Trend in Temperature: Is July 2021 in Jaipur warmer than average?

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Summary

Global warming is a phenomenon with worldwide impacts and consequences. IPCC and various other internationally reputable organisations have provided evidence in support of warming temperature trends(IPCC 5th assessment report;IPCC 2014:47;NOAA Global climate change indicators,NASA GISTEMPv4)). However, most research on temperature changes are based on large scale measurements of countries,continents and global variations. The present research investigates the trend in temperatures in a single city: Jaipur(26° 55' N 75° 52' E) by analysing temperature variation within a single month (July) as well as the variation in pattern of temperature in July over a period of eleven years using first hand measurements as well as database averages. The findings of this study would help contextualize the variations of temperature within a city to changes of global temperature trend to answer the question: Is July temperature in Jaipur warmer than the average? The results demonstrate a cooling trend in July temperature over the period of eleven years and a cooling pattern of July temperature in 2021. Our work suggests that variation in temperature over a short time period is not definite and without a predictable pattern and the cooling temperature trend calls for further research to assess the implications of anthropogenic aerosols on Indian monsoon and other possible explanations of the observed trends in temperature.

Introduction

According to the IPCC 5th assessment report, warming of the climate system is unequivocal. The IPCC special report on climate change and land also states that the average temperature overland between 2006-2015 was 1.58 ◦C higher than for the period 1850-1900, and 0.66◦C larger than the equivalent global mean temperature change. Additionally, the planet's average surface temperature has risen about 1.18 ◦C since late 19th century(NASA) which was driven largely by carbon dioxide emissions and other anthropogenic activities((IPCC 2014:47);Gaffney and Steffen,2017; Gabriele C Hegerl et al 2019;A. De Matteis,2017)). .As a result of this increase in global temperature,2016 and 2020 are tied for the warmest years on record(NOAA Global climate change indicators,NASA GISTEMPv4, HadCRUT, Global Temperature Dataset))

The IPCC report in 2013 states that "since the 1950s,many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen and the concentration of greenhouse gases have increased" (Watts et al.2015)
The impact of climate change spans from its effect on the earth's biodiversity in terms of species abundances and distributions, habitats and composition and the functioning of the ecosystem(Biodiversity and Climate Change: Transforming the Biosphere;Nunez aet al,2019;ALINY P. F. PIRES ET AL 2018) to adverse effects on urban structures (Gonzalez et al. 2013) by the rise in sea level and intensity of storms (Grimmond et al.2011). Moreover, the increase in temperature due to climate change is also associated with human health losses and these losses are relatively pronounced in poorer countries(Meierrieks,2020). Climate change has led to an increase in prevalence of immunologic diseases and worsended respiratory allergic diseases as well (Katelaris & Beggs 2017;Ray& Ming 2020).

In India, one can expect more extreme rainfalls, longer dry spells,higher sea levels, and more severe heat waves in the future. Climate change will also have a more pronounced effect on India as compared to other countries due to the higher population density,larger spatial and temporal variability of rainfall and more poor people who are susceptible to climate variability(Srinivasan 2019). Moreover, changing climate would also lead to increased frequency and duration of heat stress that has been the cause of thousands of deaths in India in recent years(Rohini et al. 2016) as well as the reduction in irrigated rice yields by 10-15% and wheat yield by 22% by the end of the 21st

Century(Soora et al. 2013; Birthal PS et al.2014). Additionally, there could be adverse impacts generated from extreme events like heat stress and climate related diseases.Diarrhea incidence in North India is projected to rise by 13% by the 2040s(Moors E et al. 2013). Malaria transmission window is also expected to expand in the North and Northeast(Dhiman et al. 2010).

Arid region of western part of India is under threat due to severe droughts, irregularity of rainfall and severe climatic characteristics(Jain et al,2013). Rajasthan, which lies in the Northwestern part of India, also has the maximum probability of occurrence of drought (Mall et al,2006). And as it is predicted by many GCMs(Global Climate Models) the frequency and magnitude of extreme events will be aggravated under climate change in the future (Chen et al,2011. IPCC;2014. Siliverstovs et al,2010). Additionally, Pingale et al,2014 observed both positive and negative trends in mean and extreme events of rainfall and temperature in the urban center of Rajasthan State. The minimum and maximum temperature showed significant increasing warming trends on a seasonal scale in the region. Sharma et al 2017 has also predicted via temperature model for Rajasthan that the average mean temperature for the period of 2011-2040 ie. 26.5 °C would be highest in a region which includes Jaipur, Nagaur, Bikaner, Bans-wara, Jhalawar and Jodhpur.

It can be interpreted from the findings of A. Mathew et al 2018 that there is a continuous increase in land surface temperature of Jaipur city and the gradient between hotspot and area surrounding it is falling ie. more and more areas are experiencing temperatures closer to that of the hotspot. Additionally, according to Chandra et al 2018, there is less change in extreme temperature range but more area increase in mean temperature(30-35 °C).
This research aims to determine the trend in July temperature over the period of 2009 to 2020 in Jaipur and whether the July temperature in 2021 is higher or lower than the average temperature of those years. Moreover, the study will assess whether the 2021 July temperature at 6PM over a period of 16 days will follow the trend of the July temperature over the same period of days from 2009-2020 given that various studies and models (Sharma et al 2017; A. Mathew et al 2018; Chandra et at 2018) have predicted warmer temperatures in the city of Jaipur and the state of Rajasthan. Furthermore, this study will determine the associated consequences and potential solutions to global warming.

Methodology

To compare the July temperature in 2021 to July temperature from 2009-2020, secondary data was collected from Worldweatheronline. For each day in July, the maximum temperature and the minimum temperature of the day was identified. This was then calculated into the average temperature per day in July. The average of the maximum and minimum temperatures of each day in July was calculated and average of these daily measurements were used to create an average temperature for the month of July in each year between 2009 and 2021.Graph of data collected then allowed for comparison between the selected years.

To determine whether temperatures measured at 26°52'07.0"N 75°45'52.5"E at 18:00 from July 14th to 31st are higher or lower than the average temperature at 18.00 from 2009 to 2020, primary data was collected and compared to secondary data from Worldweatheronline. Measurements were taken using a digital thermometer with measurement accuracy of ±1 °c. The reading is taken approximately 2 metres away from any building to minimise the effect of radiation. Moreover, to ensure that the thermometer is not in direct contact with sunlight, frost or rain, the readings were taken in a shaded area. For each reading, the thermometer was allowed to adjust to sudden temperature change for 2 minutes and was kept 5 feet above the ground. Graph of average temperature per day of July 2009 to 2020 was compared to the temperature measured for each day in July 2021.

