DRAFT

CURRENT CLIMATE VARIABILITY ASSESSMENT, CLIMATE CHANGE PROJECTIONS AND IDENTIFICATION OF "CLIMATE HOTSPOT BLOCKS" FOR ICRG BLOCKS UNDER MGNREGA IN BIHAR

SUBMITTED BY

INDIAN INSTITUTE OF SCIENCE

BANGALORE

TO

IPE GLOBAL LIMITED

NEW DELHI

&

DFID

JULY 2017

CURRENT CLIMATE VARIABILITY ASSESSMENT, CLIMATE CHANGE PROJECTIONS AND IDENTIFICATION OF "CLIMATE HOTSPOT BLOCKS" FOR ICRG BLOCKS UNDER MGNREGA IN BIHAR

Project Investigators

Prof N H Ravindranath and Prof G Bala

Project Coordinator

Indu K Murthy

Research Team

Chaitra Arakesha., Vidya Naveen and Sushma Sridhar

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

CURRENT CLIMATE VARIABILITY ASSESSMENT, CLIMATE CHANGE PROJECTIONS AND IDENTIFICATION OF *"CLIMATE HOTSPOT BLOCKS"* FOR ICRG BLOCKS UNDER MGNREGA IN BIHAR

1. INTRODUCTION

Climate change is one of the most important global environmental challenges facing humanity. Climate change, driven by the increasing concentration of greenhouse gases (GHG), is projected to impact natural ecosystems and socio-economic systems. According to IPCC (2014), climate change is already occurring and impacting natural ecosystems and socio-economic systems such as food production. India, is already experiencing a significant level of warming and changes in the rainfall pattern accompanied by increasing rainfall variability. The agriculture sector and farming communities are already experiencing higher levels of climate variability and extreme events (e.g., droughts and floods).

The Paris Agreement aims at "Enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change". Further, the Agreement highlights "The current need for adaptation is significant", and "The need for assessment of climate change impacts and vulnerability" and "Building resilience of socio-economic and ecological systems". India's INDC also aims "To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture and water resources".

The vulnerability of developing countries to potential impacts of climate change and the need for adaptation is thus rapidly emerging as the central issue in the debate around policy responses to climate change. There is also a need for combining disaster reduction, natural resource management and climate change adaptation in a new approach to reduce vulnerability and enhance resilience to climate risks. Given the inherent costs involved, adaptation should be pursued not as an end but as a means to meet the development objectives. India has been implementing a large number of developmental programmes and projects as part of national economic development goals largely with domestic funding, which may have to be climate proofed. One such major developmental programme is the MGNREGA.

Climate change projections for India indicate that different parts of India will experience different levels of warming as well as changes in rainfall pattern. **A good understanding of the historical climate trends, current climate variability and climate change projections is very critical for identifying the most vulnerable regions, cropping systems, communities, etc., and to prioritize and implement adaptation / resilience measures.** This study aims at assessing the trends in observed climate, current climate variability and make climate change projections for the selected 35 blocks under the ICRG programme in the state of Bihar. The specific objectives of the study are:

1. Based on the IMD historical climate data, conduct climate trend analysis for monsoon seasonal rainfall, temperature changes and droughts at block level;

2. Conduct current climate variability analysis and a trend analysis of monsoon season rainfall at block level;
3. Make climate change projections at block level for 2030s (2020 to 2050); maximum and minimum temperature, monsoon seasonal rainfall, monthly rainfall and droughts;
4. Rank and prioritize the 35 ICRG blocks in Bihar to **identify the "Hotspots" of current climate variability and future climate change** according to:
   - Current monsoon season rainfall variability;
   - Projected monsoon season rainfall and its variability.

2. METHODOLOGY

2.1. STUDY AREA

The study was conducted in state of Bihar, covering the 35 blocks, identified under the DFID Infrastructure for Climate Resilient Growth in India (ICRG) Programme. The blocks selected under the ICRG program are presented in Figure 1.

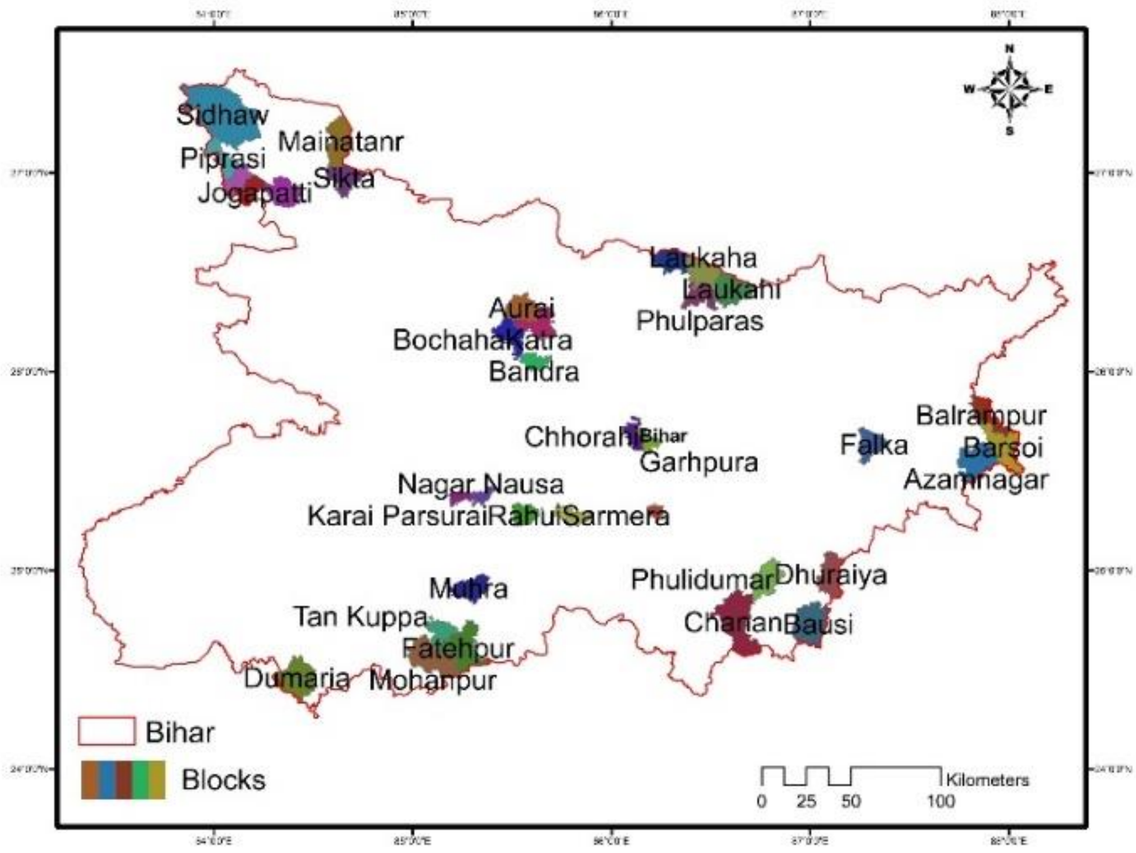

Figure 1: Study blocks included in the ICRG project in Bihar

2.2. APPROACH AND STEPS ADOPTED FOR RAINFALL AND TEMPERATURE TREND ANALYSIS FOR PAST 30-YEARS (1984 TO 2014)

The procedure adopted for historical climate analysis is presented in Table 1. Daily gridded rainfall dataset of 0.25° latitude x 0.25° longitude provided by Indian Meteorological Department (IMD) for the India region for the 30-year period of 1984– 2014, for precipitation (Pai et al. 2014), and 1.0°x1.0° latitude and longitude gridded daily temperature data, spanning over 30 years (1984-2014) for maximum and minimum temperature (Rajeevan et al. 2006), has been used to calculate the variability and trend in precipitation and temperature respectively. Rainfall variability is assessed only for the critical southwest monsoon (rainy) season and temperature is assessed only for the summer season for heat stress. For assessing the temperature variability block-wise data was obtained by re-gridding the temperature dataset to 0.2°x0.2°, and re-aggregating by the districts to study the maximum and minimum temperature variability at block level.

