Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Introduction
Methodology
Results
Conclusions

Home
Previous
Next
Detailed Contents

Scan me
Author's webpage
Lab's webpage

EGU General Assembly 2019

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Introduction

1. UHI can be affected by radiation budget and land-use configuration of the local and urban-rural environment (Kalnay et al., 2003; Peng et al., 2012; Zhao et al., 2014).

2. During heatwaves, UHI can enhance biophysical hazards such as heat stress, air pollution and other public health related issues, including heat related mortality, which are projected to become more prominent in the future (Im et al., 2017; Mishra et al., 2017).

3. This localized phenomenon may interact with synoptic scale events such as heatwaves and storms leading to further risks to infrastructure and life.

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

The gaps

1. The seasonal variability and causes of daytime UCI is largely unexplored in India. The role of agriculture and irrigation is also not validated although it also modifies the water and thermal balance of the region.

2. Previous studies link urbanization to heatwave intensification using UHI as a metric (Fischer et al., 2012; Li et al., 2015; Peng et al., 2018; Wang et al., 2015; Yu et al., 2018; L. Zhao et al., 2018) and report that urban population is at higher risk. Such risks need to be addressed for India.

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Methodology

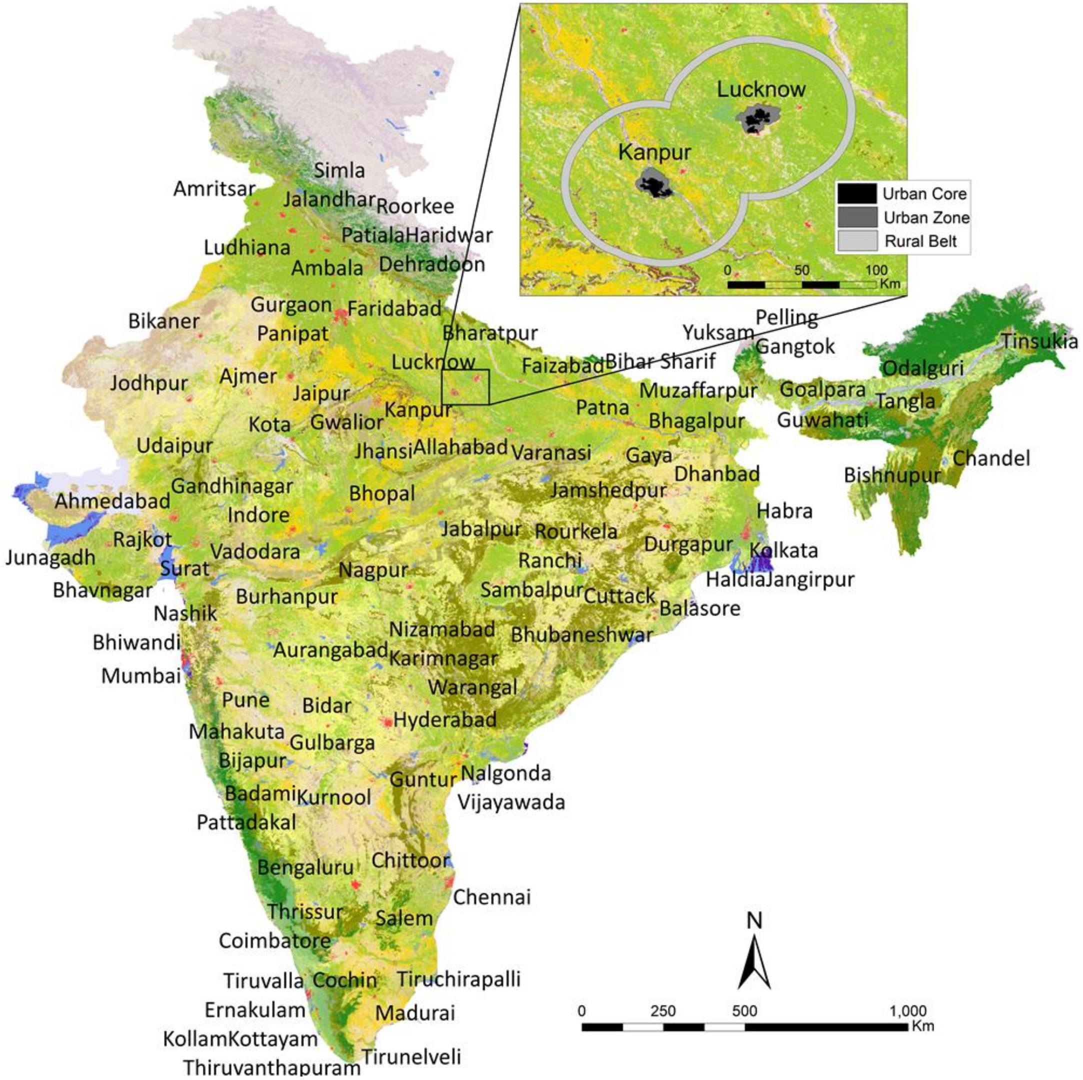


Figure 1. 89 major urban locations and surrounding non-urban zones selected for study in India (Background map shows LULC from 2011).

Table 1. Buffer zone ranges for different tier cities.

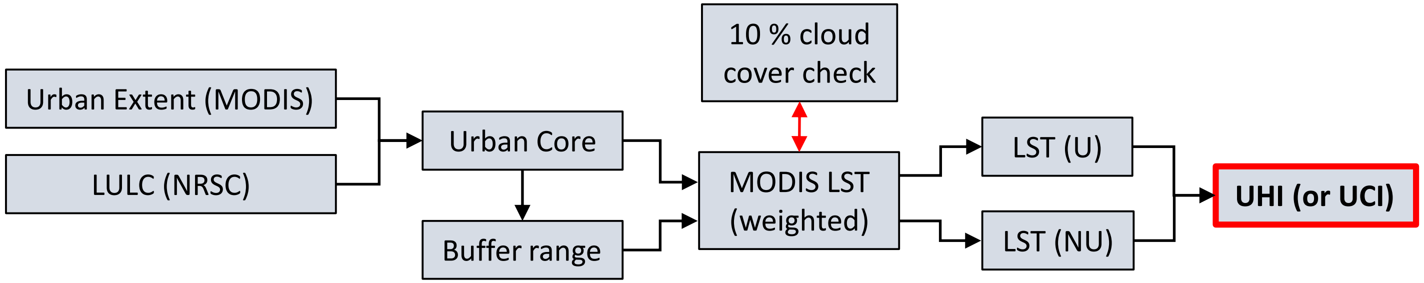
Type	Area range (sq. m)	Rural range from boundary
Tier I	> 40,00,00,000	45 - 50 km
Tier II	20,00,00,000 - 40,00,00,000	40 - 45 km
Tier III	10,00,00,000 - 20,00,00,000	35 - 40 km
Tier IV	5,00,00,000 - 10,00,00,000	30 - 35 km
Tier V	< 5,00,00,000	25 - 30 km

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Methodology

1. UHI (UCI) intensity time series from quality-controlled MODIS LST data and Urban zones.



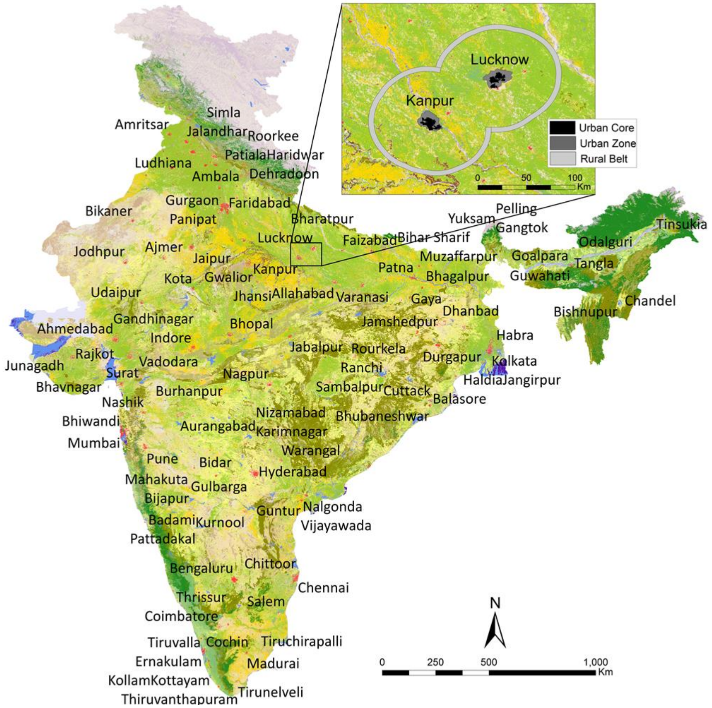
The weighted mean LST of a zone $(\overline{LST})$ is determined as

$$\overline{LST} = \frac{\sum_1^n w_p LST_p}{\sum_1^n w_p} \tag{1}$$

where, w_p and LST_p are weight and LST of the p[th] pixel. The pixel-wise weight (w_p) is based on the quality flag information taken as

$$w_p = \begin{cases} 3, good quality\ LST \\ 2, fair quality\ LST \\ 1, poor quality\ LST \end{cases} \tag{2}$$

$$\text{UHI (or UCI)} = \Delta T = LST_u - LST_{nu} \tag{3}$$



Type	Area range (sq. m)	Rural range from boundary
Tier I	> 40,00,00,000	45 - 50 km
Tier II	20,00,00,000 - 40,00,00,000	40 - 45 km
Tier III	10,00,00,000 - 20,00,00,000	35 - 40 km
Tier IV	5,00,00,000 - 10,00,00,000	30 - 35 km
Tier V	< 5,00,00,000	25 - 30 km