Results

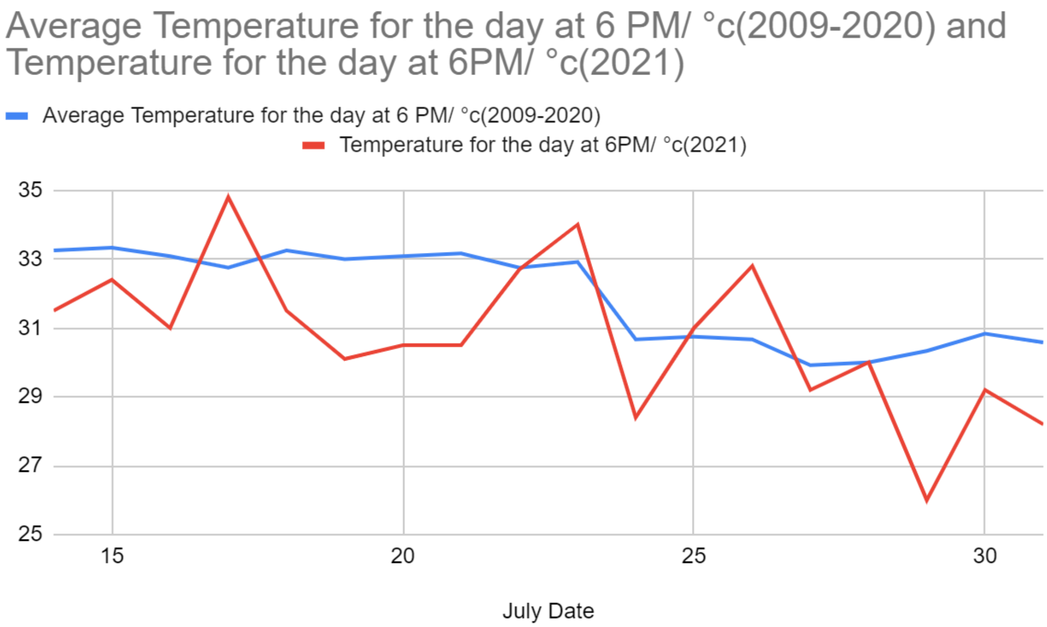


Figure 1.Graph of average July temperature at 6PM from July 14th to 31st(2009-2020) VS Graph of measured temperature at 6PM from July 14th to 31st(2021)

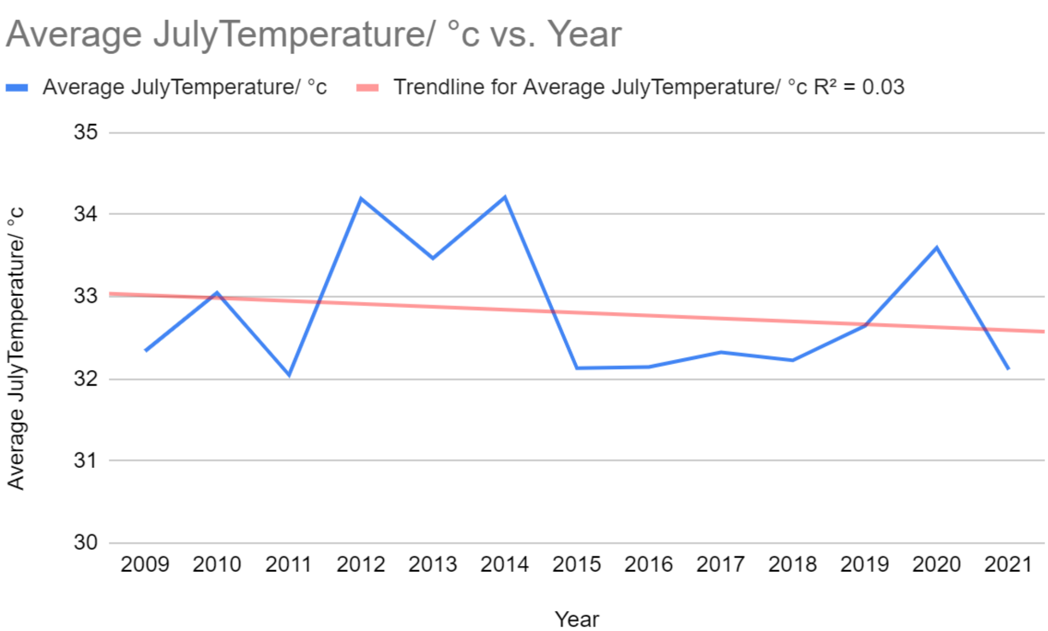
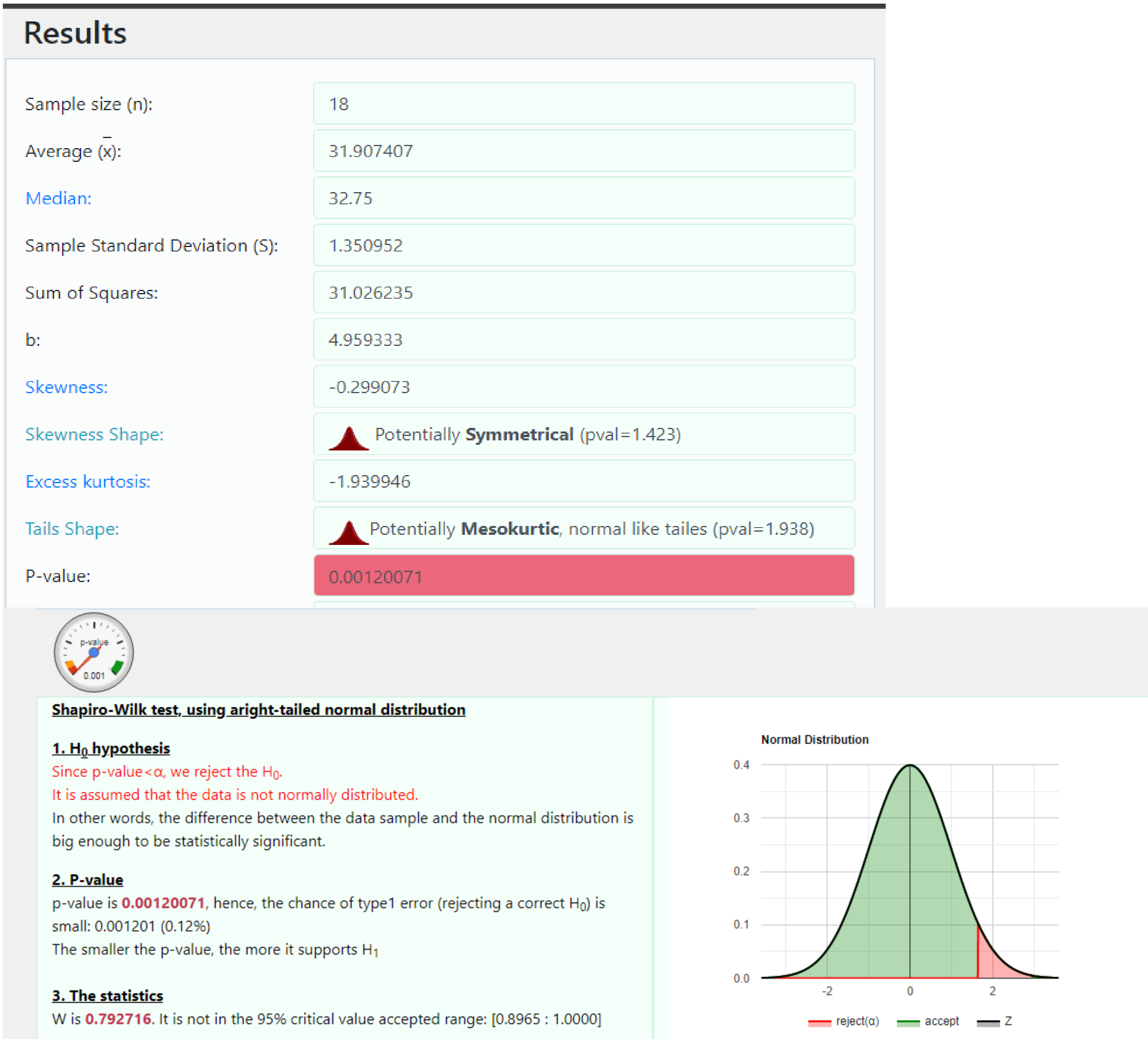