Table 1: Steps and approach to historical climate trend analysis

STEP 1	Selection of blocks	– Blocks identified under the DFID – ICRG programme
STEP 2	Access the IMD historical data for the past 30 years at block level	– Mean monthly temperature, max-min temperature, and daily rainfall (Source: IMD, Pune (http://imd.gov.in/)) Grid resolution: 1° x 1°(temp) and 0.25° x 0.25 (rainfall)
STEP 3	Conduct analysis of trends in climate parameters at block level	– Trends in Mean Monthly Max – Trends in Monsoon Season rainfall – Monsoon rainfall variability – Trends in occurrence of high intensity rainfall events – Trends in frequency of droughts

2.3. Approach and Steps Adopted for Climate Change Projections – 2021-2050

The CORDEX South Asia modeled data on precipitation, maximum temperature and minimum temperature have been analyzed for 35 blocks. The details of data used for historical/observed and climate change analysis for 35 blocks in Bihar is given in Table 2.

The CORDEX South Asia model data on precipitation and maximum temperature have been analysed for the 35 blocks for the mid-century period (2021-2050). Climate change projections on precipitation and maximum temperature been assessed for the ICRG blocks. Projections have been made at a grid-spacing of 0.5°x0.5° resolution (50 km x 50 km) for the RCP 8.5 scenario.

IPCC has provided multiple pathways of future GHG emissions and radiative forcings. The pathways are used for climate modeling and research. The recent IPCC Assessment Report (2014) used four possible climate futures. The four RCPs - RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively) (Weyant et al., 2009).

CORDEX is a WCRP-sponsored program to organize an international coordinated framework to produce an improved generation of regional climate change projections world-wide for input into impact and adaptation studies within the AR5 timeline. CORDEX produced an ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs from the CMIP5 archive. Initially 50 km grid spacing has been selected. For the present study only the SMHI-RCA4 model data which was available is used.

2.3.1. CORDEX MODELS AND RCP SCENARIO USED FOR PROJECTIONS

The CORDEX South Asia data on precipitation, maximum and minimum temperature have been analysed for 35 blocks for baseline (1984-2014) and mid-century (2021-2050) RCP 8.5 scenario for RCM SMHI-RCA4 and the ensemble of the RCMs are taken for this study. List of CORDEX models used and their details are given Table 2.

Table 2: List of CORDEX models used in this study for climate change projections

Asia CORDEX RCM	RCM	GCM boundary condition	Institute	Scenario	Resolution (º lon x º lat)	Daily time period
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	SMHI-RCA4	CNRM	SMHI	RCP8.5	0.5X0.5	1951-2100
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	SMHI-RCA4	GFDL	SMHI	RCP8.5	0.5X0.5	1951-2100
IPSL-CM5A-MR_SMHI-RCA4	SMHI-RCA4	IPSL-CM5A	SMHI	RCP8.5	0.5X0.5	1951-2100
MIROC-MIROC5_SMHI-RCA4	SMHI-RCA4	MIRCO	SMHI	RCP8.5	0.5X0.5	1951-2100
MPI-M-MPI-ESM-LR_SMHI-RCA4	SMHI-RCA4	MPI-M	SMHI	RCP8.5	0.5X0.5	1951-2100

Source: CORDEX South Asia, IITM Pune (RCP 8.5) RCM - SMHI-RCA4 (Rossby Centre regional atmospheric model V.4, Swedish Meteorological and Hydrological Institute.)

Daily data for the study blocks have been used for rainfall intensity analysis. Climate change projections on precipitation, maximum temperature and mean temperatures have been assessed. Grid-resolution for the climate projection is 0.5°x0.5°. The ensemble mean of 5 RCM models for precipitation, maximum temperature, and mean temperature data has been analyzed for RCP 8.5 scenario, which is more likely.

PART 1

HISTORICAL CLIMATE TRENDS IN THE ICRG BLOCKS OF BIHAR

Climate in a narrow sense is defined as average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to hundreds of years. The relevant climate parameters include temperature, rainfall and wind. Climate variability refers to variations in the mean state of temperature, monthly or seasonal rainfall, etc. and other statistics such as standard deviations, statistics of extremes, etc. of the climate on a temporal and spatial scale, beyond that of individual weather events.

3. HISTORICAL CLIMATE: TRENDS AND EXTREMES

In this section, the historical trends in temperature and rainfall across the ICRG blocks in Bihar, for the 30-year period of 1984-2014 is presented.

3.1. TEMPERATURE TRENDS DURING THE HISTORICAL PERIOD (1984-2014)

In this section, temperature analysis has been carried out for the March to May period (summer), since this is the period when heat stress events are likely to occur. Analysis of the IMD (Indian Meteorological Department) temperature data shows that the mean summer maximum temperature for the selected ICRG blocks varied from 32.1 ^{O}C to 36.6 ^{O}C, whereas the mean summer minimum temperature varied from 14.9 ^{O}C to 18.2 ^{O}C.

3.1.1. *TRENDS IN MAXIMUM TEMPERATURE DURING THE HISTORICAL PERIOD*

Trends in maximum temperature during the historical period was analysed and the results of this analysis are presented in this section. Average maximum temperature during the initial 10-year period of 1984-1994 and that during the recent 10-year period of 2004-2014 was compared to compute the change in temperature over the 30-year historical period (Figure 2).

Figure 2: Change in mean maximum temperature (^{O}C) during the 30-year period of 1984-2014 in the identified ICRG blocks of Bihar

- The identified ICRG blocks of Bihar experienced mostly warming but also a decrease in temperature in a few blocks during the historical period.
- The temperature increase was recorded in 77% of the blocks, in the range of 0.03 to 0.7 ^{O}C.
    - Highest increase in temperature of 0.7 ^{O}C was recorded in Laukha block, followed by Laukahi with 0.6 ^{O}C increase in temperature.
- A very marginal decrease in temperature in the range of 0.01 ^{O}C to 0.1 ^{O}C was recorded in eight of the 35 blocks (about 23%) of Bihar.
    - Blocks with decrease in temperature included Sikta, Azamnagar and Barsoi with the maximum decrease, followed by Ladania, Balrampur, Bausi, Dhuraiya and Falka.
- All the blocks experienced greater than 40 ^{O}C during the 30 years period and none of the blocks experienced 45 ^{O}C (Figure 3).
- All the blocks recorded a mean in the range of 35 to < 40 ^{O}C during the period.

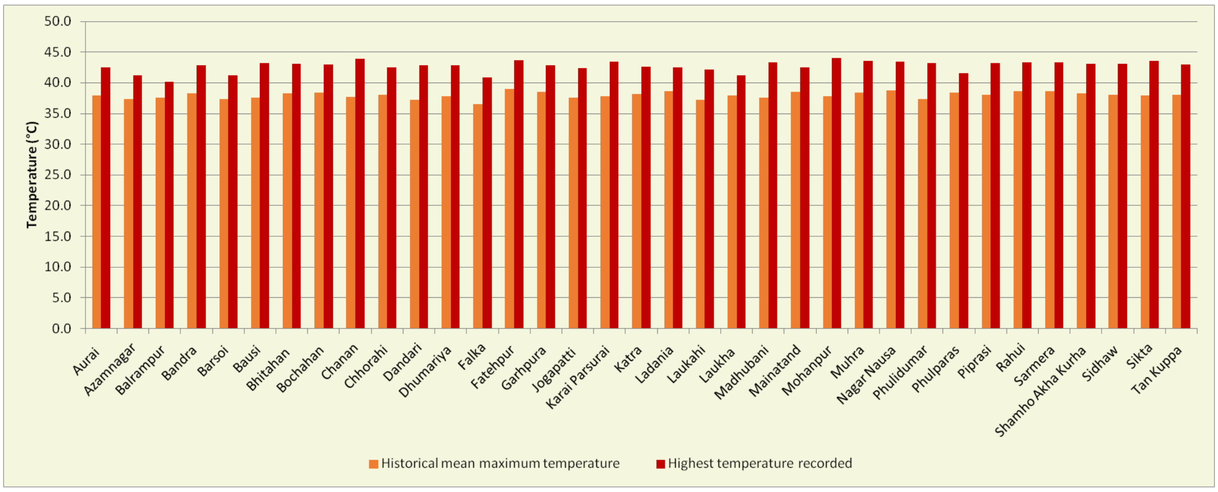

Figure 3: Mean maximum temperature and highest temperature recorded during the historical period (1984-2014) in the ICRG blocks of Bihar

Overall there was an increasing trend in warming as indicated by the increase in mean maximum temperature across all the identified ICRG blocks. The increase in temperature in the range of 0.26 ^{O}C to 0.5 ^{O}C was recorded in 46% of the blocks (Figure 2) in Bihar. An increase of > 0.5 ^{O}C up to 0.75 ^{O}C was recorded in a few blocks of Bihar. None of the blocks recorded 45 ^{O}C, and most blocks had a maximum temperature events in the range of 40 to 45 ^{O}C.

