgir hill, also known as "Rajhara" hills lie near the city of Rajgir. The hills consist of two parallel ridges extending for around 65 km. The

Bateshwar hills are situated in the Katihar within the Purnia division. In the 24 km north of Gaya the Barabar Hills containing four Caves are one of the oldest surviving rock-cut caves in India. Sita-Kund, situated 4 miles east of Munger town, is not only a hot-spring but a popular visitor's attraction. Deep seated thermodynamics action and variation of underground volcanic activities may be the responsible factors for its formation.

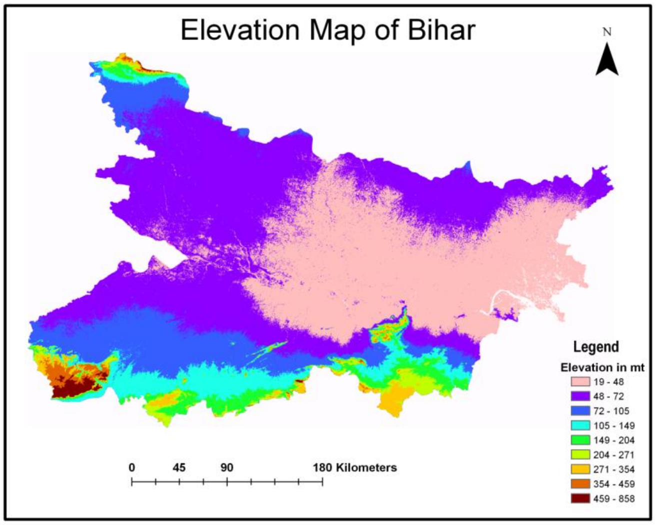
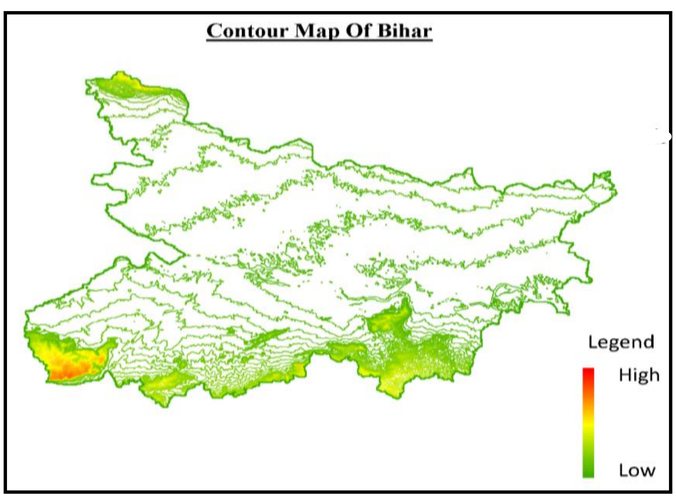