Figure2. Graph of average July temperature from 2019 to 2020

Figure 3. Shapiro-Wilk Test for average July temperature at 6PM from July 14th to 31st(2009-2020)



Results

Sample size (n):	18
Average ($\bar{x}$):	31.907407
Median:	32.75
Sample Standard Deviation (S):	1.350952
Sum of Squares:	31.026235
b:	4.959333
Skewness:	-0.299073
Skewness Shape:	Potentially **Symmetrical** (pval=1.423)
Excess kurtosis:	-1.939946
Tails Shape:	Potentially **Mesokurtic**, normal like tailes (pval=1.938)
P-value:	0.00120071

Shapiro-Wilk test, using aright-tailed normal distribution

1. H_0 hypothesis

Since p-value<α, we reject the H_0.
It is assumed that the data is not normally distributed.
In other words, the difference between the data sample and the normal distribution is big enough to be statistically significant.

2. P-value

p-value is **0.00120071**, hence, the chance of type1 error (rejecting a correct H_0) is small: 0.001201 (0.12%)
The smaller the p-value, the more it supports H_1

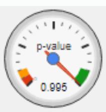
3. The statistics

W is **0.792716**. It is not in the 95% critical value accepted range: [0.8965 : 1.0000]

Figure4. Shapiro-Wilk Test measured temperature at 6PM from July 14th to 31st(2021)

Results

Sample size (n):	18
Average ($\bar{x}$):	30.766667
Median:	30.75
Sample Standard Deviation (S):	2.161699
Sum of Squares:	79.440000
b:	8.856710
Skewness:	-0.175069
Skewness Shape:	Potentially **Symmetrical** (pval=1.256)
Excess kurtosis:	0.288873
Tails Shape:	Potentially **Mesokurtic**, normal like tailes (pval=0.781)
P-value:	0.994978
Outliers:	



Shapiro-Wilk test, using aright-tailed normal distribution

1. H_0 hypothesis

Since p-value > α, we accept the H_0.

It is assumed that the data is normally distributed.

In other words, the difference between the data sample and the normal distribution is not big enough to be statistically significant.

2. P-value

p-value is **0.994978**, hence, if we would reject H_0, the chance of type1 error (rejecting a correct H_0) would be too high: 0.9950 (99.50%)

The larger the p-value, the more it supports H_0

3. The statistics

W is **0.987428**. It is in the 95% critical value accepted range: [0.8965 : 1.0000]

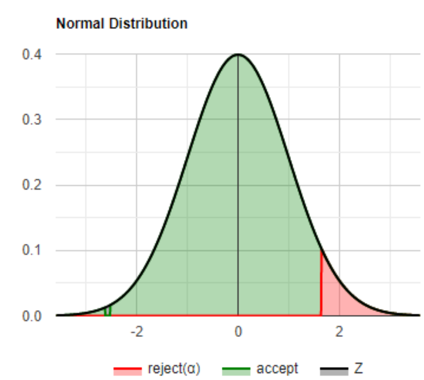


Figure 5. Levene's test

Sample 1 (a)	Sample 2 (b)
33.25	31.5
33.33	32.4
33.08	31
32.75	34.8
33.25	31.5
33	30.1
33.08	30.5
33.17	30.5
32.75	32.7
32.92	34
30.67	28.4
30.75	31
30.67	32.8
29.92	29.2
30	30
30.33	26
30.83	29.2
30.58	28.2

Mean a - a_i (c)	Mean b - b_i (d)	(Mean c - c_i)^2	(Mean d - d_i)^2
1.3428	0.7333	0.0141	0.5303
1.4228	1.6333	0.0015	0.0295
1.1728	0.2333	0.0834	1.5085
0.8428	4.0333	0.3829	6.6141
1.3428	0.7333	0.0141	0.5303
1.0928	0.6667	0.136	0.6318
1.1728	0.2667	0.0834	1.4277
1.2628	0.2667	0.0395	1.4277
0.8428	1.9333	0.3829	0.2226
1.0128	3.2333	0.2014	3.1392
1.2372	2.3667	0.0503	0.8192
1.1572	0.2333	0.0926	1.5085
1.2372	2.0333	0.0503	0.3269
1.9872	1.5667	0.2763	0.0111
1.9072	0.7667	0.1986	0.4829
1.5772	4.7667	0.0134	10.9238
1.0772	1.5667	0.1477	0.0111
1.3272	2.5667	0.018	1.2213

Summary of Data			
	Sample Variances		
	c	*d*	Total
N	18	18	36
∑X	23.0156	29.6	52.6156
Mean	1.2786	1.6444	1.462
$\sum X^2$	31.013	79.44	110.453
Std.Dev.	0.3053	1.3452	0.9791

Result Details				
Source	***SS***	***df***	***MS***	
Between-treatments	1.2043	1	1.2043	*F* = 1.26578
Within-treatments	32.3488	34	0.9514	
Total	33.5531	35		

The *f*-ratio value is 1.26578. The *p*-value is .26844. The result is *not* significant at $p < .05$.