3.2. Trends in Rainfall during the Historical Period (1984-2014)

Total rainfall and the distribution of monsoon rainfall is critical for agriculture and water supply in rural areas. The rainfall trend is analysed for the monsoon period – JJAS (June to August), which is the most important cropping season in the states. The mean seasonal rainfall trend and the seasonal rainfall variability is analysed and presented in this section for the period 1984 to 2014.

3.2.1. Mean Seasonal (JJAS) Rainfall during 1984-2014

Mean seasonal rainfall during June to September is analysed and presented in this section for the historical 30-year period of 1984-2014. Table 3 presents the mean JJAS rainfall in the identified ICRG blocks.

- The mean JJAS rainfall ranged from 744 mm to 1274 mm during the historical period.
- Balrampur block received the highest mean monsoon rainfall of 1274 mm, followed by Mainatand (1260 mm), Barsoi (1253 mm), Azamnagar (1253 mm) and Sikta (1217 mm) during the monsoon months.
- The lowest mean rainfall during JJAS was recorded in Sidhaw with 744 mm only, followed by five blocks receiving mean seasonal rainfall of 837 mm to 889 mm.

3.2.2. Monsoon Rainfall Variability during 1984-2014

One of the major challenges faced by Indian agriculture is the monsoon rainfall variability. According to several studies, the monsoon rainfall variability has been increasing in the recent decades. Rainfall variability creates uncertainty and significantly impacts water availability and crop production. Rainfall variability is an important indicator which can be used to target resilience enhancement programmes. In this section, rainfall variability is estimated at block level based on data for 30-year historical period of 1984-2014. The coefficient of variation (CV) is taken as an indicator of rainfall variability (Table 3).

- The CV of the monsoon rainfall varied from 24% to 39% in the ICRG blocks.
- Blocks with the highest rainfall variability are: Piprasi (39%), Sidhaw (36%), Aurai (34%), Katra (32%) and Nagar Nausa (32%).
- The blocks with low rainfall variability are: Rahui (25%), Phulidumar (24.6%), Fatehpur (24.5%), Shamho Akha Kurha (24%) and Mohanpur (23.9%).
- The standard deviation of the monsoon rainfall across the ICRG blocks varied from 207 (Mohanpur) to 430 (Piprasi).

The rainfall variability analysis of the ICRG blocks shows that 5 blocks in Bihar have a CV of over 30%. Further, the top five districts with respect to high CV are; Piprasi, Sidhaw, Aurai, Katra and Nagar Nausa blocks. Thus, these blocks could be considered as hotspots of current rainfall variability, requiring MGNREGA activities aimed at increasing irrigation water availability. The rainfall variability in the ICRG blocks is moderate to high for most blocks.

Table 3: Historical June to September rainfall, standard deviation and Coefficient of Variation

Blocks	Mean JJAS rainfall (mm)	Standard deviation (mm)	Coefficient of Variation (%)
Piprasi	1106	430	38.88
Sidhaw	744	266	35.75
Aurai	929	315	33.91
Katra	946	305	32.24
Nagar Nausa	904	288	31.86
Phulparas	868	274	31.57
Madhubani	1068	327	30.62
Garhpura	988	302	30.57
Muhra	871	266	30.54
Tan Kuppa	995	297	29.85
Bandra	943	280	29.69
Ladania	1086	317	29.19
Bhitahan	1076	313	29.09
Laukha	1136	329	28.96
Falka	1081	312	28.86
Laukahi	995	287	28.84
Sarmera	843	242	28.71
Jogapatti	1154	327	28.34
Karai Parsurai	901	251	27.86
Chanan	934	259	27.73
Dandari	1098	300	27.32
Bochahan	957	259	27.06
Sikta	1217	329	27.03
Mainatand	1260	337	26.75
Chhorahi	928	247	26.62
Balrampur	1274	337	26.45
Dhuraiya	1119	289	25.83
Barsoi	1253	321	25.62
Azamnagar	1253	321	25.62
Bausi	1110	283	25.50
Rahui	837	213	25.45
Phulidumar	930	229	24.62
Fatehpur	889	218	24.52
Shamho Akha Kurha	968	233	24.07
Mohanpur	866	207	23.90

3.2.3. *Trends in Sowing Rains (June rainfall) during 1984-2014*

June is the month of onset of monsoon in most parts of India. June rainfall is critical for crop production. The decision of farmers in deciding cropping pattern depends on the extent of rainfall received in June. Here we analyse the trends in rainfall during the month of June over the 30-year period. Appendix 1 presents the number of years with onset of normal sowing rain across the ICRG blocks. Figure 4 presents the number of blocks receiving normal sowing rain under three frequencies of 1-5 years, 6-10 years and >10 years during the 30-year period of 1984-2014.

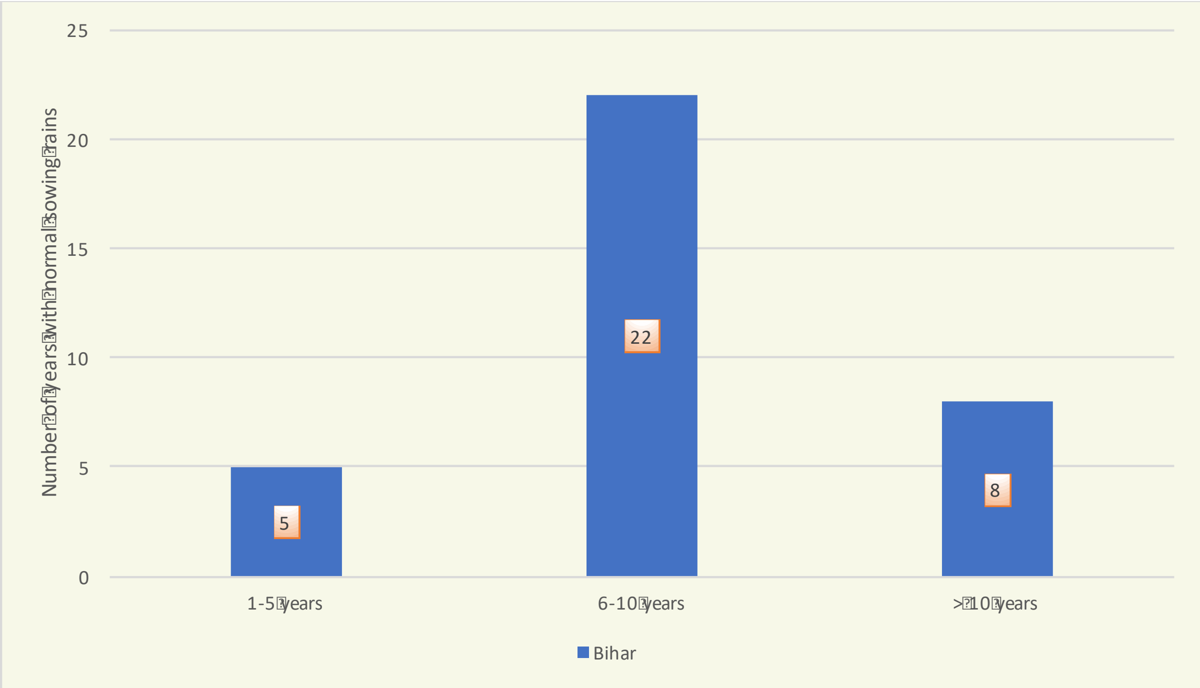

Figure 4: Number of blocks receiving normal sowing rains during June under three frequencies of 1-5 years, 5-10 years and >10 years during the 30-year period of 1984-2014

- In a majority of the ICRG blocks, less than a–third of the years received normal sowing rains.
- In all the ICRG blocks, normal sowing rain has not been received in 50% of the 30-year period (1984-2014)
- In 8 blocks, it was 10-12 years out of 30 years, in 22 blocks-, it was 6-10 years and in the remaining three blocks it was less than 5 years
- Sidhaw, Karai Parsurai and Mohapur blocks have recorded less than 5 years with normal sowing rains out of 30 years.