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Role of irrigation in cooling

1. Two simulations
   one with cropland on and irrigation off
   one with cropland on and irrigation on.
2. Summer (AMJ) period median cooling of 1.2^{o}C and 1.6^{o}C in IGP at day and night time respectively.
3. For non-IGP regions, the cooling was 0.37^{o}C and 0.4^{o}C at day and night time respectively.
4. High aerosol concentration in the IGP region could also be the reason for such cooling (to a much lower extent). But, here CLM only accounts for irrigation cooling.

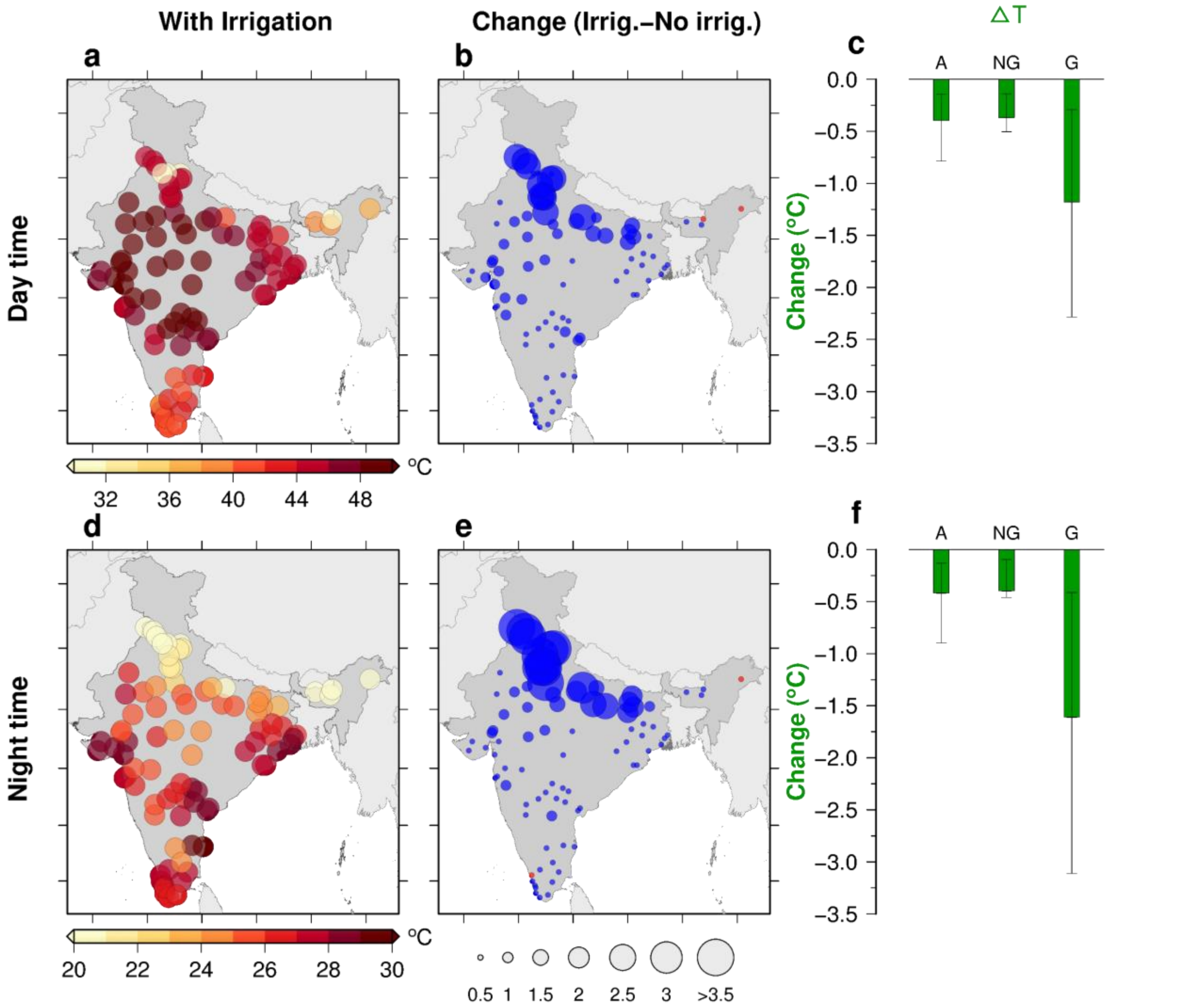


Figure 2. Effect of irrigation on surface cooling in the selected non-urban locations in the summer term (April, May, and June) for the period 2003-2014 as simulated by CLM.

AMJ: April-May-June **IGP**: Indo-Gangetic Plain **CLM**: Community Land Model

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Heatwaves and SUHI

1. Kumar et al. (2017) showed that SUCI is more prevalent at day time during peak summers (AMJ) at day time. Which means:

   Non-urban temp. > Urban temp.

2. Decline in SUHI (i.e. $SUHI_{HW} < SUHI_{Ref}$) during heatwaves.

   63% at day-time
   74% at night-time

3. This shows no intensification of Heatwaves in the urban regions in India.
   (This is contrast to other studies e.g. Li et al. (2015), Ramamurthy et al. (2017) and Zhao et al. (2018)).