Figure 43: Elevation map of Bihar

Figure 43A: Contour map of Bihar



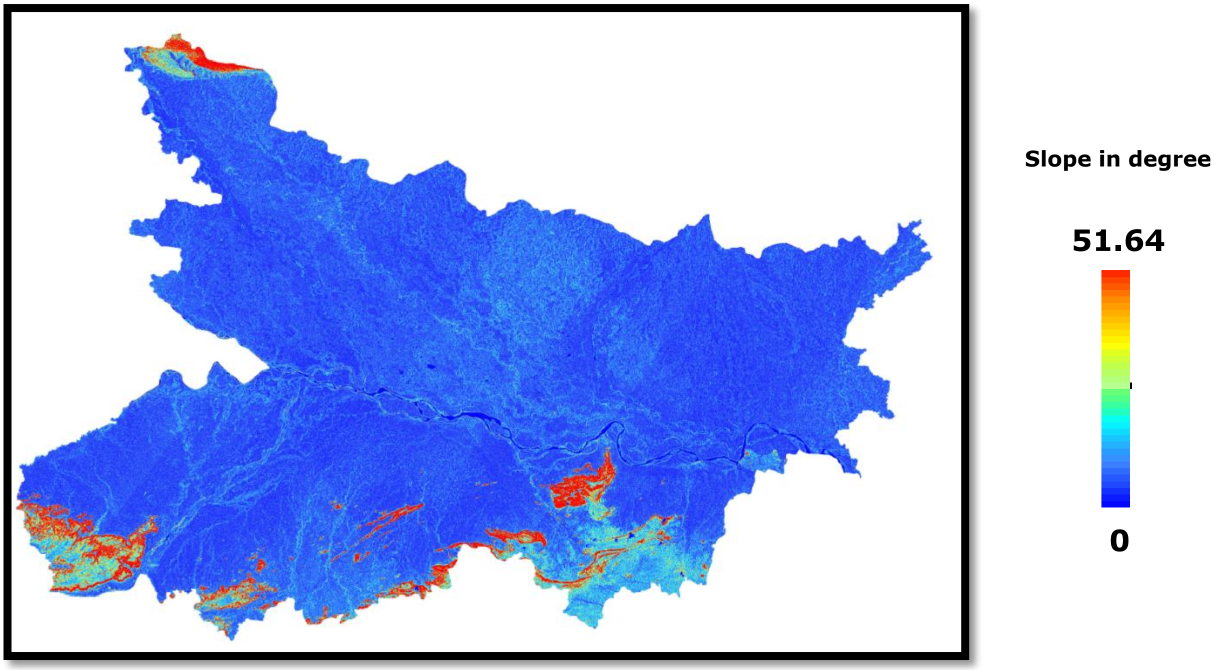


Figure 43B: Slope map of Bihar

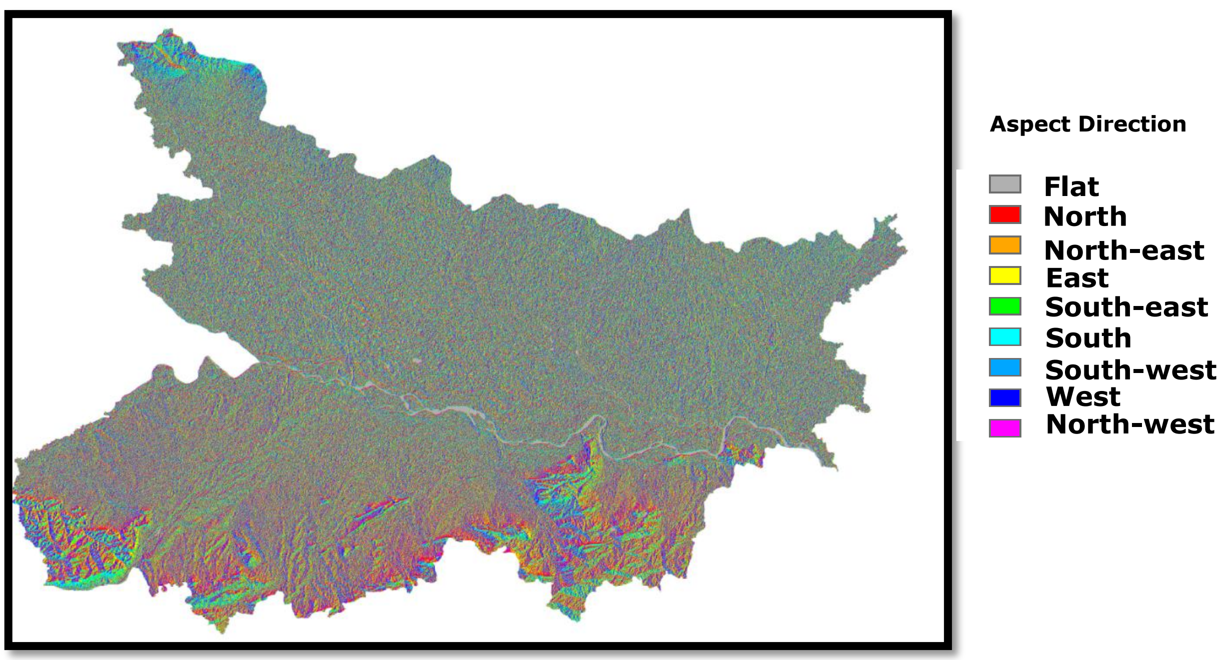


Figure 43C: Aspect map of Bihar

Geology:

Bihar is located in Indo-Gangetic plain, so, fertile soil is one of asset of the state. Thus, Indo-Gangetic plain's soil is the backbone of agricultural and industrial development in Bihar. The Indo-Gangetic plain in Bihar consists of a thick alluvial mantle of drift origin overlying in most part of the Siwalik and older tertiary rocks. The soil is mainly young loam rejuvenated every year by constant deposition of silt, clay and sand brought by different streams but mainly by floods in Bihar.