Analysis of occurrence of sowing rainfall events during June for the historical 30-year period showed that majority of the blocks did not receive June sowing rainfall in most of the years. This means only in few years the farmers received the normal sowing rain in June. This will have implications for designing MGNREGA works to assist farmers to cope with delayed sowing rains. The famers may require access to rainfall prediction in June and MGNREGA may need to have a provision for contingency planning in case of delayed sowing rains.

3.2.4. Occurrence of Droughts: Frequency and Intensity during 1984-2014

Drought is the bane of Indian agriculture. Periodic occurrence of droughts adversely impacts food production, water availability, farmers' livelihoods and survival. India is likely to experience increased frequency and intensity in occurrence of droughts in the coming decades due to climate change. The historical climate data has been analysed for occurrence of droughts during the 30-year period of 1984 to 2014. The criteria for this analysis is presented in Table 4. Figure 5 presents the occurrence of mild, moderate and severe drought in the study blocks.

Table 4: Criteria for analysis of drought

Drought type	Rainfall deficit from normal
Mild Drought	0-25%
Moderate Drought	26-50%
Severe Drought	>50%

Source: Lala et al., 2013

- Most of the blocks experienced several years of mild to moderate drought. 24 of the 35 blocks experienced mild to moderate drought in over 50% of the years.
- 11 blocks out of 35 experienced moderate drought more than once in 5 years.
- Over the 30-year period, Piprasi block had two years of severe drought.
- In 34 out of 35 blocks, moderate drought is recorded ranging from two in Phulidumar block to 15 in Bhitahan block.
    - Pirasi and Aurai experienced moderate drought in a quarter of the 30 years
- Most of the blocks experienced moderate drought in 13% to 20% of the 30-year period.
- Barsoi block did not experience any moderate drought and Phulidumar experienced only two years of moderate drought.

Thus drought is a common occurrence in Bihar with 24 of the 35 blocks experiencing mild to moderate drought in over 50% of the years. Severe drought is not common in Bihar. Thus there is need for adaptation strategies to cope with mild to moderate drought in the identified ICRG blocks of Bihar.

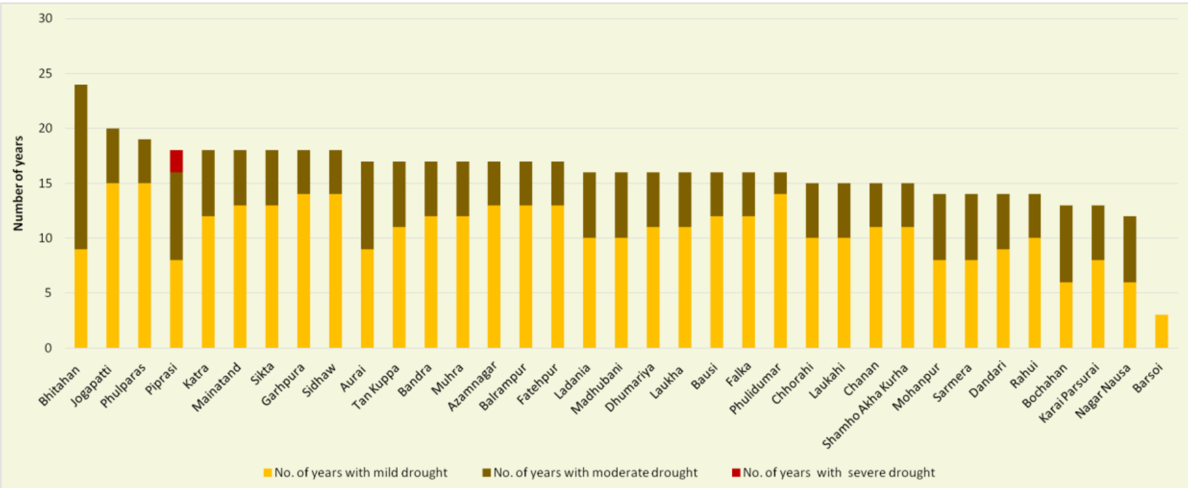

Figure 5: Drought occurrence frequency (No. of years) in study blocks of Bihar during 1984-2014

3.2.5. Number of High Intensity Rainy Days During the Historical Period (1984-2014)

In this section, an analysis of frequency of occurrence of high intensity rainfall events of intensity of 51-100 mm and > 100 mm per day is presented for the historical period of 1984-2014 for the identified ICRG blocks of Bihar. Table 5 presents the frequency of occurrence of rainfall events with intensity of 51-100 mm to > 100 m per day.

Table 5: Frequency of occurrence of rainfall events of 51-100 mm and > 100 mm (units are in days) in the ICRG blocks of Bihar

Blocks	**Number of days receiving a rainfall of**		Highest rainfall (mm) received in a day	2nd highest rainfall (mm) received in a day
	51-100 mm	**> 100 mm**		
Aurai	13	7	150	144
Azamnagar	121	21	386	345
Balrampur	125	20	313	307
Bandra	81	7	200	179
Barsoi	125	22	386	345
Bausi	79	16	235	161
Bhitahan	116	36	261	181
Bochahan	81	7	182	171
Chanan	61	12	226	155
Chhorahi	72	8	133	127
Dandari	78	9	130	126
Dhuraiya	79	17	228	207
Falka	113	29	200	198
Fatehpur	47	10	118	115
Garhpura	25	11	192	163
Jogapatti	25	11	278	194
Karai Parsurai	64	8	175	152
Katra	67	10	159	149
Ladania	94	20	224	185
Laukahi	105	15	235	208
Laukha	103	12	235	208
Madhubani	116	35	261	155
Mainatand	131	42	268	206
Mohanpur	46	6	177	154
Muhra	55	7	129	115
Nagar Nausa	67	6	127	110
Phulidumar	63	19	180	138
Phulparas	86	10	182	160
Piprasi	110	38	262	224
Rahui	57	8	254	124
Sarmera	55	6	249	120
Shamho Akha Kurha	96	8	139	135
Sidhaw	116	40	286	279
Sikta	122	41	242	161
Tan Kuppa	62	6	188	160

Number of rainy days - 51-100/day mm rainfall

- All the blocks received higher number of rainy days with 51-100 mm rainfall than > 100 mm rainfall.
- Among the 35 identified ICRG blocks in Bihar, the number of rainy days with this intensity rainfall varied from 13 days in Aurai block to 131 days in Mainatand.
- 14 blocks received more than 3 days of 51-100 mm rainfall intensity days per year.

Number of rainy days - > 100 mm/day rainfall

- The number of rainy days with > 100 mm rainfall during the historical period varied from 6 (Tan Kuppa) to 42 days (Mainatand) in the ICRG blocks.
- Mainatand, Sikta and Sidhaw blocks received 40-42 days of > 100 mm rainfall.
- Only 6 blocks received around 1 high rainfall intensity of >100 mm/day in a year.
- 11 of the 35 blocks received 10-20 cm of > 100 mm rainfall.
- 13 out of the 35 blocks received less than 10 days of > 100 mm rainfall.

Highest rainfall event in a day

- Highest rainfall event occurring in a day varied from 118 mm in Fatehpur block to 386 mm in Barsoi block.
- Majority of the blocks received events of 150 mm to about 300 mm rainfall/day.
- Twenty blocks received more than 200 mm high rainfall event in a day. Further, three blocks (Balrampur, Azamnagar and Barsoi blocks) received > 300 mm rainfall/day.
- The second highest rainfall event ranged from 110 mm (Nagar Nausa) to 345 mm (Azam Nagar).
- Only 3 blocks received flood causing rainfall event of >300 mm/day.

Occurrence of high intensity rainfall is an indicator of flood causing rainfall events. More than 100 mm of rain/day could lead to damage to land, crops and may cause excessive runoff and even flooding. These high intensity rainfall events could damage the soil and water conservation structures created under MGNREGA. It can be observed that the frequency of high intensity rainfall of > 100 mm is low in the blocks of Bihar. But many blocks have received more than 300 mm in a day potentially causing flooding. This information will have implications for designing soil and water conservation structures and flood control measures under MGNREGA.

PART 2

TEMPERATURE AND RAINFALL (CLIMATE CHANGE) PROJECTIONS

4. CLIMATE CHANGE PROJECTIONS FOR 2021-2050

All blocks and districts will be subjected to warming and climate change, in particular changes in total rainfall and rainfall variability to varying degrees. Climate change is also projected to impact the frequency and intensity of occurrence of droughts. Thus it is necessary to assess the projected impacts of climate change at block level, especially the impact on rainfall variability and intensity. This would enable identification of *hotspot* blocks with respect to monsoon seasonal rainfall variability, so that adaptation or resilience programs can be targeted first.