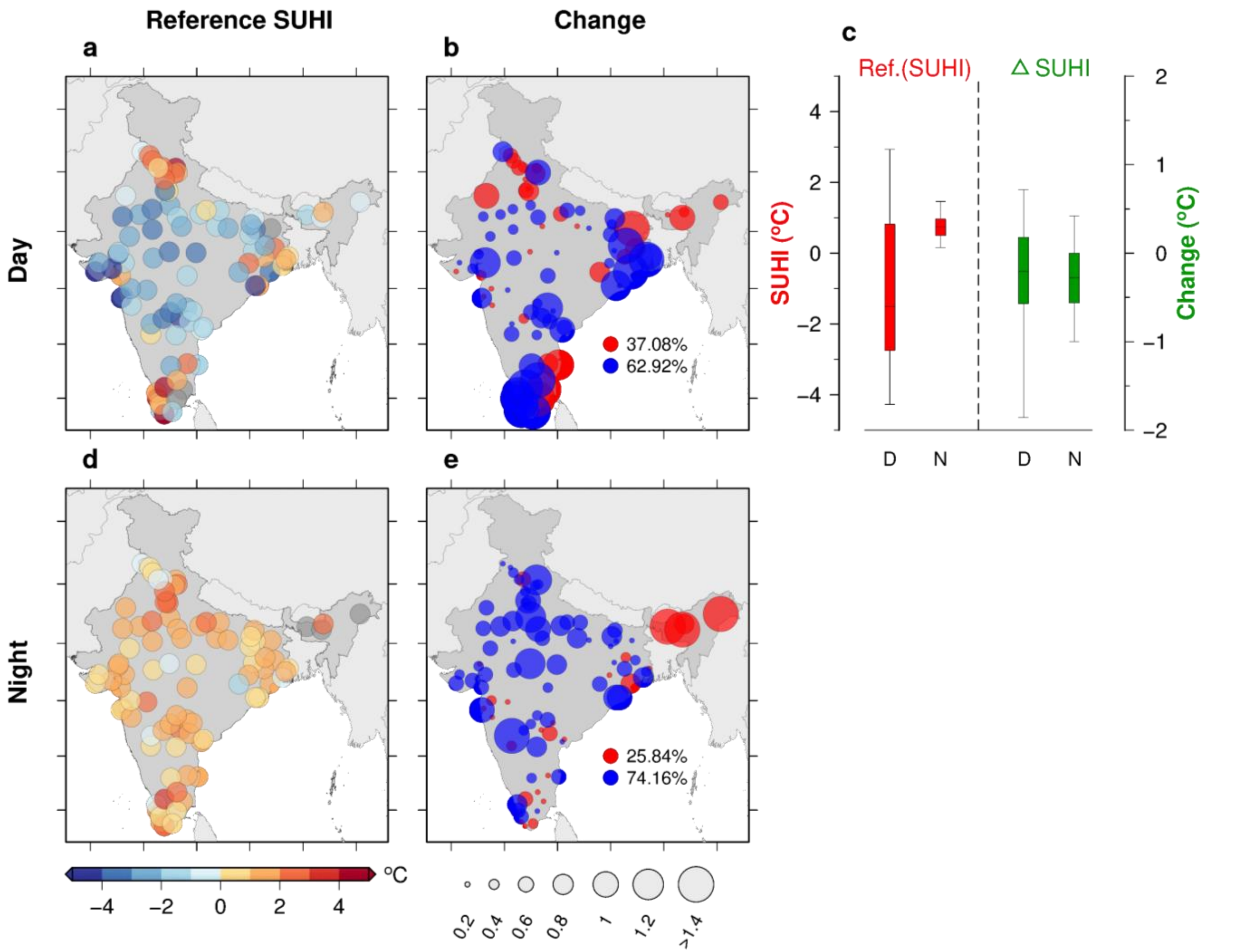


Figure 3. Surface Urban Heat Island (SUHI) intensity changes during heatwaves in the summer term (April, May, and June) for the period 2003-2016 from MODIS Aqua satellite.

AMJ: April-May-June **SUHI (or SUCI)**: Surface Urban Heat/Cool Island **HW**: Heatwaves

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Heatwaves and LST

1. We compared ref. LST of urban and non-urban regions to estimate the amplifications, if any.
2. Ref. LST = Non-heatwave days of summer (AMJ) period.

   $LST_{Ref.(NU)} > LST_{Ref.(U)}$

3. Mean amplification in ΔLST

   i.e. $\Delta LST = (LST_{HW(U/NU)} - LST_{Ref.(U/NU)})$

4. We found that

   $\Delta LST_{NU} > \Delta LST_{U}$

   ($1.9^{o}C$ in non-urban than $0.14^{o}C$ in urban)

5. The night-time reference LST was higher for urban than NU regions.

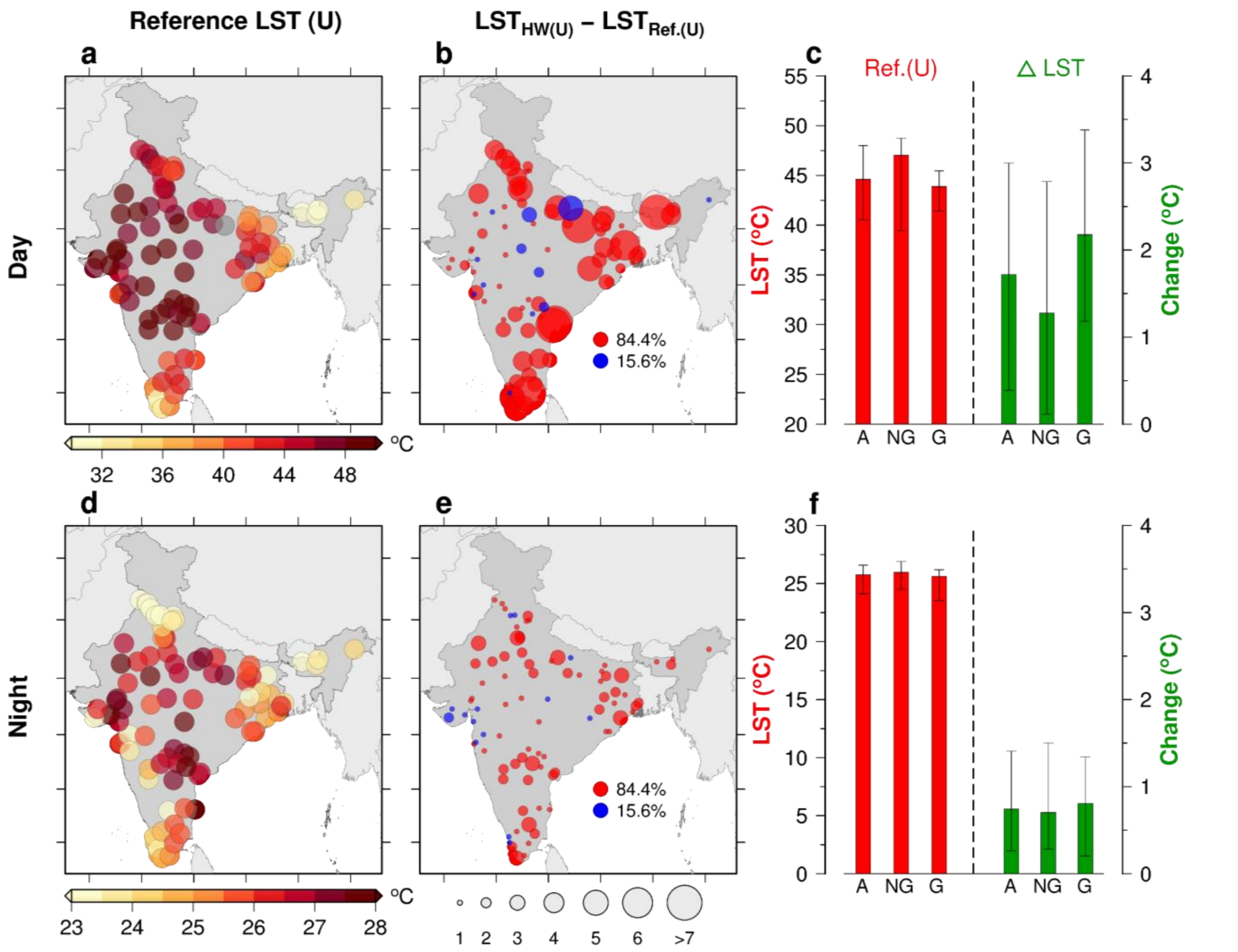


Figure 4. LST amplification during HWs in the summer term (AMJ) (a) Reference LST of urban areas at day time; (b) change in LST during HWs from reference LST (LSTHW(U) – LSTRef(U)) at day time; (c) summary of LST(Ref.) in urban areas at day time for all selected locations (A), locations in NGR and locations in IGP (G); (d) same as (a) but for night time; (e) same as (b) but for night time; (f) same as (c) but for night time.

LST: Land Surface Temp. **NGR**: Non-Gangetic Region **IGP**: Indo-Gangetic Plain **NU**: Non-urban **HW**: Heatwaves

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Conclusions

1. Majority (44%) of the selected locations show significant ($p<0.05$) rise in day time heatwave frequency. While 35% of the locations show decline in extreme hot-nights frequency.

2. IGP show considerable decline in hot nights frequency. Using CLM simulations, we show that the intensive irrigation in the regions lead to the decline in hot nights and a limited increase in hot days frequency.

3. Amplification was lesser for Arid and semi-arid regions at day-time due to higher heat capacity.

4. Majority (63% and 74%) of the locations show drop in SUHI intensities during heatwave periods at day and night time, respectively. This leads to the understanding that during non-urban regions face higher LST amplification that urban counterpart.

5. These results show that SUHI declines during heatwaves which shows that non-urban regions are at higher risks than urban region during HWs in India.

CLM: Community Land Model **LST**: Land Surface Temp. **SUHI (or SUCI)**: Surface Urban Heat/Cool Island

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Detailed Contents

Scan me

Author's webpage   Lab's webpage

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Objective 1

Urban Heat Islands: Its drivers and mechanisms

Science questions:

1. How urbanization modifies surface and near surface air temperatures?
2. What factors influence these temperatures?
3. Do vegetation and irrigation in the surrounding regions affect these temperatures?
4. How does aerosols affect the temperatures?