This soil is deficient in phosphoric acid, nitrogen and humus, but potash and lime are usually present in sufficient quantity. The most common soil in Bihar is Gangetic alluvium of Indo-Gangetic plain region, Piedmont Swamp Soil can be found in northwestern part of West Champaran district and Terrai soil are common in northern part of Bihar along the border of Nepal. Clay soil, sand soil and loamy soil are also common in Bihar.

Flora and Fauna:

Bihar has notified forest area of 6,764.14 km², which is 7.1 per cent of its geographical but it is decreasing day by day. The sub Himalayan foothill of Someshwar and Dun ranges in Champaran district is a belt of moist deciduous forest. These also consist of scrub, grass and reeds. Here the rainfall is above 1,600 mm and thus promotes luxuriant Sal forests in the suitable areas. The hot and dry summer promotes the growth of the deciduous forests in Bihar. The most important trees are Sal, Shisham, Cedrela Toona, Khair, and Semal. This type of forests also occurs in Saharsa district and Purnia district. Bihar has 3,208 km² of Protected Forest Area and 76.30 km² Protected Non-Forest Area.

Bihar has 21 wildlife sanctuaries. Valmiki National park, Kanwar Lake Bird sanctuary, Gautam Buddha Wildlife sanctuary, Kaimur Wildlife sanctuary etc. are some of the protected forest areas. Valmiki National Park earned the recognition as the 18th tiger reserve of India and is ranked fourth in terms of density of tiger population. The Kanwar Taal or Kabar Taal Lake is located in the Begusarai district of Bihar and it is Asia's largest fresh water Oxbow lake.

The Ganges River dolphins are found in the Ganges. Vikramshila Gangetic Dolphin Sanctuary near Bhagalpur is set up to ensure the protection of this species. It is designated in 1991. It is the First and only protected area established in Asia for protection and conservation of the endangered Gangetic dolphins. Also known as Susuk locally, Gangetic dolphins have been declared as the National Aquatic Animal of India on October 5, 2009 in the first meeting of National Ganga River Basin Authority (NGRBA).

Administrative Unit:

Patna is the capital of Bihar, and the principal language spoken all over Bihar is Hindi. Bihar's administrative unit is divided into 9 major divisions with 38 districts. It is further divided into 101 sub-divisions, includes 130 towns, 534 blocks, 8471 panchayats. Bihar is divided into 43 police districts and holds almost 853 police stations under its command. The Patna High Court is the High Court of the state of Bihar. It was established on February 3, 1916 and later affiliated under the Government of India Act, 1915.

Demographics:

Bihar is the 3rd largest state of India with a population of 10,38,04,637 (Male: 5,41,85,347 and Female: 4,96,19,290) (Census: 2011). Nearly 85% of Bihar's population lives in rural areas. Almost 58% of the population is below 25 years age and nearly 17.9% of total population of Bihar is under 0-6 years of age. Population density is 1,102 per sq km. Highest density (1882 per sq km) is observed in Sheohar. The most populous district is Patna (57, 72,804) (2011). The literacy rate of Bihar is 63.82% and in numbers 5, 43, 90,254 (Male: 73.39% & Female: 53.33%). Sex ratio of the state is 916:1000 (female/ thousand male). The total population growth in this decade was 25.07 percent while in previous decade it was 28.43 percent. The population of Bihar forms 8.58 percent of India in 2011. In 2001, the figure was 8.07 percent. Bihar has a total literacy rate of 47%. Overall Male and Female literacy rate is 59.7% and 33.1% respectively. Everyone in Bihar talks a dialect. Each region has its own brand of vernacular. The different dialects are spoken by both the common people and rich educated classes. Hindi and Urdu are the official languages of the state.

Recently, Maithili is also included as one of the official languages of the state. The majority of the people speak one of the Bihari languages – Maithili, Angika, Magadhi or Bhojpuri. Urdu is the second government language in Bihar and is the mother tongue of Muslims who form about 17% of state's population. Nearly 25% people in Bihar can read and write Urdu. The majority of Biharis are Hindu (82%) by religion. The other religions of Bihar are Islam, Christianity and Sikhism. The Hindu majority observes all the traditional festivals of Hindu religion- Durga Puja, Dusserah, Holi, Deepavali, Bhaiya Dooj, Saraswati Puja, etc. But the festival that is unique to Bihar is the Chhath festival. A considerable number of Buddha and Jain followers are present in Bihar.

