Mehewa Ward, Gorakhpur, India:
Extreme Rainfall, Climate Change and Flooding

Author: Sarah Opitz-Stapleton
December 2013

Introduction

The causes of waterlogging and flooding in Gorakhpur City are diverse and complex. Rainfall events during the monsoon – some extreme amounts falling in short durations and others comprised of multiple days of steady rain – can trigger these in the city. In many wards of the city, such as Mehewa Ward, the areal extent, duration and depth of waterlogging and flooding is more determined by drainage, development and solid waste management than it is by any single rainfall event. Some areas of Mehewa are located along the Rapti River and can experience flooding from the river even when local rainfall amounts are minimal. In these instances, river flooding is triggered by heavy rainfall events in the Nepal Mid-Hills where the Rapti originates. The in-filling of historic ponds and lakes for development, without the necessary stormwater and wastewater drainage network, reduces rain infiltration and causes localised flooding and waterlogging that disrupts business and damages household assets in Mehewa.

Key Findings:

- Much of the flooding and waterlogging in various parts of Mehewa Ward are triggered by rainfall events lasting 4 days (8 days) that total more than 165.4mm (192.6mm).
- Years in the past, such as 1980 or 2010, when three or more of these rain events occurred can contribute to widespread waterlogging that lasts for weeks.
- In the near future (2010-2050), climate change may increase the number of 4-day events in a single monsoon season from an average of 1 to 2 to 2 to 3 per year. In some years, there may be more than three 4-day events that each exceed 165.4mm.
- The number of 8-day rainfall events exceeding 192.6mm is also likely to increase due to climate change, but not at as fast a rate as the 4-day events.

This policy brief describes the types of rainfall events that currently trigger flooding and waterlogging in Mehewa, and how climate change might alter the frequency of these events. Areas of Mehewa experience flooding and waterlogging on a nearly annual basis, even though the triggering rainfall is not necessarily an extreme event from a climatological perspective.[*] The

[*] Climatologists consider an event 'extreme' if it occurs only 5% or less of the time over a historical record of at least 30 years in length.

Gorakhpur Environmental Action Group (GEAG) and the Institute for Social and Environmental Transition (ISET) have been working in Mehewa Ward to develop a ward-level resilience plan. This plan will guide a wide range of stakeholders – from civil society, Urban Local Bodies and city- to the national-level government – in promoting decentralised climate resilient planning. The results of the micro-ward resilience plan can be scaled up and incorporated into the Gorakhpur city resilience plan, and help serve as a template for other urban resilience plans. Additionally, it will strengthen the provisions under the 74th Amendment of the Constitution by demonstrating ways of developing and effectively incorporating climate information and considerations of climate risk into urban development plans.

Rainfall Typology for the Gorakhpur Area

Gorakhpur is located in the broad, flat plains of Uttar Pradesh with no distinct topographic features (mountains or steep hills) that would influence rainstorms in the area. Even though Gorakhpur has only a few weather stations measuring precipitation, rainfall recorded at these is representative of the overall, average rainfall behaviour and amounts for the whole area as orographic influences are minimal. The majority of Gorakhpur's (and Mehewa's) annual precipitation falls as rainfall during the Indian Summer Monsoon in June-September. There is considerable natural variability in monsoon rainfall year-to-year and across decades, as well as within a single monsoon season. This natural variability is *independent* of climate change, and due to natural physical processes like the El Niño Southern Oscillation (ENSO). The figure below shows total annual monsoon rainfall for Gorakhpur from 1910-2010. Overall, there has been a slight downward trend (black line of 10-year moving average) in annual monsoon rainfall.