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Data

S. No.	Details	Time period	Spatial Resolution	Temporal Resolution
1	NRSC LULC (2011)	-	56 m	-
2	MODIS Urban extent	-	500 m	-
3	MODIS LST (Terra & Aqua)	2003 - 2014	1 km	8 day
4	GSOD 2 m air temp		-	daily
5	MODIS NDVI (Terra)	2003 - 2014	250 m	16 day
6	MODIS AOD (Terra & Aqua)	2003 - 2014	10 km	monthly
7	Irrigation map (Ambika et al, 2016)	2000 - 2015	250 m	-

Models

S. No.	Details	Objective(s)
1	CLM	Effect of irrigation on UHI
2	NASA GISS Atmospheric Model	Spatial variation of AOD with temperature change

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Detailed Contents

Results

Day and night-time UHI/UCI

1. UCI prominent at day time in western and central India in both pre and post-monsoon period.
2. UHI more prominent at night-time which results in a lower diurnal range of temperature than surrounding non-urban areas due to warming of min. temp. in Urban regions than NU.

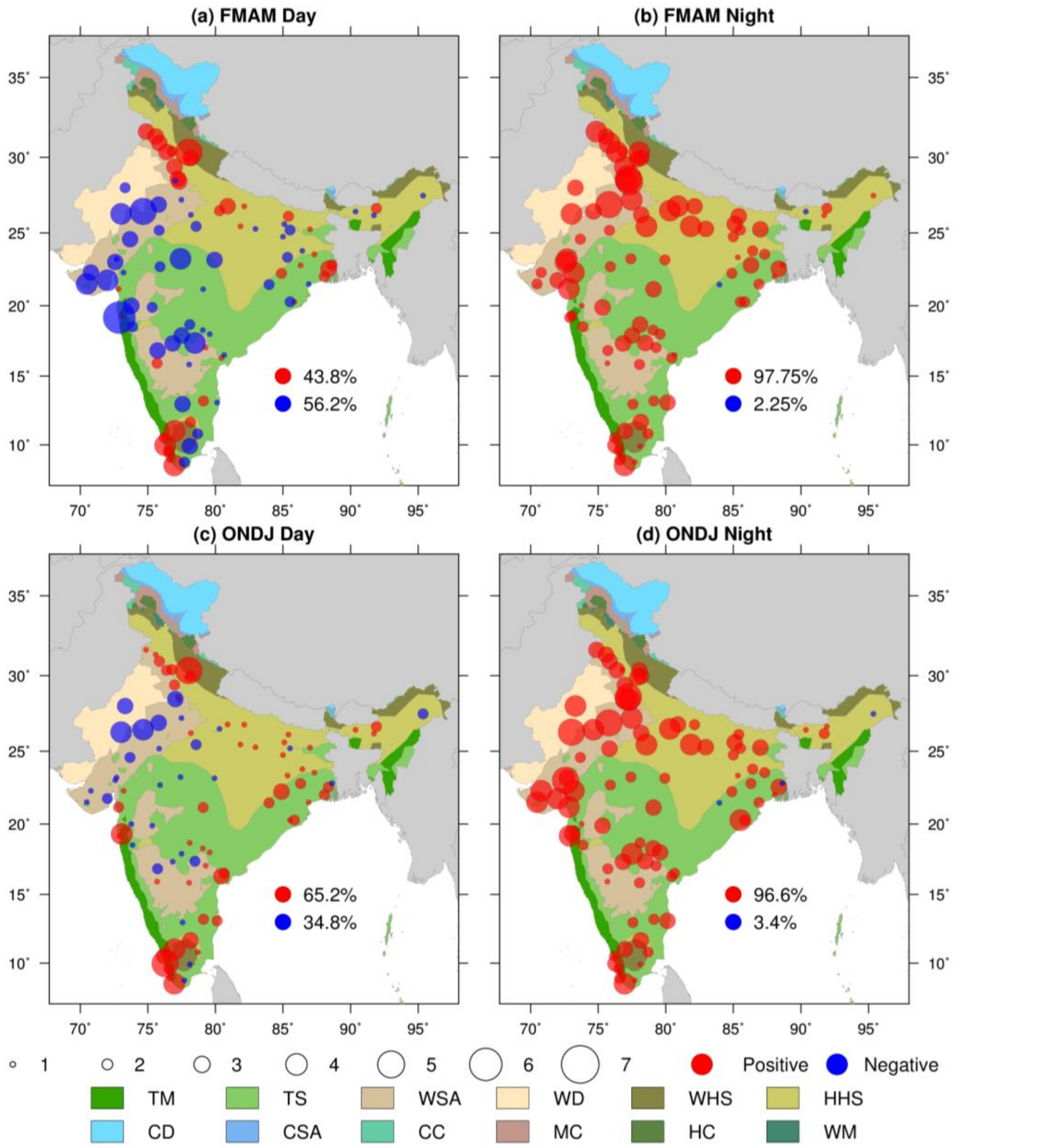


Figure 2. Day and night time Urban Heat Island (UHI) in the pre and post monsoon seasons in India for the 89 largest out of 100 urban areas that are planned as Smart Cities. (*Source:* Kumar et al., 2017)

Kumar et al., 2017, Scientific Reports

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Monthly variation in UHI/UCI

1. The seasonal variation shows the role of vegetation and available soil moisture at different months.
2. During April-May, when the air temp. is at peak, LST gets higher than that in pre-monsoon in the absence of crops.
3. The arid and some parts of semi-arid regions show UCI consistently throughout the year.

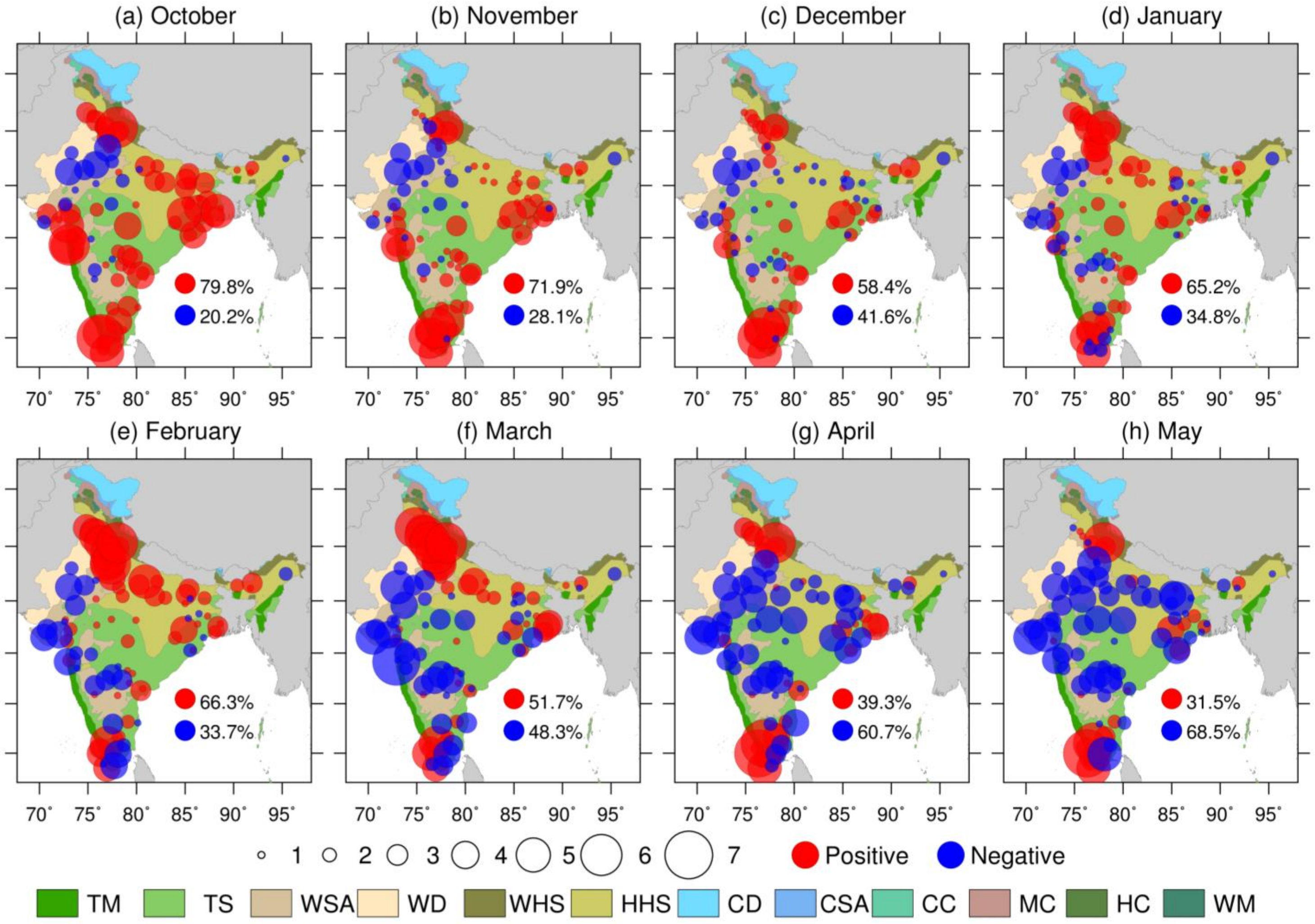


Figure 3. Monthly variation in day-time UHI in the pre and post monsoon seasons. (*Source:* Kumar et al., 2017)

Kumar et al., 2017, Scientific Reports

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Vegetation and UHI/UCI

1. May month UCI locations were selected (blue) to establish relation between UCI and vegetation.
2. The locations have 50% or more agri-dominated NU regions.
3. 70% of all locations (blue) show steep decline in NDVI in ONDJ with crop harvesting at the end of March.
4. Dominant role of presence of vegetation cover in the NU region in modulating UHI/UCI during peak summer months.