The requirement of homogeneity is met.

Figure 6. Independent T Test

Treatment 1 (X)	*Diff* (X - M)	*Sq. Diff* $(X - M)^2$
33.25	1.34	1.80
33.33	1.42	2.02
33.08	1.17	1.38
32.75	0.84	0.71
33.25	1.34	1.80
33	1.09	1.19
33.08	1.17	1.38
33.17	1.26	1.59
32.75	0.84	0.71
32.92	1.01	1.03
30.67	-1.24	1.53
30.75	-1.16	1.34
30.67	-1.24	1.53
29.92	-1.99	3.95
30	-1.91	3.64
30.33	-1.58	2.49
30.83	-1.08	1.16
30.58	-1.33	1.76
	M: 31.91	SS: 31.01

Treatment 2 (X)	*Diff* (X - M)	*Sq. Diff* $(X - M)^2$
31.5	0.73	0.54
32.4	1.63	2.67
31	0.23	0.05
34.8	4.03	16.27
31.5	0.73	0.54
30.1	-0.67	0.44
30.5	-0.27	0.07
30.5	-0.27	0.07
32.7	1.93	3.74
34	3.23	10.45
28.4	-2.37	5.60
31	0.23	0.05
32.8	2.03	4.13
29.2	-1.57	2.45
30	-0.77	0.59
26	-4.77	22.72
29.2	-1.57	2.45
28.2	-2.57	6.59
	M: 30.77	SS: 79.44

Significance Level:

- ○ .01
- ◉ .05
- ○ .10

One-tailed or two-tailed hypothesis?:

- ◉ One-tailed
- ○ Two-tailed

Difference Scores Calculations

Treatment 1

N_1: 18
$df_1 = N - 1 = 18 - 1 = 17$
M_1: 31.91
SS_1: 31.01
$s^2_1 = SS_1/(N - 1) = 31.01/(18-1) = 1.82$

Treatment 2

N_2: 18
$df_2 = N - 1 = 18 - 1 = 17$
M_2: 30.77
SS_2: 79.44
$s^2_2 = SS_2/(N - 1) = 79.44/(18-1) = 4.67$

T-value Calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((17/34) * 1.82) + ((17/34) * 4.67) = 3.25$

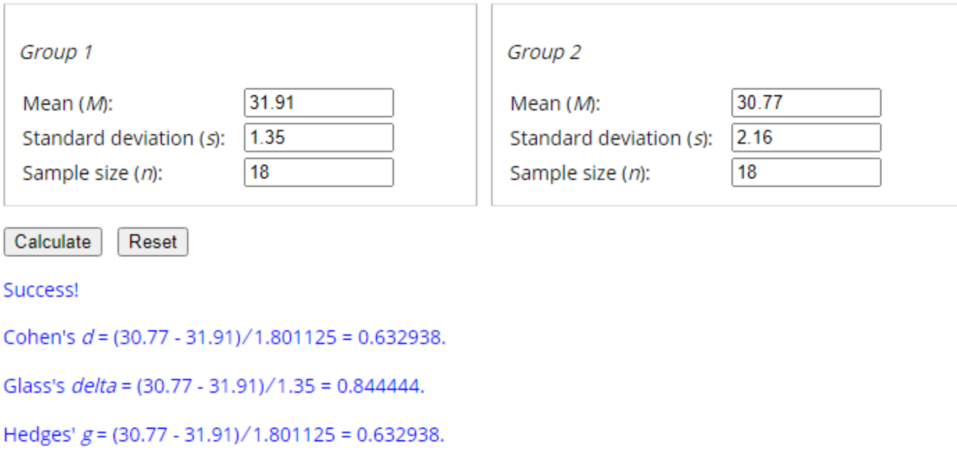
$s^2_{M_1} = s^2_p/N_1 = 3.25/18 = 0.18$
$s^2_{M_2} = s^2_p/N_2 = 3.25/18 = 0.18$

$t = (M_1 - M_2)/\sqrt{(s^2_{M_1} + s^2_{M_2})} = 1.14/\sqrt{0.36} = 1.9$

The *t*-value is 1.8984. The *p*-value is .033079. The result is significant at $p < .05$.

P-value is 0.033079. The result is significant at p< .05

Figure 7. Effect size



Group 1

Mean (*M*): 31.91
Standard deviation (*s*): 1.35
Sample size (*n*): 18

Group 2

Mean (*M*): 30.77
Standard deviation (*s*): 2.16
Sample size (*n*): 18

Calculate Reset

Success!

Cohen's *d* = (30.77 - 31.91)/1.801125 = 0.632938.

Glass's *delta* = (30.77 - 31.91)/1.35 = 0.844444.

Hedges' *g* = (30.77 - 31.91)/1.801125 = 0.632938.

All statistical tests were calculated from Social Science Statistics Calculator

The graph of average temperature at 6PM from July 14th to 31st(2009-2020) VS Graph of measured temperature at 6PM from July 14th to 31st(2021) is shown in Figure 1. Independent T-test was chosen to analyse whether there was a significant difference between the average temperature of 2009-2020 (From July 14th to 31st) and temperature of 2021(From July 14th to 31st) at 6PM. Similar variation in each condition is the most essential criteria for a parametric test and this was shown by Levene's test(Figure 5) that the requirement for homogeneity was met. However, the average temperature of 2009-2020 was not normally distributed(Shown by Shapiro-Wilk Test) in Figure 3 and so this criteria was violated to some extent. Nevertheless since similar variation in each condition is the most essential and other three criterias ie. interval/ratio data, random selection and normal distribution can be violated to some extent (Bowers 2008), the use of parametric independent T-test was justified. The results showed that the p-value is 0.033079. The result is significant at $p< 0.05$ (Figure 6) . This shows that 6PM during 14th to 31st July 2021 is significantly lower than the average July temperature for the day at 6PM from 2009-2020 .