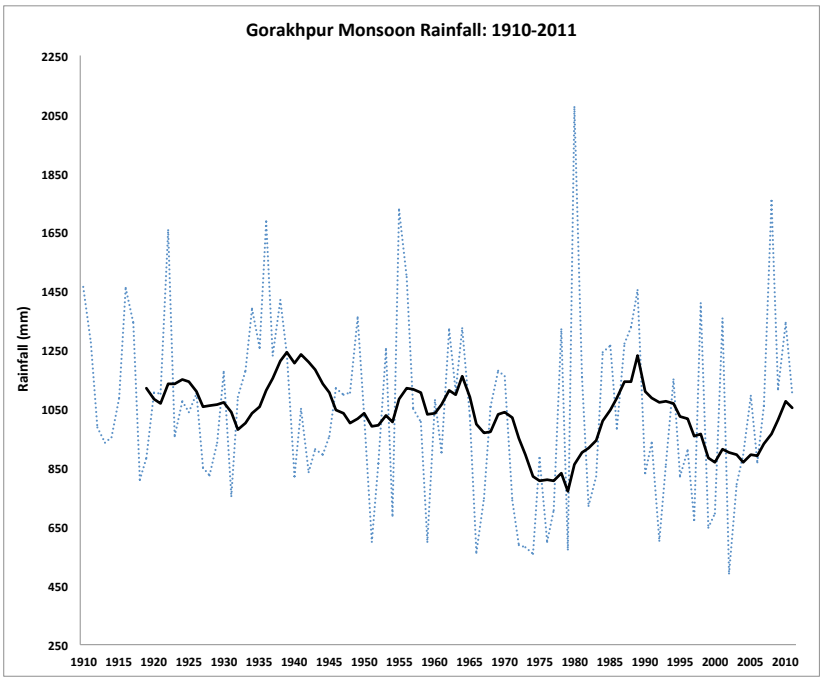

Figure 1: Gorakhpur Annual Monsoon Totals: 1910-2011

Heavy rainfall events – either as a single day of rain or continuous days of moderate to heavy rainfall – can trigger flooding and waterlogging in some areas of Gorakhpur, including sub-wards of Mehewa. Extreme rainfall is described from a climatology perspective by how frequently it occurs (Return Period), average rain rate per time (Intensity) and how long it lasts (Duration). Climate change is likely to increase the frequency of extreme rainfall events between 2010-2050 compared with 1960-2000, making more intense rain events happen more often for the Gorakhpur area (see Opitz-Stapleton and Hawley, 2013a). This has profound implications for flood risk in Mehewa Ward and its sub-wards, given the current pace of development and ways of laying out infrastructure that leave the rainwater few places to infiltrate.

Methodology

Researchers at GEAG and ISET interviewed a number of households and businesses in Mehewa Ward to investigate the rainfall thresholds at which flooding and waterlogging begin to occur in various sub-wards. This method of establishing rainfall-flooding thresholds is not as precise as data collected through direct hydro-meteorological data measurements. However, there are no weather stations,

flood gauges or community-trained recorders to measure rainfall or flood depths at various locations throughout Mehewa Ward. Therefore, interviewing community members about their flood experiences was the only way to loosely qualify how monsoon rains trigger flood events. Rainfall-flooding thresholds were semi-quantitatively established using the following steps:

1. **Step 1:** Community members in four sub-wards recalled the year and approximate month of flooding in their sub-ward. Data collected in the interviews included:
    - Approximate flood depth and duration, notation of whether the flooding/ waterlogging was due to rainfall or to overflow from the Rapti.
    - Approximate month of each year flooding occurred.

2. **Step 2:** The historical daily rainfall data (1960-2000) for Gorakhpur were then analysed to assess the possible sequences of rainfall that could have triggered flooding in the month and year noted by community members.

3. **Step 3:** The possible sequences of rainfall were then analysed for patterns to establish likely rainfall thresholds. Three rainfall thresholds emerged as likely to trigger flooding in some sub-wards:
    - *Threshold 1*: *A single day of heavy rain of 208.8mm or greater, in which the previous 10 days have been completely dry.* Such type of extreme event represents a 1 in 20 year event.
    - *Threshold 2*: *Four consecutive days of rain in which the rainfall total is equal to or greater than 165.4mm.* This rainfall amount represents the 97th percentile of four-day rain totals over the historical record of 1960-2000. If there has been moderate to heavy rainfall within the last week to week-and-half of the 4-day rain event and the soil is saturated, the event will likely trigger waterlogging and limited flooding in some sub-wards.
    - *Threshold 3: Eight consecutive days of rain in which the rainfall total is equal to or greater than 192.6mm.* This rainfall amount represents the 94th percentile of eight-day rain totals over the historical record of 1960-2000. If there has been moderate to heavy rainfall within the last week to week-and-half of the 8-day rain event and the soil is saturated, the event will likely trigger waterlogging and limited flooding in some sub-wards.

4. **Step 4:** Simulated daily rainfall from the six general circulation models (GCMs) described in Opitz-Stapleton and Hawley (2013a and 2013b) was analysed according to the thresholds established in Step 3 over the historical time period of 1960-2000 and the future period of 2010-2050, to see how climate change might alter the frequency of the types of events that trigger flooding in Mehewa.