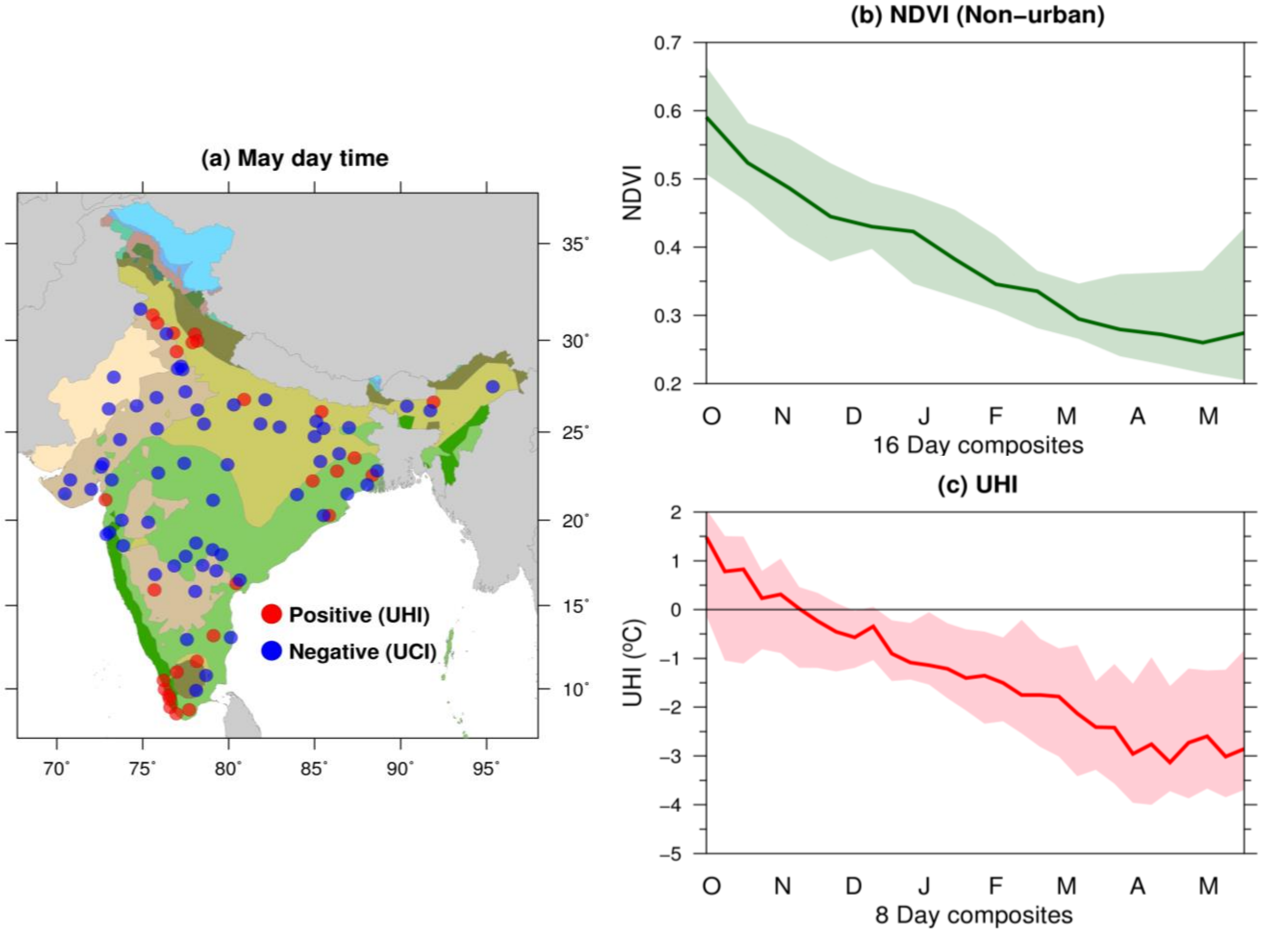


Figure 4. Influence of vegetation on UHI/UCI intensity in urban areas in India. (*Source:* Kumar et al., 2017)

Kumar et al., 2017, Scientific Reports

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Irrigation and UHI/UCI

1. two simulations
   one with cropland on and irrigation off
   one with cropland on and irrigation on.
2. Highly irrigated regions (blue) with and without irrigation shows irrigation reduces the NU temp.
3. The same effect in not observed at night-time suggesting evaporative cooling at day-time.
4. This explains the patterns in the Indo-Gangetic region LST.

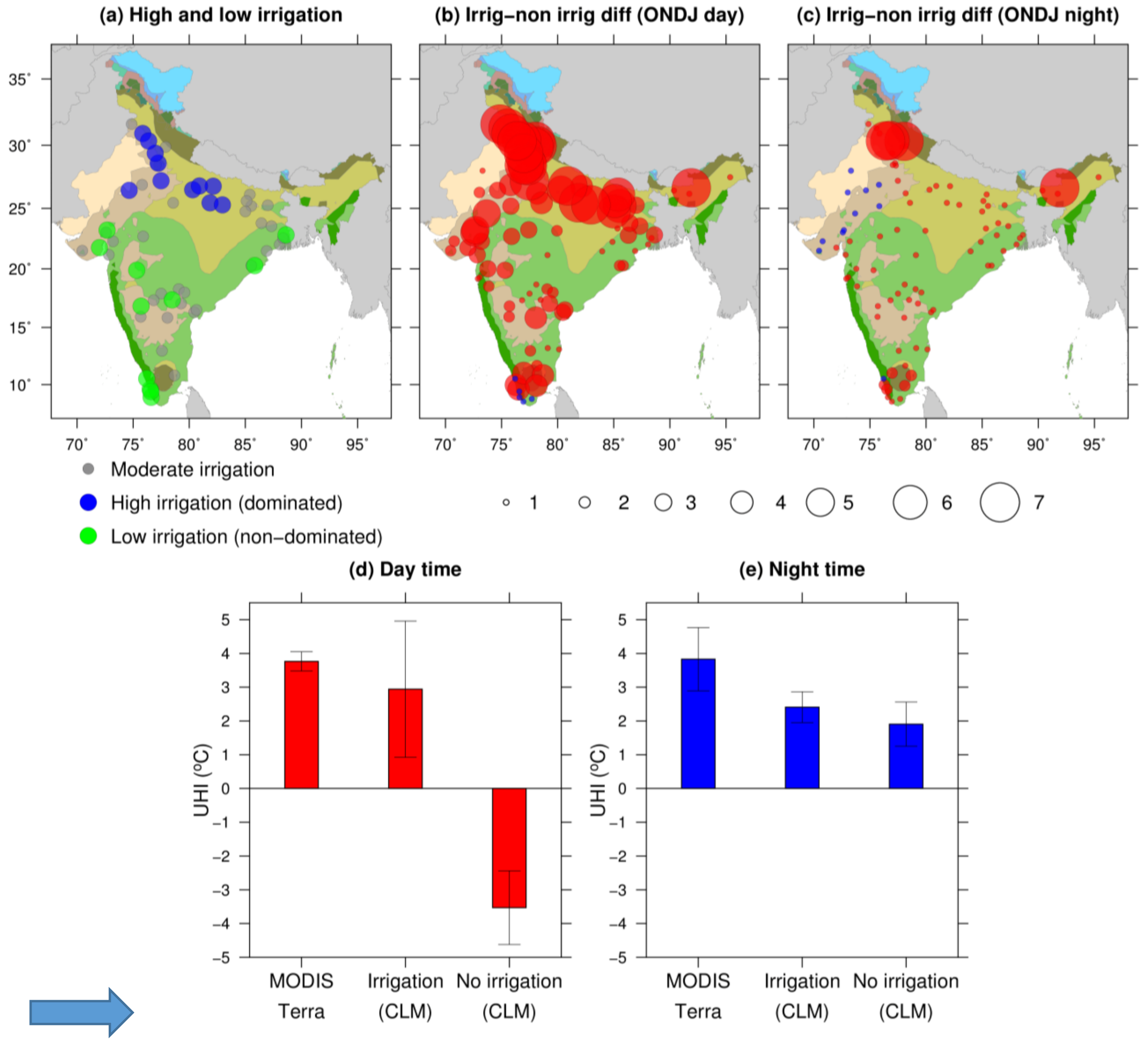


Figure 5. Influence of irrigation on UHI/UCI intensity in urban areas in India. (*Source:* Kumar et al., 2017)