4.1. TEMPERATURE PROJECTIONS FOR 2021-2050

Temperature projections have been estimated for the summer months of March to May for the 30-year period of 2021-2050.

4.1.1. TRENDS IN MAXIMUM TEMPERATURE DURING 2021-2050 (BY 2035) COMPARED TO THE HISTORICAL PERIOD OF 1984-2014

Increase in temperature due to greenhouse warming can impact crop yields directly, increase evapo-transpiration demand and moisture stress, ultimately contributing to increased water demand and irrigation needs for agriculture. This will have implications for MGNREGA works related to water management. Further, under extreme cases high temperatures can lead to heat strokes, harming humans. In this section changes in maximum temperature during 2021-2050 over the historical period of 1984-2014 is analysed and presented for the identified ICRG blocks (Figure 6).

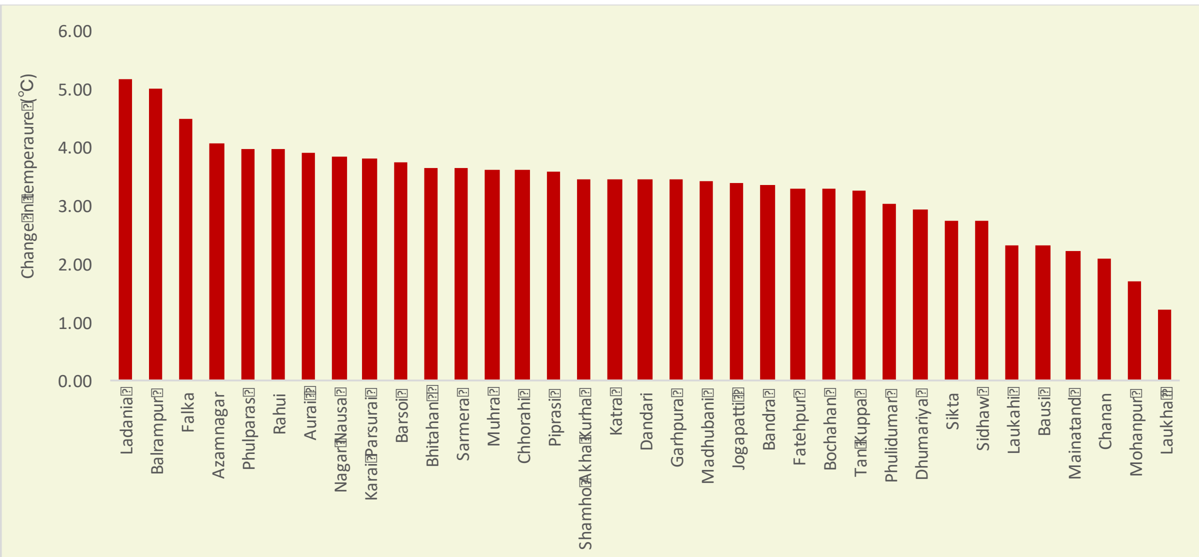

Figure 6: Change in temperature (°C) by 2035 (2021-2050) relative to the historical 1984-2014 period in the ICRG blocks of Bihar

- In the various ICRG blocks of Bihar an increase in maximum temperature during 2021-2050 over the historical period (1984-2004) is seen.
- The temperature increase is in the range of 1.2 °C to 5.1 °C.
    - Maximum increase of over 5 °C is seen in Ladania block, followed by Balrampur block.
    - Least increase of 1.2 °C is recorded in Laukha block.
- The temperature increase in the majority of the blocks over the historical period in Bihar is in the range of 3 °C to 4 °C (63% of the blocks).

4.2. Rainfall Projections for the Period 2021-2050 (2035)

In this section, assessment of rainfall projections for the period 2021-2050, with respect to number of rainy days and in comparison to the historical period (1984-2014) are presented. Any reduction in the number of rainy days, accompanied by either increase in total rainfall or no significant change in rainfall indicates the occurrence of flood events. Number of rainy days and rainfall intensity are also critical for designing water storage structures under MGNREGA.

4.2.1. Changes in Mean Monsoon (JJAS) Rainfall During 2021-2050 Compared to the Historical Period 1984-2014

The mean monsoon (June to September-JJAS) rainfall for the two periods – historical (1984-2014) and projected (2021-2050) is compared in this section to understand the changes in rainfall during the critical agricultural season. Figure 7 presents the trend in monsoon rainfall during the historical as well as the projected period.

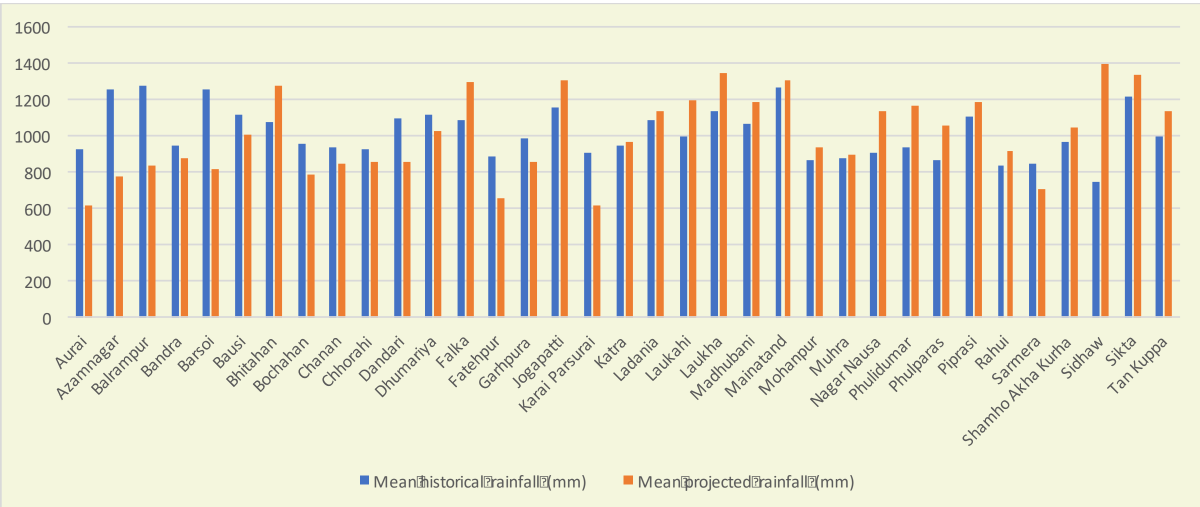

Figure 7: Mean JJAS rainfall (mm) during historical and projected period

Blocks with increasing rainfall trend

- 20 out of 35 blocks are projected to receive increased rainfall in the range of 14 mm (Katra) to 647 mm (Sidhaw) during the monsoon season.
- Further, the increase in rainfall ranges from 1% to 47%; with Sidhaw block projected to receive the highest increased rainfall of 47% (Figure 8).

- In 12 blocks, the increase in rainfall is projected to be > 100 mm. Further, six blocks are projected to have > 200 mm rainfall.

Blocks with decreasing rainfall trend

- 15 blocks (43%) are projected to experience a decline in rainfall in the range of 71 mm (Bandra block) to 476 mm (Azamnagar) during the monsoon season (JJAS).
- Further, 11 blocks are projected to experience a decline of > 100 mm and two blocks are projected to experience a decline of > 200 mm.
- Seven blocks are projected to experience > 25% decline in monsoon rainfall and further, four blocks are projected to experience > 50% decline in rainfall (Figure 8).