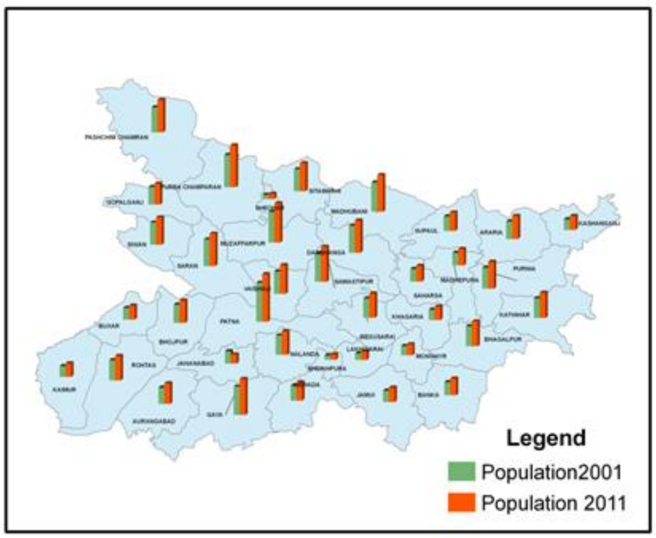


Figure 44: Population change in Bihar 2001 to 2011

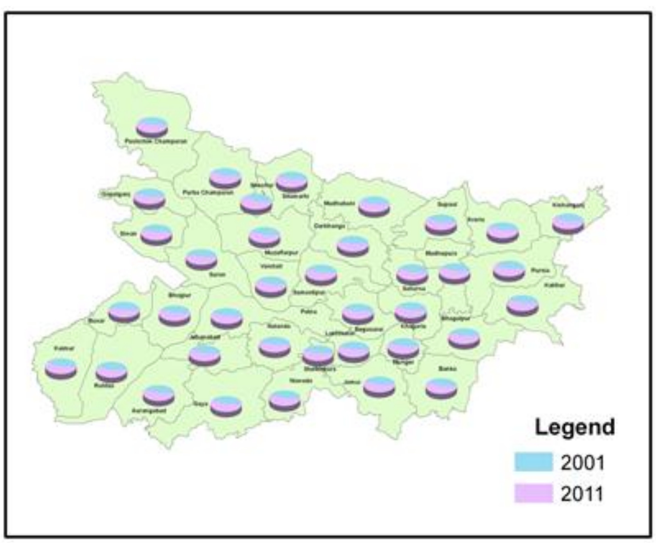


Figure 45: Change in population Density 2001 to 2012

Economy:

The State of Bihar is now a part of the economically emerging states of Northern India. Despite recent economic gains it still has a per capita income of $148 per year, against India's average of $2,538. 30.6% of the populations live below the poverty line against India's average of 22.15%. During an assessment in 2008, it was found that, in Bihar, agriculture accounts for 35%, industry 9% and service 55% of the economic practice of the state. The percentage of population employed in agricultural production system in Bihar is estimated to be 81%, which is much higher than the national average. Nearly 42% of GDP of the state (2004-05) was from agriculture sector (including forestry and fishing). The gross and net sown area in the State is estimated at 80.26 lakh ha and 56.38 lakh ha, respectively. The intensity of cropping is 1.42%. The principal crops are paddy, wheat, pulses, maize, potato, sugarcane, oil seeds, tobacco, and jute. Rice, wheat and maize are the major food grains. Commercial cultivation of mangoes, bananas, jack-fruit, and litchis is very common. Forest product like hard wood timber, Sal and Sakhua from the Northern Bihar contributes to the economy of Bihar. The scenario has been improving since last four years.

Commerce and Industry:

In 2008, the industry in Bihar was sharing only 9% of the state economy. Among all the sectors, the manufacturing sector performed very poorly in the state from 2002–2006, with an average growth rate of 0.38% only, as compared to India's 7.8%. Export of silk and jute as raw materials also strengthen its financial growth. North Bihar, a rich agricultural region, has many industries associated with agricultural products. Many rice and edible oil mills, sugar factories are scattered throughout the area. However, a major industrial complex has grown around Barauni with the Fertilizer Factory, the Oil (petroleum) Refinery and the Thermal Power Plant.