Kumar et al., 2017, Scientific Reports

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Detailed Contents

Conclusions

1. Land use change can alter the thermal balance of Earth's surface leading to localized UHI/UCI phenomenon.

2. Background climate has significant role in UHI/UCI intensity.

3. The UHI/UCI intensity varies spatially as well as temporally.

4. Agriculture and irrigation are dominant drivers of UHI in India.

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Objective 2

Interactions of Urban microsystems with heatwaves.

Science questions:

1. What is the frequency and trends of heatwave occurrences in India?
2. How does urban and surrounding non-urban region respond to heatwaves?
3. Do urbanization intensify heatwaves?
4. Does irrigation also influence the responses of land use change during large scale heatwave phenomenon?

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Data

S. No.	Details	Time period	Spatial Resolution	Temporal Resolution
1	NRSC LULC (2011)	-	56 m	-
2	MODIS Urban extent	-	500 m	-
3	MODIS LST (Terra & Aqua)	2003 - 2016	1 km	8 day
4	IMD SAT at 2m	2002 - 2016	111 km (1^o)	daily
5	CRU CRUNCEP (forcings)	1901 - 2002	0.5^o	-

Models

S. No.	Details	Objective(s)
1	CLM	Effect of irrigation on UHI

Urban interactions with heatwaves in India

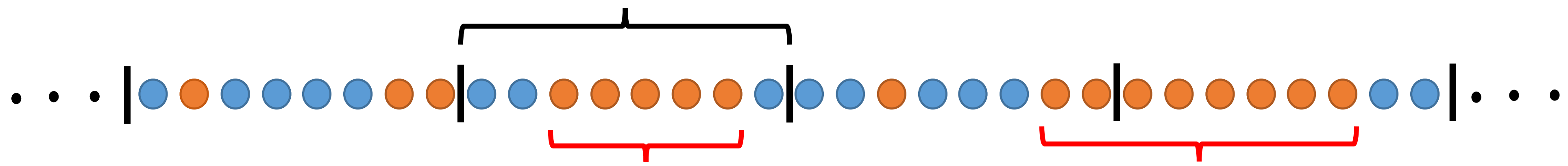
Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Methodology

1. UHI (UCI) intensity time series from quality-controlled MODIS LST data and Urban zones. (As obtained in objective 1)
2. Heatwave identification and matching with MODIS LST

	Day-time	Night-time
Exceptional hot day/night	$T_{max} > T_{95\ max}$	$T_{min} > T_{95\ min}$

where $T_{95\ max/min}$ is obtained from AMJ, 1970-2010



Amplification in LST = 8 day baseline – 8 day with heatwave

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Hot day/night change

1. 44% show ↑ hot days frequency
2. 35% show ↓ hot nights frequency
3. We observed a contrasting pattern in Indo-gangetic plain (IGP) region both at day and night-time.
4. IGP region show non-significant change in hot days while a significant decline in hot nights.
5. Intensive irrigation played a significant role in cooling in IGP.

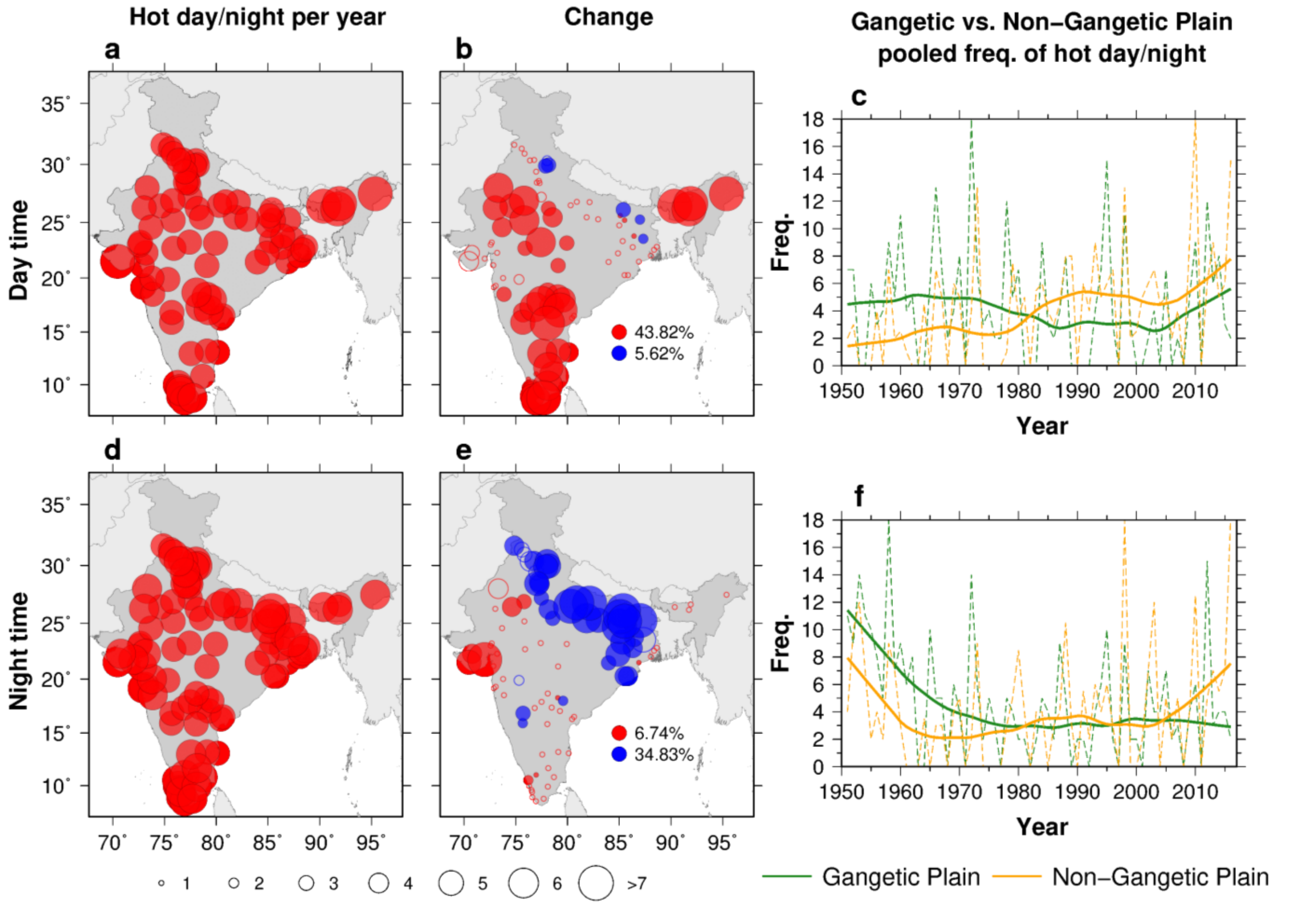


Figure 6. Hot day and night frequency changes during the summer term (April, May, and June) for the period 1951-2016. (*Source:* Kumar et al., 2019, Envir. Res. Commun.)

Kumar et al., 2019, Envir. Res. Commun.

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Introduction

Results

Role of irrigation in cooling

1. Two simulations
   one with cropland on and irrigation off
   one with cropland on and irrigation on.
2. Summer (AMJ) period median cooling of 1.2°C and 1.6°C in IGP at day and night time resp..
3. For non-IGP regions, the cooling was 0.37°C and 0.4°C at day and night time respect..
4. High aerosol concentration in the IGP region could also be the reason for such cooling (to a much lower extent). But, here CLM only accounts for irrigation cooling.