For the average July temperature, there appears to be a slightly decreasing trend in Jaipur. 2012-2014 was warmer than average (Figure 2) while 2012-2014 was cooler than average. However, in the past 11 years in Jaipur, the average July temperature has not shown any significant increase or decrease as shown by the sudden rise and fall in temperature. Although the number of years below the trend line is more than the number of years above the trendline, we are unable to recognise any definite trend.

Discussions

Ross et al. 2018 has documented a pattern consisting of two warming regions over India, one to the northwest and one to the south and a region of reduced warming with greatest magnitude in northeastern India but with an extension southwestward into central India. Despite the IPCC report in 2014 suggested that the warming trend is observed in Northwest and southern India with the greatest warming in the Northwest and several studies has shown that global warming is taking place on the planet(IPCC 5th assessment report, NASA;NOAA Global climate change indicators,NASA GISTEMPv4,HadCRUT Global Temperature Data) the question rises as to why there is an interruption in the temperature trend in India.

Although the warming trend in Northwestern India is notable (beginning in 1970s and accelerated in the 2000s and 2010s) and the maximum temperatures observed during warm pre monsoon season with an accelerating pace particularly in the last two decades, the pattern in India is interrupted by a broad cooling pattern extending from northeast to southwestward of the country(Ross et al,2018; Krishnan et al,2002). Krishnan et al. 2002 has shown that all India surface air temperature from January to May has shown relative cooling by as much as 0.3◦C from the 1950s onwards when global effects of greenhouse gases and natural variability has been filtered out from time series of temperature data. However, the authors in cited study showed that this cooling effect was not observed during the wet season ie. July to September.
Thus, it is unclear as to whether the explanations for the decreasing trend in the temperature cited will be relevant to the findings for the trend in July 2021 temperature at 6PM.

Krishnan et al, 2002 explained that this surface cooling was attributed to anthropogenic emissions over Asian region that produced a large region of brownish haze over most of the North Indian ocean and south Asia. The research further explained that the haze region is composed of aerosol that absorb solar radiation by direct aerosol effect which could reduce surface insolation by about −10 to −30 W/m2 (cooling effect) and increasing absorption in the aerosol layer (0 to 3 km) by about 10 to 30W/m2 (warming effect). With regards to cloudiness, radiation balance by increase in cloudiness through the two aerosol indirect effects has been small compared to the aerosol direct effect (Norris, J.R 2001). Other studies have also supported this trend. Satellite observations from MODIS and MISR for the period of 2001-2013 showed an increasing trend in Aerosol Optical Depth during parts of the year due to increase in anthropogenic activities(Mehta et al.2015). Moreover, MODIS and MISR data for the period of 2001-2014 has observed increasing trends in the economically growing portions of Asian landmass and surrounding oceanic regions(Mehta et al.2016). Krishnan et al 2002 stated that “the climate system could respond by transporting the (heat from) absorbed radiation to regions outside the haze layer and thus warm the surface there. In other words, the region that contributes to the haze will be subject to surface cooling whereas the regions outside could be warming, thus contributing to global warming". Thus, the aerosol cooling effect may provide explanations to the cooling temperature trend in Jaipur from 2009-2021 as urbanisation, growth of factories and transportation increases anthropogenic aerosol emissions during the time period.

However, with regards to 6PM July 2021 temperatures(Figure1), the explanation that anthropogenic aerosol contributed to the decrease in temperature trend in 2021 seems unlikely. During the COVID-19 lockdown in Mumbai particulate matter(PM) reduced and oxides of nitrogen and sulfur sharply declined(Chattopadhyay, A., & Shaw, S. 2021). Moreover, research in other parts of China and India supports that COVID-19 lockdown policies have led to improvements in air quality by reducing Air Quality Index(AQI) (Bao & Chang. 2020). Thus air quality would be expected to improve during 2021 in light of lockdown policies and reduction in transportation would have reduced aerosol levels as well.

Another possible explanation to the cooling trend in Jaipur is the arrival of early monsoon season which could explain the significant cooling trend in 6PM temperature(Figure1). The results of Viswambharan 2018 also showed a contrasting trend in rainfall over India(in heavy, moderate as well as low rainfall regions) in each month of the summer season. And the monthly trend is also not uniform in moderate to low rainfall occurring regions of India. Thus, the variability in rainfall trend and pattern may have led to a significant cooling effect in July 2021.

It is also noteworthy to consider the random variation in temperature trends from year to year. Even with a wide range of models, temperature maps and large databases there are chances that the variation in temperature will be a random occurrence. Hence, taking into account the random variation in temperature,significant cooling trend in July temperatures at 6PM in Jaipur(Figure1) or even the trend in average July temperature in Jaipur from 2009-2021(Figure2) may be simply due to this random variation.

Even though the findings of this study remain inconclusive of the definite trend in temperature in the city of Jaipur, several pieces of evidence have already demonstrated that the 2010s is the hottest decade(Fischer, Sippel & Knutti 2021;Gaworecki, Mike. 2020) and the data obtained was within the range of the hottest decade which is a confirmation that heating in India is continuing as there is no evidence to suggest a reversal in the trend of rising temperature. And according to the IPCC 5th assessment report, warming of the climate system is unequivocal. The impacts of climate change are likely to be a diminishing amount of ice and snow(European Union Climate Action), reduction in biodiversity(Watts et al.2015) and even adverse impacts on urban structures(Grimmond 2011). In terms of human health, climate change could lead to increased prevalence of immunologic diseases and worsening respiratory allergic disease(Meierrieks,2020). The impacts of climate change on deaths from heat stress in India(Rohini et al.2016) and reduction in agricultural yield(Soora et al. 2013) as well as increased in diarrhea (Moors E et al. 2013)and Malaria transmission(Dhiman et al. 2010) has also been well documented.

Future Research

Considering the various factors that influence temperature changes this short-term study could only demonstrate variations in temperatures that might not necessarily be reflective of the long term trend. A larger data set and temperature measurements would allow for more credible findings. In order for this to happen, continuous measurements must be taken. Continuous data obtained may also help reduce random variation in individual measurements. Moreover, since climate change is a long term phenomenon, taking place over many years, documenting temperature over a longer period of years than what was done in this study may provide greater insights into the trend in changing temperature of Jaipur.