Results: Climate Change and Extreme Rainfall in Mehewa

Over the historical period of 1960-2011, the four-day rainfall threshold of 165.4mm is exceeded on average one to two times during a monsoon season. There is considerable variation between monsoon seasons, though, as seen in Figure 2. The records of flooding along the Rapti River extend back to the 1970s, and when coupled with the memories of the interviewees, provide approximate dates of flooding and waterlogging in various areas of Mehewa Ward. The rainfall analysis corroborates the reports of flooding – the years with the *most* exceedences of the 4-day rainfall threshold are the years in which flooding/waterlogging occurred in various areas of Mehewa. Residents recalled flooding and waterlogging in some areas of Mehewa in 1988, 1998, 2004, 2008 and 2010 – these years generally correspond with at least three incidences of 4-day rainfall exceeding the threshold of 165.4mm. A single incidence exceeding the 4-day (8-day) threshold is not likely to cause much flooding or waterlogging; such types of waterlogging will be confined to a few

areas and last only a day or two. If there is significant rainfall in the weeks or month before the 4-day event (or 8-day event), the soil is likely to already be saturated, and much of the low-lying areas of the ward are likely to experience some level of flooding or waterlogging. If more rain continues to fall, then flooding and waterlogging can persist for a number of weeks and cause severe damage.

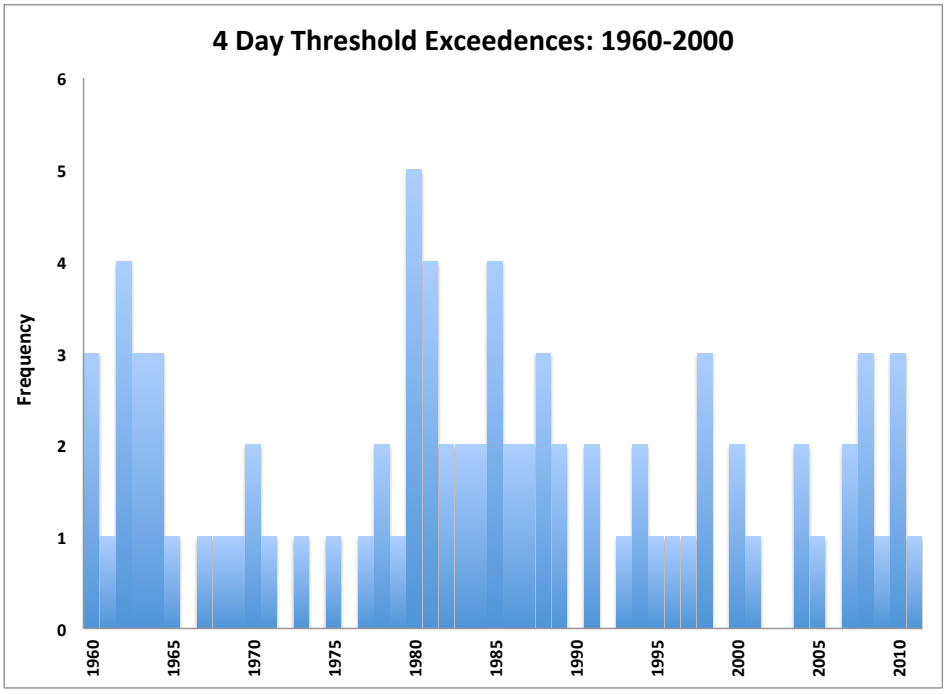

Figure 2: Frequency of 4-Day Rainfall Threshold Exceedences in Gorakhpur: 1960-2011

When we look to the future (2010-2050), it appears that climate change will likely increase the frequency of occurrence of both the 4-day and 8-day threshold, extreme rainfall events that contribute to flooding in Mehewa Ward. A multi-model comparison revealed:

	Per cent Change between (2010-2050) and (1960-2000)	Implications
4-Day Threshold	5.3 to 52% increase	One 4-day event of 164.5mm or more is not likely to cause much flooding on its own, but will if there was moderate rain in the prior week. If significantly more rain than 180mm falls in 4 days, then flooding will occur. The overall occurrence of 4-day rain events is likely to increase ~5 to 52% for Gorakhpur, making it more likely that such types of events will happen on average two or more times per monsoon season. This can contribute to flooding and waterlogging in Mehewa.
8-Day Threshold	0 to 28% increase	The frequency of occurrence of 8-day events is also likely to increase, but not as much as the 4-day events. One possible way to interpret this is that the same or more amount of rain (total), will be falling over fewer days (shorter duration) as more intense events. Heavier rain falling over a shorter period of time has the potential to cause significant flooding and waterlogging issues for Mehewa Ward unless different development choices are made in the future.

Climate change is also likely to cause an overall shift in the monsoon rainfall distribution, with the monsoon being considerably weaker in some years and with strong monsoon years remaining roughly the same in the near future. It is not yet clear if the overall decrease (downward trend) in annual monsoon rainfall will continue in the future. There is not yet enough clarity about shifts in the near-term (out to 2050) to decisively say how the overall monsoon might yet change for the Gorakhpur region.