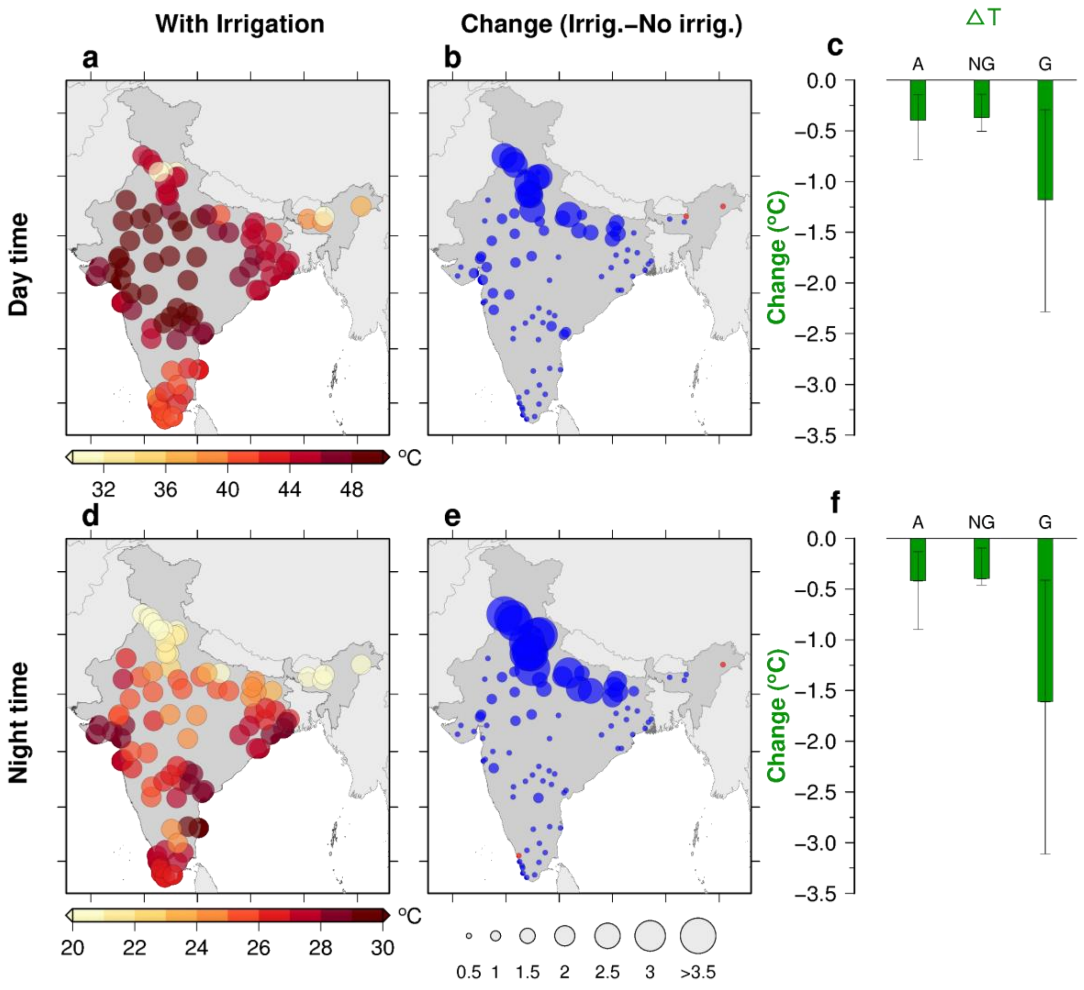


Figure 7. Effect of irrigation on surface cooling in the selected non-urban locations in the summer term (April, May, and June) for the period 2003-2014 as simulated by CLM. (*Source:* Kumar et al., 2019, Envir. Res. Commun.)

Kumar et al., 2019, Envir. Res. Commun.

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India
WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Results

Heatwaves and UHI

1. Kumar et al. (2017) showed that UCI is more prevalent at day time during peak summers (AMJ) at day time. Which means:

   Non-urban temp. > Urban temp.

2. Decline in SUHI (i.e. $SUHI_{HW} < SUHI_{Ref}$) during heatwaves.

   63% at day-time
   74% at night-time

3. This shows no intensification of Heatwaves in the urban regions in India.
   (This is contrast to other studies e.g. Li et al. (2015), Ramamurthy et al. (2017) and Zhao et al. (2018)).

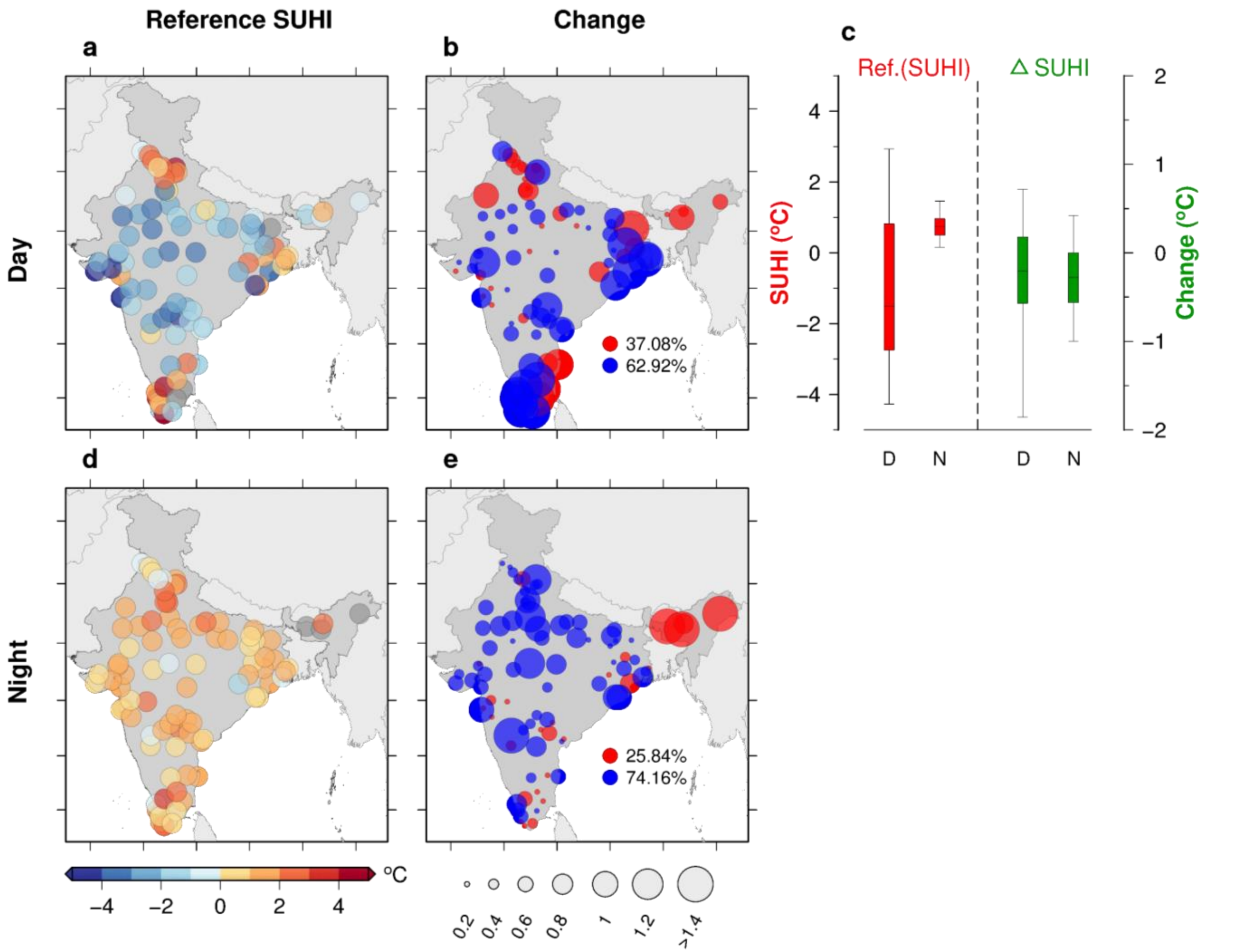


Figure 8. Surface Urban Heat Island (SUHI) intensity changes during heatwaves in the summer term (April, May, and June) for the period 2003-2016 from MODIS Aqua satellite. (*Source:* Kumar et al., 2019, Envir. Res. Commun.)