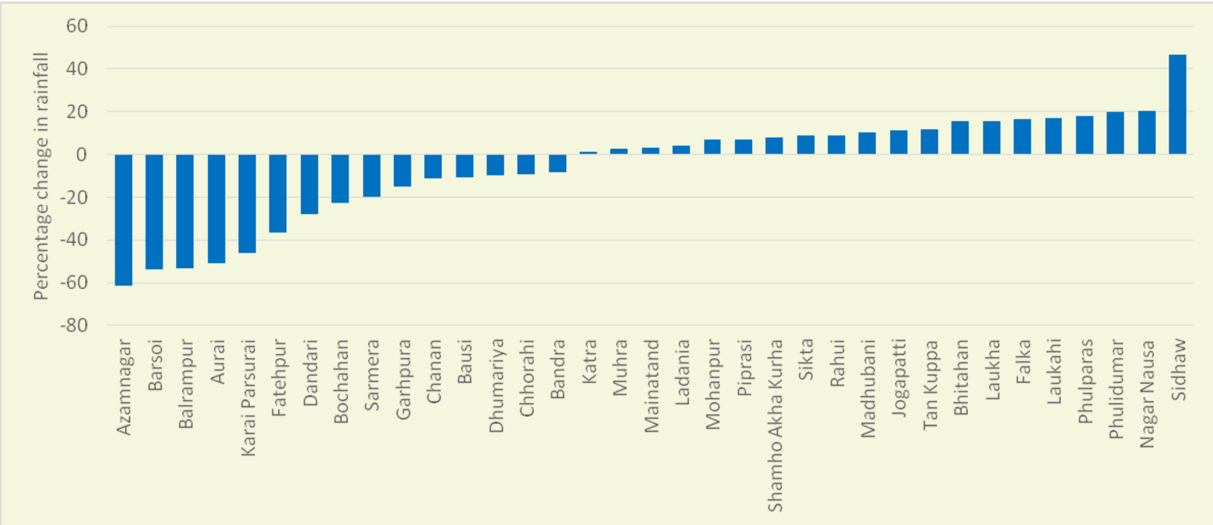

Figure 8: Percentage change in mean JJAS rainfall during the projected period (2021-2050) compared to the historical period of 1984-2014

It is clear from this analysis that change in rainfall varied even within a state across the different blocks. This data will help in decisions on whether to plan for coping with decreased or increased rainfall in the blocks. Further, this information will help in designing land-water structures under MGNREGA according to changes in rainfall projected for the blocks.

4.2.2. Change in Frequency and Intensity of High Intensity Rainfall During the Projected Period (2021-2050) Over the Historical Period (1984-2014)

The total number of rainy days of (> 2.5 mm) received during the historical period and the projected number of rainy days under climate change scenario are given in Table 6.

Changes in the number of rainy days due to climate change

Total number of rainy days (>2.5 mm) during historical period (Table 6)

- The total number of rainy days in the historical period ranged from 51 days/year in Karai Parasurai block to 73 days/year in Balrampur block.
- Further, 14 blocks (out of 35) received more than 60 days of rainfall/year.

Table 6: Number of rainy days (> 2.5 mm/day) during the historical period and projected climate change

Blocks	Historical (1984-2014)		Projected (2021-2050)		
	Total number of rainy days (>2.5mm/day)	**Average number of rainy days/year**	**Total number of rainy days (>2.5mm/day)**	**Average number of rainy days/year**	**% change in number in days**
Laukahi	1854	62	1888	63	2
Ladania	1762	59	1850	62	5
Phulparas	1973	66	2110	70	6
Sidhaw	1695	57	1826	61	7
Sikta	1642	55	1778	59	8
Balrampur	2201	73	2480	83	11
Tan Kuppa	1583	53	1832	61	14
Laukha	1904	63	2218	74	14
Falka	2083	69	2436	81	14
Azamnagar	2101	70	2525	84	17
Katra	1756	59	2191	73	20
Dandari	1937	65	2422	81	20
Barsoi	2011	67	2525	84	20
Shamho Akha Kurha	1891	63	2398	80	21
Piprasi	1744	58	2212	74	21
Rahui	1796	60	2294	76	22
Fatehpur	1687	56	2156	72	22
Nagar Nausa	1778	59	2284	76	22
Mainatand	1711	57	2199	73	22
Chanan	1935	65	2496	83	22
Sarmera	1790	60	2309	77	22
Garhpura	1853	62	2403	80	23
Muhra	1677	56	2205	74	24
Phulidumar	1784	59	2365	79	25
Mohanpur	1781	59	2371	79	25
Bausi	1872	62	2495	83	25
Jogapatti	1640	55	2190	73	25
Dhuraiya	1741	58	2338	78	26
Bochahan	1694	56	2363	79	28
Bandra	1673	56	2348	78	29
Chhorahi	1638	55	2405	80	32
Karai Parsurai	1541	51	2272	76	32
Aurai	1701	57	2604	87	35
Bhitahan	1624	54	2556	85	36
Madhubani	1622	54	2557	85	37

Total number of rainy days (> 2.5 mm) during the projected period (Table 6)

- Monsoon season rainfall increased significantly under climate change scenario, and ranged from 59 days/year (Sikta block) to 87 days/year in Aurai block.
- All blocks are projected to have increased number of rainy days of more than 60 days/year with >2.5 mm rainfall, compared to only 14 blocks in the historical period.

Thus, it could be concluded that there is a significant increase in the number of rainy days under climate change scenario. Further, number of blocks receiving rainfall (>2.5 mm) over 60 days/year increased from 14 blocks during the historical period to 34 blocks during the projected climate scenario. The percentage increase in number of rainy days (with >2.5 mm rainfall) is 2 (Laukahi) to 37% (Madhubani) under climate change scenario.

Changes in the frequency of occurrence of high rainfall events under climate change

A comparison of the frequency of occurrence (number of days) of rainfall of different intensities between the historical period (1984-2014) and the projected period (2021-2050) is presented in this section (Figure 9).

Number of rainy days - 51 – 100 mm rainfall/day

- Among the identified ICRG blocks in Bihar, the frequency of occurrence of rainfall events of 51-100 mm intensity is projected to increase in all except two blocks – Azamnagar and Bausi.
  - The increase in frequency projected for the blocks of Bihar ranges from ≤ 10 days in Phulparas (7 days) and Bochahan (10 days) blocks to 151 days in Falka block.
  - About one-third of the blocks are projected to receive rainfall of 51-100 mm intensity for more than 100 days and 51-100 days, respectively.

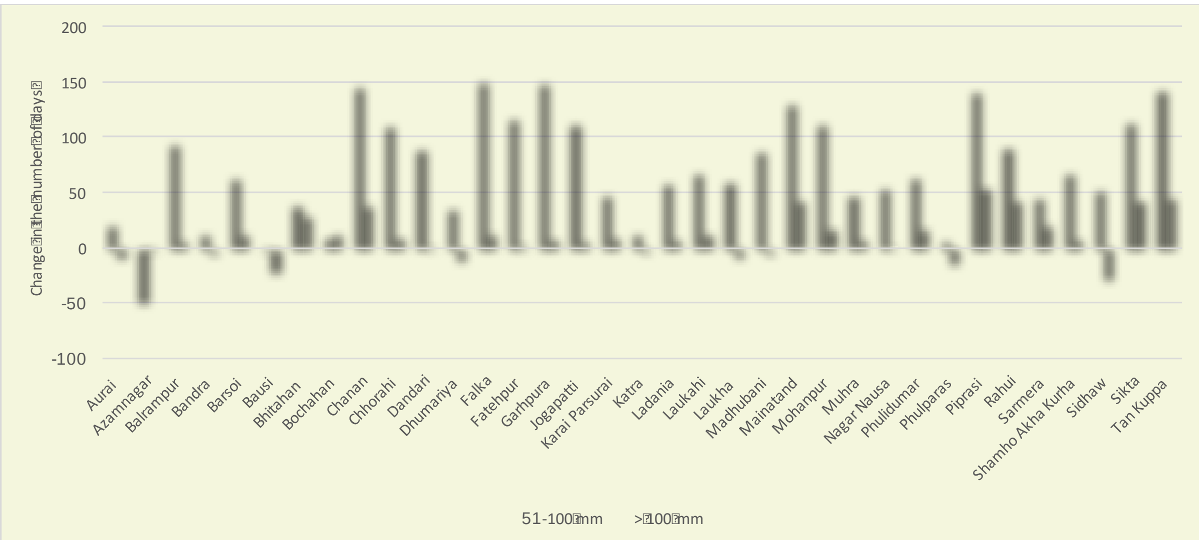

Figure 9: Change in the number of days receiving rainfall of 51-100 mm/day and > 100 mm/day intensity rainfall during projected period relative to the historical period

Number of rainy days - > 100 mm rainfall/day

- The number of rainy days of > 100 mm intensity is projected to increase in 24 of 35 blocks while in ten blocks, a decrease is projected. In one block (Nagara Nausa), no change in frequency of occurrence of rainfall of this intensity is projected.
- The increase ranges from 2 days in Dandari to as high as 55 days in Piprasi block.