Tourism:

Bihar is well known for its historical and cultural heritage. Rich traditions and aesthetic tourist spots attract both the national and international tourists. The state, full of tourism potential, has accorded tourism as the status of industry. The state government is sincerely trying to develop important tourist destinations and circuits. These projects are, by and large, judicious mix of cultural, spiritual, heritage and ecotourism with a view to provide the tourists an experience of the people and culture of the state. Important places of tourist interest are Rajgir, Nalanda, Vaishali, Pawapuri (where Lord Mahavira attained Nirvana), Bodh Gaya, Vikramshila (ruins of Buddhist University of higher learning), Gaya, Patna (ancient city of Patliputra), Sasaram (tomb of Shershah Suri) and Madhubani (known for famous Madhubani Paintings).

Natural Disasters in Bihar

Flood

Bihar is under a constant threat of flood hazard. Floods in Bihar are a recurring disaster and destroy thousands of human lives apart from livestock and assets worth millions. All the rivers excluding the Burhi Gandak join the Ganga in Bihar after a considerable length of flow through Nepal and larger part of their catchment is the glacial regions of Himalayas. Thus the flood problem of Bihar has attained the status of an international issue to the policy makers and government. Sinha and Friend (1994) have shown that these different classes of river systems exhibit distinctive morphological, hydrological, and sediment transport characteristics.

As a part of river prone disaster, the two elements i.e. flood and shifting of rivers are intimately related consequential fluvial phenomena. The most dynamic among rivers is the Kosi, which has avulsed over 120 km of lateral width, from east to west, in about 220 years. Also, the Gandak has migrated over a distance of 105 km, from west to east, while the Sone has shifted considerably towards west since the Epic period.

The link between India and Nepal through Kosi River is one of the main reasons for the flood in Bihar. The heavy rainfall in Nepal and the dams also cause the flash flood (A sudden but short- lived flooding in a usually dry valley, in semi- arid area after a rare but intense rain storm.) in the region. Topographically, Nepal is a hilly region. When it rains heavily, the water flows to Kosi River. And when the level goes higher, Nepal opens the shutters of Kosi Barrage Pool subsequently causing water logging in the Gangetic plains of Bihar, India. The huge amount of water discharged from Nepal mainly reaches the three main rivers called Bagmati, Burhi Gandak and Ganges. Once the water level in the rivers goes up above the banks and over flow, the real flood situation arises. Moreover, unusual rain in certain season boosts this phenomenon. Nepal released almost 17,000 cubic gal of water to India in the month of July, 2009 and the pouring rain in both Nepal and Bihar added to the misery. The huge quantity of water collected through rainfall and the water that rushed from Nepal region impacted the mud banks.

Kosi also gathers water from some of the highest mountains in the world. It has changed its course due to the breach in the barrage in the river built in the 1950s on the Indo-Nepal border. The river has shifted over 120 Km eastwards, going back to the same course that it had abandoned more than 200 years ago. More than 300 km of embankments, built to control the fury of Kosi, rendered useless. The flooding of Kosi has submerged 1.1 lakh hectares of farmland. Due to out-flushing of debris, Kosi has no permanent channel. Originating from the glaciers of Tibet and Nepal, it has a steep fall in the plains of Nepal and therefore it is known for its turbulence.

According to Jha and Raghavan (2008), from the arguments and counter-arguments about the reasons behind the disaster, it is clear that degradation of the vast catchments of Kosi spread over large parts of India and Nepal is a result of the negligence in the repair and maintenance of Kosi barrage. Massive siltation in the absence of catchments area treatment and the embankments resulted in breach and a change of river course. The infamous river 'Kosi' took a route where it used to flow 200 years ago. This has resulted in submergence of thousands of villages in several districts of Bihar. Experts have opined that jacketing of Kosi River has proved disastrous because the barrage managed to control the flow of river but there was no mechanism to check the siltation. It is important to highlight here that the Kosi carries over 81 million MT silt every year. The heavy silt deposits and the land tilt from west to east has turned the river eastward. Madhepura, Supaul, Saharsa, Araria and Purnia districts are the worst affected areas as they are in the direct path of the Kosi River after it changed its course.