Kumar et al., 2019, Envir. Res. Commun.

EGU General Assembly 2019

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

Introduction

Results

Heatwaves and LST

1. We compared ref. LST of urban and non-urban regions to estimate the amplifications, if any.
2. Ref. LST = Non-heatwave days of summer (AMJ) period.

   $LST_{Ref.(NU)} > LST_{Ref.(U)}$

3. Mean amplification in ΔLST
   i.e. $\Delta LST = (LST_{HW(U/NU)} - LST_{Ref.(U/NU)})$
4. We found that

   $\Delta LST_{NU} > \Delta LST_{U}$

   (1.9^oC in non-urban than 0.14^oC in urban)
5. ΔLST for NGR was 2.1^oC and 2.4^oC in urban and non-urban regions.
6. The night-time reference LST was higher for urban than NU regions.

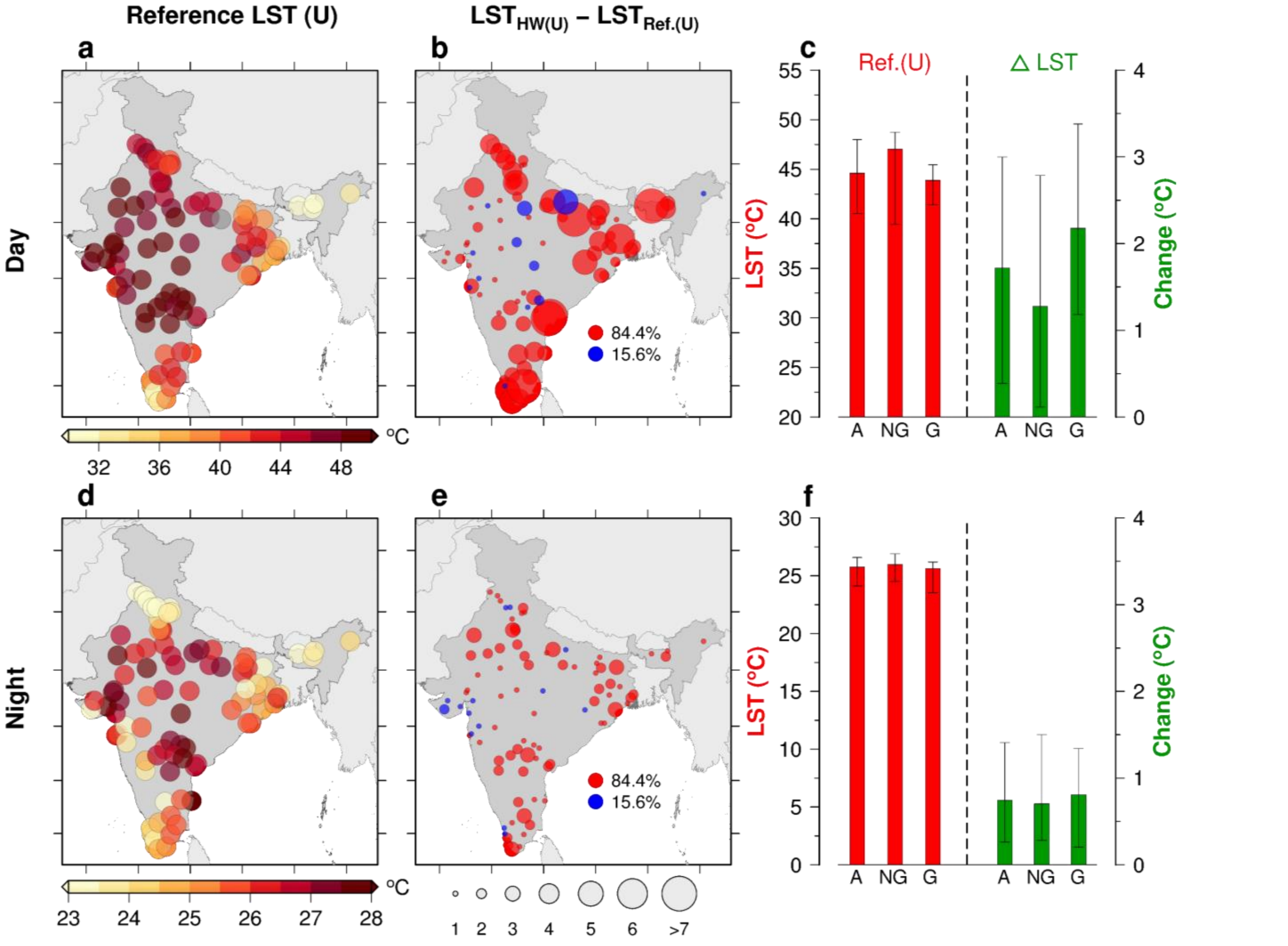


Figure 4. LST amplification during HWs in the summer term (AMJ) (a) Reference LST of urban areas at day time; (b) change in LST during HWs from reference LST (LSTHW(U) – LSTRef(U)) at day time; (c) summary of LST(Ref.) in urban areas at day time for all selected locations (A), locations in NGR and locations in IGP (G); (d) same as (a) but for night time; (e) same as (b) but for night time; (f) same as (c) but for night time.

Kumar et al., 2019, Envir. Res. Commun.

Urban interactions with heatwaves in India

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

Conclusions

1. Majority (44%) of the selected locations show significant ($p<0.05$) rise in day time heatwave frequency. While 35% of the locations show decline in extreme hot-nights frequency.
2. IGP show considerable decline in hot nights frequency. Using CLM simulations, we show that the intensive irrigation in the regions lead to the decline in hot nights and a limited increase in hot days frequency.
3. Amplification was lesser for Arid and semi-arid regions at day-time due to higher heat capacity.
4. Majority (63% and 74%) of the locations show drop in UHI intensities during heatwave periods at day and night time, respectively. This leads to the understanding that during non-urban regions face higher LST amplification that urban counterpart.
5. These results show that urbanization does not amplify heatwaves in India.

Rahul Kumar and Vimal Mishra
Indian Institute of Technology Gandhinagar, India

References

1. Ali, H., & Mishra, V. (2018). Increase in Subdaily Precipitation Extremes in India Under 1.5 and 2.0° C Warming Worlds. *Geophysical Research Letters*, 45(14), 6972-6982.
2. Fischer, E. M., Oleson, K. W., & Lawrence, D. M. (2012). Contrasting urban and rural heat stress responses to climate change. *Geophysical Research Letters*, 39(3), 1–8.
3. Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India in a warming environment. *Science*, 314(5804), 1442-1445.
4. Kumar, R., Mishra, V., Buzan, J., Kumar, R., Shindell, D., & Huber, M. (2017). Dominant control of agriculture and irrigation on urban heat island in India. *Scientific Reports*, 7(1), 1–17.
5. Li, D., & Bou-Zeid, E. (2013). Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology*, 52(9), 2051–2064.
6. Li, D., Sun, T., Liu, M., Yang, L., Wang, L., & Gao, Z. (2015). Contrasting responses of urban and rural surface energy budgets to heat waves explain synergies between urban heat islands and heat waves. *Environmental Research Letters*, *10*(5), 054009.
7. Mishra, V., Mukherjee, S., Kumar, R., & Stone, D. A. (2017). Heat wave exposure in India in current, 1.5 C, and 2.0 C worlds. *Environmental Research Letters*, 12(12), 124012.
8. Rajeevan, M., Bhate, J., & Jaswal, A. K. (2008). Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophysical Research Letters*, 35(18).
9. Ramamurthy, P., & Bou-Zeid, E. (2017). Heatwaves and urban heat islands: A comparative analysis of multiple cities. *Journal of Geophysical Research*, 122(1), 168–178.
10. Ramamurthy, P., Li, D., & Bou-Zeid, E. (2015). High-resolution simulation of heatwave events in New York City. *Theoretical and Applied Climatology*, 1–14.
11. World Urbanization Prospects 2014. (2014). Demographic Research. https://doi.org/(ST/ESA/SER.A/366)
12. Zhao, L., Lee, X., Smith, R. B., & Oleson, K. (2014). Strong contributions of local background climate to urban heat islands. *Nature*, 511(7508), 216–219.
13. Zhao, L., Oppenheimer, M., Zhu, Q., Baldwin, J. W., Ebi, K. L., Bou-Zeid, E., … Liu, X. (2018). Interactions between urban heat islands and heat waves. *Environmental Research Letters*, 13(3), 034003.