Under the climate change scenario, nearly all the blocks are projected to receive higher frequency of high intensity rainfall events of 51-100 mm/day and > 100 mm/day. This will have significant implications for designing MGNREGA structures. These rainfall events may also lead to floods.

5. Changes in Rainfall Variability due to Projected Climate Change

In this section, the changes in rainfall variability due to projected climate change is compared with the historical rainfall variability. The blocks are ranked according to the current climate variability (Coefficient of Variation) and then the projected rainfall variability is compared. Table 7 provides a comparison of changes in rainfall variability due to climate change compared to the historical rainfall variability.

- When CV of monsoon seasonal rainfall of all the blocks of Bihar is considered, 32 out of 35 blocks are projected to experience increased rainfall variability.
- Further, it is projected that six blocks may experience increase in rainfall variability by over 100% and 12 blocks out of 35 are projected to experience > 50%.

Comparison of projected rainfall variability (2021-2050) with the historical 30-year variability (1984-2014) shows an increase in rainfall variability under climate change for most of the blocks. Further, six blocks in Bihar are projected to experience more than doubling of the rainfall variability. Similarly, 34% of blocks in Bihar are projected to experience over 50% increase in rainfall variability. Thus, this is a significant impact of climate change on monsoon rainfall variability. This will have implications for agriculture, water availability and design of MGNREGA structures.

Table 7: Current and future rainfall variability based on Coefficient of Variation in rainfall

Blocks	CV-Historical (1984-2014)	CV-Projected (2021-2050)
Aurai	33.9	60.5
Azamnagar	25.6	44.6
Balrampur	26.5	44.3
Bandra	29.7	38.0
Barsoi	25.6	41.8
Bausi	25.5	51.6
Bhitahan	29.1	34.3
Bochahan	27.1	30.0
Chanan	27.7	35.9
Chhorahi	26.6	38.9
Dandari	27.3	40.3
Dhuraiya	25.8	53.8
Falka	28.9	64.1
Fatehpur	24.5	30.5
Garhpura	30.6	40.3
Jogapatti	28.3	36.6
Karai Parsurai	27.9	29.9
Katra	32.2	41.7
Ladania	29.2	50.9
Laukahi	28.8	58.9
Laukha	29.0	65.9
Madhubani	30.6	30.6
Mainatand	26.8	36.6
Mohanpur	23.9	73.1
Muhra	30.5	41.1
Nagar Nausa	31.9	44.3
Phulidumar	24.6	35.6
Phulparas	31.6	49.9
Piprasi	38.9	30.6
Rahui	25.5	36.8
Sarmera	28.7	26.6
Shamho Akha Kurha	24.1	33.3
Sidhaw	35.8	36.5
Sikta	27.0	38.9
Tan Kuppa	29.9	31.4

6. Hotspots of Rainfall Variability

It is possible to rank the various identified ICRG blocks based on variability in monsoon rainfall, which is crucial for agriculture. The top ranked blocks with high rainfall variability (Coefficient of Variation) could be prioritized for designing climate resilient land and water related structures under MGNREGA. Table 8 lists the top five blocks with highest CV under current climate (1984-2014) as well as under the projected period – 2021-2050.

CV under current climate

- It can be seen from Table 7 that climate variability is greater than 32% in the top five blocks, showing highest CV.
- It is highest in Piprasi (39%) and lowest in Nagar Nuasa (32%)

CV under projected climate

- Climate variability under this scenario as indicated by the CV is very high and ranges from 59% in Laukahi block to as high as 73% in Mohanpur block.
- In the other three blocks, it is 61% to 66%.

It can be observed that the top five hotspot blocks for current monsoon season rainfall variability are different from the top five hotspot blocks under projected rainfall variability under climate change. Only two blocks remained as hotspots under current rainfall variability as well as projected rainfall variability under climate change. It is important to note that in all the top five blocks under future climate scenario, CV of monsoon rainfall more than doubled. Thus, it will be a challenge to decide whether to select the hotspot blocks of historical rainfall variability or hotspot blocks with high rainfall variability under climate change.

Table 8: Hotspots of current and future climate variability based on CV in rainfall

Top 5 blocks with highest CV under current climate (1984-2014)		Top 5 blocks with highest CV under RCP 8.5 scenario (2021-2050)	
Blocks	**CV**	**Blocks**	**CV**
Piprasi	39	Mohanpur	73 (24)
Sidhaw	36	Laukha	66 (29)
Aurai	34	Falka	64 (29)
Katra	32	Aurai	61 (34)
Nagar Nausa	32	Laukahi	59 (29)

7. Conclusions of the Study and Implications for Climate Resilient Infrastructure Development Under MGNREGA

In this study, historical rainfall analysis was carried out for the identified ICRG blocks for the period 1984-2014. Similarly, climate change projections were carried out using the latest climate models for the same blocks for the period 2021-2050. The main goal was to assess the trends in historical and projected climate for the identified ICRG blocks and to identify the hotspot blocks of rainfall variability.

7.1. Main Conclusions

Some of the key highlights of this assessment are presented below:

1. Rainfall variability differs across blocks even within a state.
2. Current rainfall variability is moderate to high for 88% of the blocks in Bihar and the number of blocks with > 25% Coefficient of Variation are 31 out of 35 blocks.
3. Majority of the blocks experienced mild to moderate drought events - 24 of the 35 blocks experienced mild to moderate drought in over 50% of the years.

4. The main implication of temperature and rainfall trend and variability shows that there is a large variation from block to block even within a state. Thus, block level detailed historical analysis of climate trends, especially rainfall trends is critical and necessary to:
    - Inform block and district level engineers and staff involved in designing MGNREGA structures and assets, such as check dams, farm ponds, and minor irrigation works.
    - Assist them in preparing coping strategies for mild and moderate droughts.
    - Assist in contingency planning in the event of delay or failure of June or early sowing rains.
    - Inform all the stakeholders about rainfall and temperature trends, frequency of potential extreme rainfall events or droughts.
5. Climate change projections show a large variation in projected temperature trends, with majority of the blocks projected to experience warming even by 2030s.
    - Bihar is projected to experience very high levels of warming with majority of the blocks likely warm by 3 to 4^0C by 2030s. This will have significant implications for irrigation water requirement, soil water stress and heat stress for humans. Thus, temperature projections and high levels of warming and heat stress are critical for majority of the blocks in Bihar.
6. Multiple CORDEX model ensemble projections of monsoon season rainfall showed the following:
    - Climate change is projected to have significant impact on total monsoon rainfall with majority of the blocks projected to experience either increase or decline.
        - In Bihar, top five blocks are projected to experience 31 to 40% increase in rainfall. But, 5 other blocks are projected to experience decline in the range of 20 to 25%.
    - Thus, it is necessary to use block level projections in designing MGNREGA structures, rather than the district or state level trends.
7. A significant increase in the number of rainy days under climate change scenario is projected for almost all the blocks of Bihar. Further, number of blocks receiving rainfall (>2.5 mm) over 60 days/year increases from 14 blocks during the historical period to 34 blocks during the projected climate scenario. The percentage increase in number of rainy days (with >2.5 mm rainfall) is 2 (Laukahi) to 37% (Madhubani) under climate change scenario.
8. Rainfall variability has increased for most blocks and some blocks are projected to experience near doubling of the coefficient of variation of monsoon rainfall.
    - Comparison of projected rainfall variability (2021-2050) with the historical 30-year variability (1984-2014) shows an increase in rainfall variability under climate change for most of the blocks. Six blocks in Bihar are projected to experience more than doubling of the rainfall variability. Further, 34% of blocks are projected to experience over 50% increase in rainfall variability. Thus, climate change is projected to have significant adverse impact on monsoon rainfall variability.