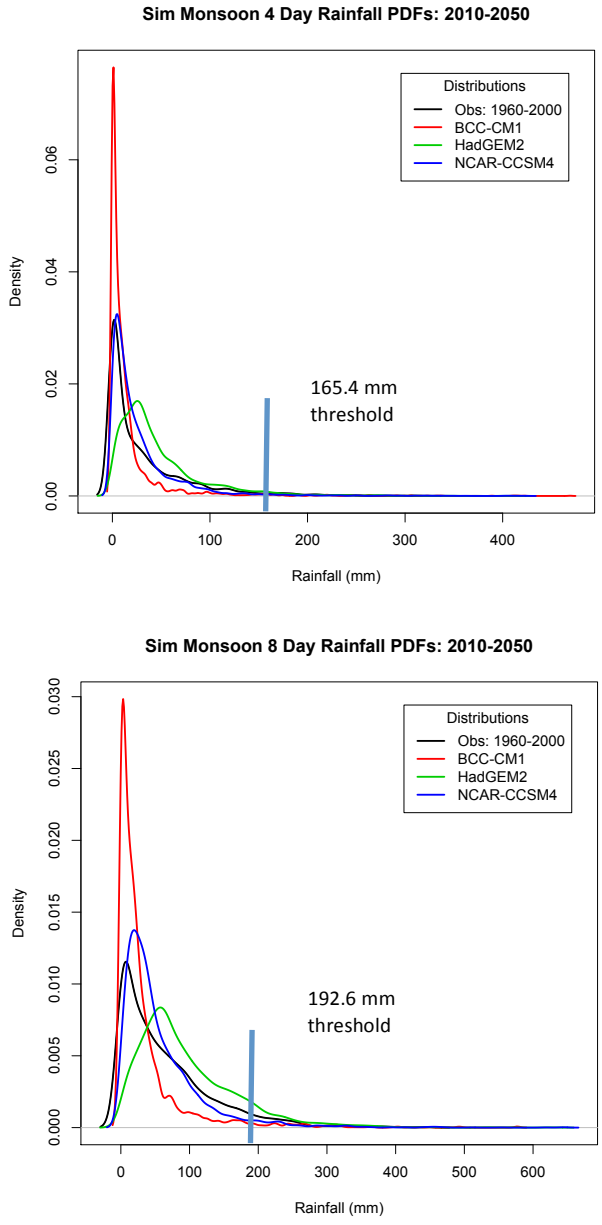

Figure 3: Projected 4- and 8-Day Rain Totals during the Monsoon for 2010-2050. The black line corresponds with historical distributions (1960-2000) and the coloured lines correspond with different climate model projections. The vertical line represents the rainfall threshold.

Figure 3 is a density plot, which is essentially a smoothed plot counting how many 4-day (8-day) events of a particular rainfall amount occurred. The majority (represented as the peak of the density curves) of 4-day (8-day) rainfall events constitute small to medium amounts of rainfall (less than 100mm in total) and will not cause flooding or waterlogging in Mehewa *unless* many of them occur in a row. This happened during the monsoon of 1980, in which the 4-day and 8-day rainfall thresholds were exceeded quite a few times and it rained almost continuously throughout the whole monsoon season, causing widespread flooding and waterlogging issues throughout Gorakhpur.

It does appear that variability within a monsoon season will continue to increase, with more break periods and the potential for more 4-day and 8-day periods of rainfall that exceed the thresholds known to currently cause problems in Mehewa Ward. Figure 3 shows the potential range of shift in 4-day and 8-day monsoon rainfall events over the period of 2010-2050, when compared with the observation period (black line) of 1960-2000. The three models shown in the figure represent the multi-model (6 GCMs) spread of projected monsoon rainfall changes.

Summary

The causes of flooding and waterlogging throughout Mehewa Ward are complex – heavy rainfall events lasting four or more days trigger these. However, lack of proper drainage and the infilling of water bodies and green spaces, as well as the citing of bunds to protect against flooding from the Rapti River, prevents rain from infiltrating into the ground. These development patterns exacerbate flood and waterlogging issues throughout the ward. Climate change is likely to increase the frequency of extreme rainfall events for the Gorakhpur

area. The development choices made today (2013) in Mehewa Ward will profoundly affect its resilience to future climate change.

References

Opitz-Stapleton, S. and K. Hawley (2013), *Gorakhpur, India: Extreme Rainfall, Climate Change, and Flooding*, Policy Brief for ISET and CDKN, http://b.i-s-e-t.org/1b3HXen accessed 13 December 2013.

Opitz-Stapleton, S. and K. Hawley (2013), *Gorakhpur, India: Extreme Rainfall, Climate Change, and Flooding*, Technical Report for ISET and CDKN, http://b.i-s-e-t.org/IKGD9O accessed 13 December 2013.

Disclaimer

This policy brief was produced with support from the Rockefeller Foundation under the Asian Climate Cities Resilience Network (ACCCRN) program. Views and opinions expressed within do not necessarily reflect the positions of all ACCCRN partners.