It is also noteworthy to consider an investigation into the average temperature trend in other months of the year in Jaipur to find whether there is any definite trend. This would also give a larger context to the findings in this study about the average July temperature in Jaipur from 2009 to 2021. Since the cooling trend was not anticipated, documenting the effects of anthropogenic aerosol on Indian monsoon would also provide insights into the findings of this study. To test the cooling effect of aerosol hypothesis, an apparatus that measures aerosol could be used to compare aerosol variation in air during different days with respect to temperature.

Solutions

Although reductions in atmospheric greenhouse gases ,which contributes to global warming, can be met by: (1) a shift from fossil fuels to renewable energy; (2) improved energy efficiency; (3) carbon capture and storage (CCS) at the point of CO_2 generation; and (4) the protection and enhancement of natural carbon sinks(Griscom et al., 2017; Rockström et al., 2017) there is a need to find solutions that are sustainable long term and contribute to Sustainable development goals(SDG) of the UN concerning human health and well-being, climate action and life on land and on water etc.

Nature based solutions(NbS) is one way to address the impacts of climate change on people. Although most solutions to the impact of climate change on people, built infrastructure and coastal protections have involved engineering solutions, nature based solutions can also be used to complement these approaches(Hobbie & Grimm, 2020; Kapos, Wicander, Salvaterra, Dawkins, & Hicks, 2019; The Royal Society, 2014). Nature based solutions involve measures such as ecosystem based adaptations, ecosystem based disaster reduction, green and blue infrastructure and forest restoration etc (Cohen-Shacham et al., 2016, 2019).Slope vegetation and wetland protection were reported to be more effective at addressing fresh water flooding than engineered approaches such as check dams, artificial water water storage alternatives or buffer tanks(Amini, A., Ghazvinei, P. T., Javan, M., & Saghafian, B. (2014)). Another advantage of NbS is that they can address multiple sustainable development goals simultaneously(Chausson et al. 2020).The study by Chausson et al. 2020 supported that investments in NbS can be beneficial for ecosystems.Chausson et al. 2020 also observed 91 cases in their study that reported ecological outcomes of nature-based interventions in addition to effectiveness in reducing a climate impact.Some of the positive outcomes were increased number of species,functional diversity, or higher plant and animal productivity(e.g., Barsoum et al., 2016; Biel, Hacker, Ruggiero, Cohn, & Seabloom, 2017; Liquete,Udias, Conte, Grizzetti, & Masi, 2016)

With regards to ocean solutions, the restoration of coastal vegetation such as salt marshes, mangroves and seagrasses could enhance carbon sink capacity and help avoid emissions from existing large carbon stocks (Mcleod et al., 2011; Herr and Landis, 2016). Fertilisation which involves artificial increase in the primary production of the ocean and carbon dioxide uptake by phytoplankton in the open ocean could be achieved by adding soluble iron to surface water where it is currently lacking is an additional method(Jean-Pierre et al. 2018). Moreover, alkalinisation, which is the addition of various alkaline substances that consume CO_2 or neutralise ocean acidity(Rau, 2011; Renforth and Henderson, 2017) could be achieved by increasing the concentration of carbonate or hydroxide ions in surface waters. This would shift the chemical equilibrium in seawater to increase the oceanic uptake of CO_2.

References

Pachauri, Rajendra K., Myles R. Allen, Vicente R. Barros, John Broome, Wolfgang Cramer, Renate Christ, John A. Church, et al. “Climate Change 2014 Synthesis REPORT. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.” the UWA Profiles and Research Repository. IPCC, January 1, 1970. https://research-repository.uwa.edu.au/en/publications/climate-change-2014-synthesis-report-contribution-of-working-grou.

“Climate Change and Land.” Special Report on Climate Change and Land. Accessed August 9, 2021. https://www.ipcc.ch/srccl/.

“Climate Change Evidence: How Do We Know?” NASA. NASA, July 28, 2021. https://climate.nasa.gov/evidence/.

Owen Gaffney, Will Steffen. “The Anthropocene Equation - Owen Gaffney, Will Steffen, 2017.” SAGE Journals, February 10, 2017. https://journals.sagepub.com/doi/abs/10.1177/2053019616688022?journalCode=anra.

“IPCC Science REPORT: Climate Change Unequivocal, Human Influence at Least 95% Certain.” Climate Action - European Commission. European Union, November 23, 2016. https://ec.europa.eu/clima/news/articles/news_2013092701_en.

Watts, Nick, W Neil Adger, Paolo Agnolucci, Jason Blackstock, Peter Byass, Wenjia Cai, Sarah Chaytor, et al. “Health and Climate Change: Policy Responses to Protect Public Health.” The Lancet 386, no. 10006 (2015): 1861–1914. https://doi.org/10.1016/s0140-6736(15)60854-6.

Nunez, Sarahi, Eric Arets, Rob Alkemade, Caspar Verwer, and Rik Leemans. “Assessing the Impacts of Climate Change On Biodiversity: Is below 2 °c Enough?” Climatic Change 154, no. 3-4 (2019): 351–65. https://doi.org/10.1007/s10584-019-02420-x.

Lovejoy, Thomas, and Lee Hannah. “Biodiversity and Climate Change.” Transforming the Biosphere, 2019. https://doi.org/10.2307/j.ctv8jnzw1.

Pires, Aliny P., Diane S. Srivastava, Nicholas A. Marino, A. Andrew MacDonald, Marcos Paulo Figueiredo-Barros, and Vinicius F. Farjalla. “Interactive Effects of Climate Change and Biodiversity Loss on Ecosystem Functioning.” Ecology 99, no. 5 (2018): 1203–13. https://doi.org/10.1002/ecy.2202.

González, Ainhoa, Alison Donnelly, Mike Jones, Nektarios Chrysoulakis, and Myriam Lopes. “A Decision-Support System for Sustainable Urban Metabolism in Europe.” Environmental Impact Assessment Review 38 (2013): 109–19. https://doi.org/10.1016/j.eiar.2012.06.007.

Grimmond, C.S. Urban climate in the coastal zone: Resilience to weather extremes. In Pelling, M. (ed.). Megacities and the Coast: Transformation for Resilience, a preliminary review of knowledge, practice and future, Abingdon: Land-Ocean Interactions in the Coastal Zone (LOICZ), pp. 37–42, 2011.