7.2. IMPLICATIONS FOR DEVELOPING CLIMATE RESILIENT INFRASTRUCTURE UNDER MGNREGA

MGNREGA works are largely related to natural resources such as water resources and land (grazing land, forests and crop management). Majority of the MGNREGA works are related to land and water conservation and management. The new "Mission Water Conservation" guidelines focus on integrated natural resource management approach. The mission calls for a paradigm shift from promoting "relief measures" to integrated natural resource management approach in implementing MGNREGA. This calls for adoption of climate resilient infrastructure approach to natural resource management under MGNREGA. Under MGNREGA, 100 works out of 153 works relate to NRM, and further, 71 relate to water. Some of the NRM related activities which require climate resilience infrastructure are given below:

- *Check Dam, Earthern Dam, Farm Pond, Feeder Channel, Mini Percolation tank, Stop Dam, Sub Surface Dam, Sunken Pond, Underground Dyke, Boulder Check, Water absorption Trench, Box Trenches, Continuous Contour Trench, Contour Bunds, Earthen Bunding, Earthen Gully Plug, Staggered Trench, Dugwell, Farm Pond Construction of canal, Distributory and Minor, Lift Irrigation, Community Well for Irrigation, Desilting, Renovation, Strengthening of Embankment, Belt Vegetation, Afforestation, Eco Restoration of Forest, Forest Protection, Grass Land Development and Silvipasture, Nursery Raising, Plantation in Government Premises, Plantation, Earthen Bunding, Land Development, Development of waste land, Land Levelling, reclamation of Land, Recharge pits, etc.*

A study conducted by Indian Institute of Science in four states (Esteves et al., 2013) has shown that MGNREGA works related to water and land development have contributed to generation of environmental benefits and natural resource conservation - ground water recharge, increased water availability for irrigation, increased soil fertility, reduction in soil erosion, and improved tree cover. These environmental benefits derived from MGNREGA works have in turn contributed to reducing the agricultural and livelihood vulnerability, thus helping to cope with current climate risks and potentially build long-term resilience to projected climate change. Thus, a large poverty alleviation programme such as the MGNREGA is demonstrated to have the potential to deliver resilience or adaptation benefits to current vulnerability.

The MGNREGA is the largest rural development programme implemented in India with a large investment in works related to soil and water conservation, land development, and afforestation, all of which address the causes of degradation of natural resources. Such works lead to the creation of durable assets. MGNREGA works have led to enhanced productivity and regeneration of the natural resource base, further strengthening its potential for generating resilience benefits. In addition, soil conservation, fodder development, afforestation, and drought proofing works have sequestered carbon, thus mitigating climate change (Esteves et al., 2013).

Potential could exist to further enhance resilience to long-term climate change, through packaging of MGNREGA as a programme to build long-term resilience to future climate change, in addition to reducing vulnerability to current climate risks. In this context, the "Infrastructure for Climate Resilient Growth (ICRG) – a technical assistance programme supported by Department for International Development (DFID) seeks to facilitate more effective investment in rural infrastructure under

MGNREGA to support rural economic growth and improve the climate resilience of vulnerable communities. This is envisaged through improving the quality of the physical assets under MGNREGA in the selected 35 blocks of Bihar. These blocks are among the 2,500 blocks that the Government of India has chosen for focussed implementation of MGNREGA works.

The identified hotspots of rainfall variability could be the priority blocks wherein planning, designing and implementation of MGNREGA works take into consideration the current climate variability and long-term climate change risks.

7.2.1. Implications for ICRG

In India, programmes such as MGNREGA rarely use historical rainfall trends, rainfall intensity, flood or drought occurrence information and data in designing the water storage and transport, land management, etc., structures at the village level. Some of the potential reasons for not utilising the historical rainfall information are as follows:

1. Historical rainfall distribution or intensity data for a given village or even block may not exist, due to limited number of rain gauge stations in a district. Thus, to start with, the basic climate data is not available at the spatial scale it is required for designing MGNREGA structures. The staff of the Rural Development Department or the *Zilla Parishad* are faced with the limitation of lack of rainfall data.
2. In some cases, even if historical climate data are available at IMD or IITM at district or block level, the data may not be accessible to the staff of Rural Development Department or *Zilla Parishad*, who design the structures under MGNREGA.
3. Even if data is accessible, a rarity, the staff at the district or block level may not have computing facility or technical capacity to analyse large volumes of daily data for 20 or 30 years.

Thus, currently it is a challenge to design the land and water related structures based on historical climate or rainfall variables at village or *panchayat* level, even under the current climate scenario. However, under the ICRG project, historical climate data could be provided to the identified hotspot blocks, along with training of junior engineers and technical staff.

7.2.2. Designing Climate Resilient MGNREGA Infrastructure

The challenges in using current and historical climate data in designing MGNREGA land-water structures were presented in previous section. In this section the challenges in utilising the climate change projections data are presented.

1. Climate change projections are at a scale of 50 km X 50 km, which is the finest scale available from CORDEX. This scale will limit the application of projected climate variables at village or *Panchayat* level for designing the MGNREGA structures.
2. GCM and CORDEX projections are for a 30-year period of 2021-2050 and the projected changes occur on decadal scale, which is inadequate for planning the small-scale structures under MGNREGA for immediate implementation.
3. Lack of simple manuals and toolkits for utilizing historical and climate change projections in designing land-water structures or assets at village, block or even district level under MGNREGA.

4. Lack of technical capacity in utilizing the data on climate variables in designing the land-water structures, even if climate projections are made available.
5. Lack of computer skills and computing facilities at the *panchayat*, block and even at district level, to use climate data for designing structures.

7.2.3. Suggested options for ICRG

Climate change is already happening and is projected to occur at a faster rate in the coming decades. Rainfall variability and intensity is projected to increase under climate change. Thus, it is important to conduct pilot projects and build capacity in ensuring climate resilient infrastructure designs are developed and implemented. Some suggested options are as follows:

1. Develop simple toolkits and manuals for utilizing historical and climate change projections in designing land-water related structures at a decentralized scale under MGNREGA.
2. Select pilot hotspot blocks based on historical rainfall variability and projected climate change rainfall variability.
3. Prepare data packages of historical climate trends, climate change projections and all the climate parameters for the pilot hotspot blocks, to assist in designing climate resilient structures.
4. Conduct training programmes to all the technical staff at block and district level in utilising historical and climate change projections data in designing MGNREGA structures.
5. Organize and provide technical back up support to the technical staff of the pilot blocks under the MGNREGA programme.
6. Monitor, evaluate and learn lessons for large-scale dissemination of climate resilient planning of MGNREGA works.

References

1. Pai D.S., Latha Sridhar, Rajeevan M., Sreejith O.P., Satbhai N.S. and Mukhopadhyay B., 2014: Development of a new high spatial resolution (0.25° X 0.25°) Long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region; MAUSAM, 65, 1(January 2014), pp1-18.
2. A K Srivastava, M Rajeevan and S R Kshirsagar. Development of a High Resolution Daily Gridded Temperature Data Set (1969-2005) for the Indian Region
3. Lala I.P. Ray, P.K. Bora, A.K. Singh, Ram Singh, N.J. Singh and S.M. Feroze (2013). Meteorological drought occurrences at Shillong, Meghalaya, Keanean Journal of Science, Vol 2, 31-36.
4. John Weyant, Christian Azar, Mikiko Kainuma, Jiang Kejun, Nebojsa Nakicenovic, P.R. Shukla, Emilio La Rovere and Gary Yohe (2009). Report of 2.6 Versus 2.9 Watts/m2 RCPP Evaluation Panel (PDF). Geneva, Switzerland: IPCC Secretariat.
5. Collins, M., et al.: Section 12.3.1.3 The New Concentration Driven RCP Scenarios, and their Extensions, in: Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility, in: IPCC AR5 WG1 2013, pp. 1045–1047.
6. Tashina Esteves, Patil Vishal, Sharma Nitasha, Shashanka Rao, Murthy I K and N H Ravindranath, Agricultural and Livelihood Vulnerability Reduction through the MGNREGA, Economic and Political weekly, Vol.. 48, Issue No. 52, 28 Dec, 2013.

APPENDIX

Appendix 1: Number of years with normal sowing rains during the historical 30-year period (1985-2014)

Blocks	No. of years
Karai Parsurai	3
Sidhaw	3
Mohanpur	4
Fatehpur	5
Muhra	5
Aurai	6
Chhorahi	6
Katra	6
Garhpura	7
Jogapatti	7
Madhubani	7
Tan Kuppa	7
Balrampur	8
Ladania	8
Bausi	9
Bhitahan	9
Bochahan	9
Chanan	9
Dandari	9
Falka	9
Laukahi	9
Phulparas	9
Rahui	9
Sarmera	9
Shamho Akha Kurha	9
Nagar Nausa	10
Phulidumar	10
Azamnagar	11
Bandra	11
Barsoi	11
Piprasi	11
Dhuraiya	12
Laukha	12
Mainatand	12
Sikta	12