Ganga enters Bihar from Uttar Pradesh at Buxar and exits into West Bengal near Malda. Within Bihar, the Ganga receives from Nepal, in the north, two snow-fed rivers such as the Kosi, (whose situation has been discussed earlier), Gandak and various smaller non snow-fed tributaries such as Baghmati, Kamala, Lakhandehi and the tributaries of the Mahananda. According to Gyawali (1999) Bihar constitutes less than 17% of the Ganga basin in India although 80% of its total area lies in the Ganga plain.

The surface run off through the mountains pour out huge amount of sediments in Ganga and impedes the flow of the river in the rainy seasons. Often the rivers cut a new path through the deposited downstream. Breaching of embankments, spilling through the gaps in the embankments are the other causes of floods in Ganga. River bank erosion also warrants serious attention. Ganga River is actively operative by constant land erosion through breaking away and detachment of bank by the river waves or toe-erosion. Such sites are: South-east of Begusarai, near Digwara, South of Bachwara etc.
Gandak is a mountain-fed river system. It is a typically braided river with well-developed channel bars (braids). It has a high sediment load. Gandak River has a high peak discharge at downstream stations during flooding. Overbank flooding is a common feature of Gandak. Baghmati is a foothills-fed river system. With few upstream channels it is dominantly single-channel. It has a fluctuating trend in peak discharge at different stations. The higher value switches between upstream and downstream stations. Burhi Gandak is a plains-fed river system. It is a single-channel river with high sinuosity. It has more or less uniform pattern except the variation of peak discharge at different stations. Peak discharge at a particular station is a function of local flood waves created by tributaries apart from the monsoonal rains in the plains. Here flood reflects a tributary influence. Son River also plays major role in Bihar for creating flood situation. After heavy rain in the hills even its wide bed cannot carry the waters of the Son.
According to Sinha and Jain (1998) the rivers of north Bihar are characterized by high sediment load, mainly wash load, which causes rapid aggradation of the river bed within the embankments. It was observed that at many locations, water level in the channel within the embankments is significantly higher than the general ground level in the surrounding areas. Deposition of sediments either within the channel or on the channel margin restricts the passage of water and thus reduces the carrying capacity of the channel. This again results in over spilling of water on the adjacent plains.
The change of course of the river would have a lasting impact on the topography of the area. Hundreds of villages and hundred kilometers of land tracts might get submerged forever and there would be the need of comprehensive resettlement and reconstruction. Unlike other rivers which bring fertile silt with them, the Kosi brings with it coarse sand and gravel from the upper reaches of the river system. Thousands of acres of farmland

might become barren resulting in severe livelihood concern for people. As Bihar is one of the most densely populated States and the State government does not have enough land for such purposes, land related disputes is likely to emerge as a major issue. Besides, the floods have washed away the demarcation lines, (through which fields are identified and separated) on farm lands. In the absence of proper land records, it becomes difficult to identify and demarcate the fields owned by the people.

According to the people, there was flood even before the construction of river embankments but those were not as severe as of today. Those floods added fertility to their lands. But now water gets logged for three to five months and destroys the lands. The soil in Bihar contains more clay. The water absorbing capacity of this soil is very low so the water remains in the plains for a longer time. In some areas, people also cut the embankments to save their villages from possible flooding. Otherwise, if the embankment breaks it will totally wash away the villages.

Drought

Among the different natural hazards, drought is one of the most disastrous as it inflicts untold numerous miseries on the human. Its beginning is subtle and difficult to be precisely identified because of lack of sharp distinction from non-drought dry spells. As a disaster, it is experienced only after it has occurred. The termination of drought is, on the contrary, easily recognizable, and associated with the occurrence of precipitation (Shewale and Kumar, 2005).

Bihar is a disaster prone state, especially with flood and drought. Almost every year, Bihar is experiencing these two natural disasters and people are losing their life and property. The area of north Bihar (north to river Ganga) is mainly flood prone while south Bihar (south of river Ganga) is under the influence of drought. There is always a tendency of shortfall in rain during the early monsoon phase and unless late monsoon made-up for the early shortfall, a 30 to 40 percent decline in crop production is expected with a gross yield (kharif + rabi) below 2 tons/ha of land. Such low agricultural output indicates the assumed increasing rate of poverty in Bihar.