Meierrieks, Daniel. “Weather Shocks, Climate Change and Human Health.”, October 23, 2020. https://doi.org/10.1016/j.worlddev.2020.105228.

Katelaris, C.H. and Beggs, P.J. (2018), Climate change: allergens and allergic diseases. Intern Med J, 48: 129-134. https://doi.org/10.1111/imj.13699

D'Amato G, Annesi-Maesano I, Vaghi A, Cecchi L, D'Amato M. How Do Storms Affect Asthma? Curr Allergy Asthma Rep. 2018 Mar 24;18(4):24. doi: 10.1007/s11882-018-0775-9. PMID: 29574559.

D'Amato G, Cecchi L, D'Amato M, Liccardi G. Urban air pollution and climate change as environmental risk factors of respiratory allergy: an update. J Investig Allergol Clin Immunol. 2010;20(2):95-102; quiz following 102. PMID: 20461963.

Ray, Carly, and Xue Ming. 2020. "Climate Change and Human Health: A Review of Allergies, Autoimmunity and the Microbiome" International Journal of Environmental Research and Public Health 17, no. 13: 4814. https://doi.org/10.3390/ijerph17134814

Soora NK, Aggarwal PK, Saxena R, Rani S, Jain S, Chauhan N. 2013. An assessment of regional vulnerability of rice to climate change in India. Clim. Change 118(3–4):683–99

Birthal PS, Khan T, Negi DS, Agarwal S. 2014. Impact of climate change on yields of major food crops in India: implications for food security. Agric. Econ. Res. Rev. 27(2):145–55

Moors E, Singh T, Siderius C, Balakrishnan S, Mishra A. 2013. Climate change and waterborne diarrhoea in northern India: impacts and adaptation strategies. Sci. Total Environ. 468–69:S139–51

Dhiman RC, Pahwa S, Dhillon GPS, Dash AP. 2010. Climate change and threat of vector-borne diseases in India: Are we prepared? Parasitol. Res. 106(4):763–73

Srinivasan, J. "Impact of Climate Change on India." India in a Warming World: Integrating Climate Change and Development. : Oxford University Press, 19. Oxford Scholarship Online. Date Accessed 24 Jul. 2021

Dubash, Navroz K. "An Introduction to India’s Evolving Climate Change Debate: From Diplomatic Insulation to Policy Integration." In India in a Warming World: Integrating Climate Change and Development, edited by Navroz K. Dubash. Delhi: Oxford University Press, 2019. Oxford Scholarship Online, 2019. doi: 10.1093/oso/9780199498734.003.0001.

Rohini, P., M. Rajeevan, and A.K. Srivastava. 2016. ‘On the Variability and Increasing Trends of Heat Waves over India’, Nature Scientific Reports, 6(26153). Available at http://dx.doi.org/10.1038/srep26153.

Mall, R. K., Akhilesh Gupta, Ranjeet Singh, R. S. Singh, and L. S. Rathore. "Water Resources and Climate Change: An Indian Perspective." <i>Current Science</i> 90, no. 12 (2006): 1610-626. Accessed August 22, 2021. http://www.jstor.org/stable/24091910.

Chen, J., F. P. Brissette, A. Poulin, and R. Leconte (2011), Overall uncertainty study of the hydrological impacts of climate change for a Canadian watershed, Water Resour. Res., 47, W12509, doi:10.1029/2011WR010602

Jie Chen, François P. Brissette, Robert Leconte,Uncertainty of downscaling method in quantifying the impact of climate change on hydrology,Journal of Hydrology, Volume 401, Issues 3–4,2011,Pages 190-202, ISSN 0022-1694,https://doi.org/10.1016/j.jhydrol.2011.02.020. (https://www.sciencedirect.com/science/article/pii/S0022169411001351)

Core Writing Team, R.K. Pachauri, L.A. Meyer (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the 5th AR of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland (2014), p. 57

P. P. Dabral & Mharhoni Z. Murry. “Modelling and Forecasting of Rainfall Time Series Using SARIMA.” SpringerLink, May 10, 2017. https://link.springer.com/article/10.1007/s40710-017-0226-y.

Jain, Sharad & Kumar, Vijay & Saharia, Manabendra. (2013). Analysis of Rainfall and Temperature Trends in Northeast India. International Journal of Climatology. 33. 10.1002/joc.3483.

Santosh M. Pingale, Deepak Khare, Mahesh K. Jat, Jan Adamowski,Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India,Atmospheric Research,Volume 138,2014,Pages 73-90, ISSN 0169-8095,https://doi.org/10.1016/j.atmosres.2013.10.024.(https://www.sciencedirect.com/science/article/pii/S0169809513003116)

Aditya Sharma, Devesh Sharma, S.K. Panda, Swatantra Kumar Dubey, Rajani K. Pradhan, Investigation of temperature and its indices under climate change scenarios over different regions of Rajasthan state in India,Global and Planetary Change,Volume

161,2018,Pages 82-96,ISSN 09218181,https://doi.org/10.1016/j.gloplacha.2017.12.008.(https://www.sciencedirect.com/science/article/pii/S0921818117302849)

Aneesh Mathew, Sumit Khandelwal, Nivedita Kaul,Investigating spatio-temporal surface urban heat island growth over Jaipur city using geospatial techniques,Sustainable Cities and Society,Volume 40,2018,Pages 484-500,ISSN 22106707,https://doi.org/10.1016/j.scs.2018.04.018.(https://www.sciencedirect.com/science/article/pii/S2210670717310867)

Chandra, S., Sharma, D. & Dubey, S.K. Linkage of urban expansion and land surface temperature using geospatial techniques for Jaipur City, India. Arab J Geosci 11, 31 (2018). https://doi.org/10.1007/s12517-017-3357-6

Seema Jalan, Kavita Sharma. "SPATIO-TEMPORAL ASSESSMENT OF LAND USE/ LAND COVER DYNAMICS AND URBAN HEAT ISLAND OF JAIPUR CITY USING SATELLITE DATA." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8, 2014 ISPRS Technical Commission VIII Symposium, 09 – 12 December 2014, Hyderabad, India, December 2014. https://pdfs.semanticscholar.org/90dc/918dea3b3b9a244ebd17a29c3352212e7408.pdf.

Ross RS, Krishnamurti TN, Pattnaik S, Pai DS. Decadal surface temperature trends in India based on a new high-resolution data set. Sci Rep. 2018 May 10;8(1):7452. doi: 10.1038/s41598-018-25347-2. PMID: 29748548; PMCID: PMC5945614.

PCC Climate Change Synthesis Report. Contribution of Working Groups I, II and III to the Fifh Assessment Report of the Intergovernmental Panel on Climate Change [(eds) Core Writing Team, Pachauri, R. K. & Meyer, L. A.]. 151 (IPCC, Geneva, Switzerland, 2014).

Krishnan, R. & Ramanathan, V. Evidence of surface cooling from absorbing aerosols. Geophys. Res. Lett. 29(9), 1340, https://doi. org/10.1029/2002GL014687 (2002).

Twomey, S. Pollution and the planetary albedo. Atmos. Environ. 8(12), 1251–6 Bibcode:1974AtmEn.8.1251T https://doi. org/10.1016/0004-6981(74)90004-3 (1974).

Albrecht, B. A. Aerosols, cloud microphysics, and fractional cloudiness. Science 245, 1227–1230 (1989)

Norris, J. R. Has Northern Indian Ocean cloud cover changed due to increasing anthropogenic aerosol? Geophys. Res. Lett. 28, 3271–3274 (2001).

Mehta, M. A study of aerosol optical depth variations over the Indian region using thirteen years (2001–2013) of MODIS and MISR Level 3 data. Atmos. Environ. 109, 161–170 (2015).

Mehta, M., Singh, R., Singh, A., Singh, N. & Anshumali. Recent global aerosol optical depth variations and trends: A comparative study using MODIS and MISR Level 3 data sets. Remote Sens. Environ. 181, 137–150 (2016).

Krishnan, R. & Ramanathan, V. Evidence of surface cooling from absorbing aerosols. Geophys. Res. Lett. 29(9), 1340, https://doi. org/10.1029/2002GL014687 (2002).

Chattopadhyay, A., & Shaw, S. (2021). Association between air pollution and COVID-19 pandemic: An investigation in Mumbai, India. GeoHealth, 5, e2021GH000383. https://doi.org/10.1029/2021GH000383

Gaworecki, Mike. 2020. 2019 was second-hottest year on record, 2010s hottest decade. Mongabay News [BLOG] (Jan 15), https://www.proquest.com/blogs-podcasts-websites/2019-was-second-hottest-year-on-record-2010s/docview/2338491269/se-2?accountid=8268 (accessed August 8, 2021).

"Nine of the Ten Hottest Years on Record All in the Last Decade." UNEP Global EnvironmentalAlert Service. UNEP, April 2011.http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.684.3290&rep=rep1&type=pdf.

Fischer, E.M., Sippel, S. & Knutti, R. Increasing probability of record-shattering climate extremes. Nat. Clim. Chang. 11, 689–695 (2021). https://doi.org/10.1038/s41558-021-01092-9

Deng, Boer. "2014 Was the Hottest Year on Record." Nature News. January 7, 2015. https://www.nature.com/articles/nature.2015.16674.pdf?origin=ppub.

Tollefson, Jeff. 2015 Breaks Heat Record. January 28, 2016. https://www.nature.com/articles/nature.2016.19216.pdf.

Amini, A., Ghazvinei, P. T., Javan, M., & Saghafian, B. (2014). Evaluating the impacts of watershed management on runoff storage and peak flow in Gav-Darreh watershed, Kurdistan, Iran. Arabian Journal of Geosciences, 7(8), 3271–3279. https://doi.org/10.1007/s1251 7-013-0950-1

Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. Philosophical Transactions of the Royal Society B: Biological Sciences, 375(1794), 20190124. https:// doi.org/10.1098/rstb.2019.0124

Kapos, V., Wicander, S., Salvaterra, T., Dawkins, K., & Hicks, C. (2019). The role of the natural environment in adaptation, background paper for the global commission on adaptation. Rotterdam, The Netherlands and Washington, DC: Global Commission on Adaptation.
The Royal Society. (2014). Resilience to extreme weather. London, UK: The Royal Society.
Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., … Walters, G. (2019). Core principles for successfully implementing and upscaling nature-based solutions. Environmental Science & Policy, 98, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014 Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. Gland, Switzerland: IUCN, 97 pp.
Chausson A, Turner B, Seddon D, Chabaneix N, Girardin CAJ, Kapos V, Key I, Roe D, Smith A, Woroniecki S, Seddon N. Mapping the effectiveness of nature-based solutions for climate change adaptation. Glob Chang Biol. 2020 Nov;26(11):6134-6155. doi: 10.1111/gcb.15310. Epub 2020 Sep 9. PMID: 32906226.
Barsoum, N., Coote, L., Eycott, A., Fuller, L., Kiewitt, A., & Davies, R. (2016). Diversity, functional structure and functional redundancy of woodland plant communities: How do mixed tree species plantations compare with monocultures? Forest Ecology and Management, 382, 244–256. https://doi.org/10.1016/j.foreco.2016.10.005
Biel, R. G., Hacker, S. D., Ruggiero, P., Cohn, N., & Seabloom, E. W. (2017). Coastal protection and conservation on sandy beaches and dunes: Context-dependent tradeoffs in ecosystem service supply. Ecosphere, 8(4), e01791. https://doi.org/10.1002/ecs2.1791
Liquete, C., Udias, A., Conte, G., Grizzetti, B., & Masi, F. (2016). Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. Ecosystem Services, 22, 392–401. https://doi.org/10.1016/j.ecoser.2016.09.011
Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., et al. (2017). Natural climate solutions. Proc. Natl. Acad. Sci. U.S.A. 114, 11645–11650. doi: 10.1073/pnas.1710465114
Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., and Schellnhuber, H. J. (2017). A roadmap for rapid decarbonization. Science 355, 1269–1271. doi: 10.1126/science.aah3443
Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Front. Ecol. Environ. 9:552–560. doi: 10.1890/110004
Herr, D., and Landis, E. (2016). Coastal Blue Carbon Ecosystems. Opportunities for Nationally Determined Contributions. Policy Brief. Gland: International Union for the Conservation of Nature, 28.

Rau, G. H. (2011). CO_2 mitigation via capture and chemical conversion in seawater. Environ. Sci. Technol. 45, 1088–1092. doi: 10.1021/es102671x
Renforth, P., and Henderson, G. (2017). Assessing ocean alkalinity for carbon sequestration. Rev. Geophys. 55, 636–674. doi: 10.1002/2016RG000533