In the district of Bhojpur, farmers mainly depend on ISMR (Indian Summer Monsoon Rainfall) and from the supply of water through canals from Sone River. Sone River is always an issue of conflict between Bihar and Uttar Pradesh. Due to these reasons, farmers are not getting sufficient water for agriculture and face acute shortage of water for irrigation purposes during Rabi and Kharif seasons. The farmers are always in great trouble in Bhojpur and it seems that agriculture is not a profitable practice for them.

Monsoon also plays an important role in controlling the drought in Bihar. If monsoon rains get delayed even by 15 days, it becomes a cause of worry for the government to maintain agricultural activities. In Bihar, as rainfall is seasonal in nature, agriculture often becomes tuned with the rainy season. Any deficiency of significant amount thus directly affects the agriculture, ruining the economy (Mooley and Parthasarathy, 1984). Not only agriculture, drought also exerts profound influence on other disciplines like hydrology, tourism, transport, water supply, hydroelectric power generation, etc. Delayed monsoon causes the dams to reach a critical level. In 2009, less monsoon rains affected several crops severely and caused the condition of drought in several parts of Bihar, which has witnessed 60% deficit in rainfall.

In recent years, it has been suggested that extra-regional climatic events like southern oscillation (the periodic reversal of pressure patterns and wind directions in the atmosphere above the equatorial Pacific Ocean) and marine event like El Nino (the periodic prolonged differences of sea surface temperature from the average value along Peruvian coast of Pacific Ocean) in the Pacific Ocean also influence occurrence of monsoon rainfall (Mooley and Paolino 1989; Mooley 1997; Shewale and Rase 2000).

Dutta. S, Patel. N. K, Srivastava. S. K, 2001, grouped the districts of Bihar on the basis of similar agro-climatic zones (Zones with similarity of rainfall pattern and distribution, temperature, soil properties, topography, and major crops and vegetation): Group 1: Patna, Nalanda, Bhojpur and Rohtas; Group 2: Bhagalpur, Munger; Group 3: Purnea, Katihar, Khagaria, Saharsa and Madhepura. They used effective rainfall, water requirements and other meteorological parameters to build coefficient correlation for this grouping.

In summer, the state lacks adequate water facilities to supply for consumption in domestic, agricultural and other uses. Due to climactic changes and uneven rainfall distribution, farmers also suffer from devastating loss in crop yields (Chand & Kumar

2011). Another problem that occurs during droughts is that people are forced to drink dirty, contaminated water, which leaves them prone to illnesses.

Earthquake:

On 15 January 1934, Bihar was devastated by an earthquake of magnitude 8.4. Some 30,000 people were said to have died in the quake. The epicenter for this event was located in the eastern Nepal about 240 km away from Kathmandu (Memoirs of the Geological Survey of India, 1939, 1981 Reprint) On 17 February 1985, earthquake occurred along the state border between Jharkhand and Bihar. Again on 15 February 1993, Bihar witnessed another earthquake in Qasba- Purnea area. On August 21, 1988 another earthquake occurred near the Indian border affecting much of northern Bihar. The magnitude was 6.6. On September 18, 2011, a magnitude 6.8 on the Richter scale, an earthquake was felt in Darbhanga district of Bihar,

Chandra (1977) from his studies suggests that the orientation of the zones of weakness with respect to the ambient stress field may be an important factor in determining the faults along which the earthquakes are likely to occur. Bilham (1995) studied the effect of Bihar-Nepal earthquake of 1934 on Kathmandu valleys. Lave and Avouac (2000) observed an average geodetic convergence rate of 18 mm/yr which is lower than the average geological slip of 21.5±1.5 mm/yr measured over the Holocene period in the central Nepal Himalaya. From the slip deficit, moment release pattern, seismic gap, and GPS data on either side of active tectonic zones, various workers have prognosticated future large earthquakes in different parts of the Himalayan arc (Mukhopadhyay et al, 2009). Banerjee (1935) observed the energy of the earthquake as 10^{22} ergs in 1934's earthquake and suggested isostatic (Isostacy: The term refers to the condition of gravitational equilibrium between earth's lithosphere and underlying mantle i.e. asthenosphere so that the tectonic plate can float at an elevation that depends on their thickness and density) consideration behind this. Wadia (1935) suggested the theory of underload of the Bihar plains, due to their being covered by thick alluvial deposits which are about 18% lighter than normal rock.

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