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The future of decent work: Forecasting heat stress and the intersection of sustainable development challenges in India's brick kilns

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Abstract

The impacts of climate change-induced heat stress on workers are most prevalent in sectors with decent work deficits and this requires consideration for sustainable development. This paper focuses on the informal economy of brick kilns in India, a sector reliant on piece-rate payments to its migrant labour force. We forecast to 2050, through satellite mapping and climate modelling, the number of days with extreme heat, loss of labour capacity, and impact on annual brick production. The high spatial coincidence shown between kiln density and intensity of increase in the number of days of extreme heat, leading to a reduction in labour capacity and brick production, has implications for workers and supply chains. We suggest that as kilns, objects of sustainable development goal intersectionality, become more environmentally sustainable, monitored and regulated, labour, and health conditions should improve and adapting to decent work in the face of climate change becomes more achievable.

KEYWORDS

brick production, climate change, climate modelling, decent work, heat stress, labour capacity, occupational safety and health (OSH), SDG intersectionality

1 | INTRODUCTION

It is estimated that almost half of the global population is exposed to high heat episodes resulting from climate change, including an estimated 1 billion workers (Ebi et al., 2021). Those workers with livelihoods consisting of outside manual labour are at greater risk to high heat exposure. High heat leads to physiological stress (where the body's internal regulation mechanisms are no longer capable of maintaining body temperature at a level required for normal functioning—ILO, 2019); impacting physical and mental health, productivity and capacity, and social well-being (Casanueva et al., 2020; Crowe et al., 2010; Kjellstrom et al., 2009; Kjellstrom & Crowe, 2011; Pörtner et al., 2022; Shayegh & Dasgupta, 2022). Vulnerability to this collective stress due to heat (known henceforth as heat stress) is dependent on factors such as age, gender, behavioural characteristics, geographies, timing, length of exposure, as well as the type of work (Parsons et al., 2021). It is predicted that economic losses due to extreme heat are likely to result in global GDP losses of 2.4 billion (USD) by 2030 (ILO, 2019). Given continued rising temperatures and the forecast of longer, more frequent, and more intense extreme heat events, understanding variability in vulnerability is important for establishing suitable frameworks for the protection of workers from heat stress.

Heat stress is now considered by the International Labour Organisation (ILO, 2019) as an Occupational Safety and Health (OSH) hazard. Consideration of heat stress is increasingly featured in frameworks for decent work—defined by the UN Committee on Economic, Social and Cultural Rights (CESCR) as "work that respects the fundamental rights of the human person as well as the rights of workers in terms of conditions of work safety and remuneration…. provides an income allowing workers to support themselves and their families…. respect[s]…the physical and mental integrity of the worker in the exercise of his/her employment" (CESCR, 2006; Garcia Lozano et al., 2022), and within the ILO's Decent Work Agenda as "productive work for women and men in conditions of freedom, equity, security and human dignity" (2012b: v; ILO, 2013). There remains no internationally accepted threshold for extreme heat for any industry (Cheung et al., 2016); nor a standardised and uniformly adopted heat stress index to assess extreme heat's physical effects on outdoor workers. However, a range of indicators may be used, including environmental conditions (e.g., air temperature, humidity, and sunlight), metrics of environmental conditions (e.g., Wet-Bulb Globe Temperature, Universal Thermal Climate Index) and metabolic indicators (e.g., body heat produced by workers based on the physical activity or workload required) (Tustin et al., 2018).

Those who cannot respond to climate change most directly feel its impacts, both individually (Humphreys et al., 2022; O'Brien et al., 2015) and economically (Kotz et al., 2024). Heat stress is more prevalent in countries with decent work deficits (Jacobs et al., 2019). Defined by the ILO, "decent work deficits take the form of underemployment, poor quality and unproductive jobs, unsafe work and insecure income, rights that are denied, and gender inequality" (ILO, 2006). Decent work deficits that may be exacerbated by heat stress include forms of work reliant on piece-rate payments, such as in the agricultural sector. In turn, the worsening of decent work deficits has implications for development trajectories of many low- and middle-income countries (LMIC) and their efforts to achieve the UN sustainable development goals (Birkmann, Jamshed, et al., 2022; Birkmann, Liwenga, et al., 2022).

Much of the extant research has focused on OSH implications of heat stress upon worker productivity, and the predicted effects of climate change (Dahl & Licker, 2021; Fenske & Pinkerton, 2021; Hanna et al., 2011; Kjellstrom et al., 2009; Varghese et al., 2018). When used to inform practical changes for workforces, this often results in individualistic adaptive behavioural strategies such as increasing rest or water breaks, shifting working hours to cooler times of the day, and reducing working hours during extreme heat (Kjellstrom et al., 2009; Kjellstrom & Crowe, 2011). However, more precarious remuneration practices common in outdoor work (e.g., piece-rate payments) may incentivise workers to not adopt these recommendations; to overwork; or to adopt new but equally unsafe practices, reducing the intended impacts of these adaptive strategies (Kjellstrom & Crowe, 2011). Other strategies emphasising access to training, heat management procedures and other protective measures tend to be unavailable. Far less common are attempts to understand the effects of heat stress on workers using a rights-based approach that considers workers' fundamental human and labour rights. A re-framing of the discussion about heat stress to focus on worker rights rather than labour productivity may help to facilitate greater worker agency in negotiating heat-related elements of their employment conditions.

This shift from a labour productivity focus to a worker protection and development rights focus has previously been raised by Lundgren-Kownacki et al. (2018) and Kubasiewicz et al. (2023) in the context of the Indian brick industry. Workers in India's brick kilns have been largely ignored, but their situation is analogous to the more commonly discussed agricultural, construction and mining workers who are most affected by loss of productivity (ILO, 2019). The nexus of environmental degradation and human precariousness that characterises the Indian brick making industry will continue to intensify as global temperatures increase. Anthropogenic climate change is driving heat stress, and one of the largest climate change contributors domestically in India is the brick kiln industry. Poor working conditions are leading to environmental degradation and perpetuating a cycle of indecent work (Brickell et al., 2018; Decker Sparks et al., 2021; Jackson et al., 2021, 2024).

India is the second-largest producer of bricks globally, manufacturing approximately 240–260 billion bricks annually and employing around 10 million workers in a manual production system (Kamyotra, 2015; Siddaiah et al., 2018). Traditional outdoor techniques for brick making are still used across India. Working conditions are harsh and the work is precarious as kilns operate only during the dry season, starting between October and January and lasting until June (Anti-Slavery International, 2017; Misra et al., 2020; Roy & Khanduri, 2018). Most workers are seasonal domestic migrants from lower castes, and agricultural backgrounds, pushed into the brick kiln industry due to the lack of viable land in their villages during the dry season, exacerbated by increased temperatures due to climate change (Maithel & Heierli, 2008). Intersecting with this existing precarity for seasonal migrant workers is the possible intensification of precipitation with global warming (Ombadi et al., 2023). Scarcity of work and the resulting risks of poverty means workers may accept offers of work with poor living and working conditions, and no written contracts, including conditions of heat exposure over which they cannot negotiate (Dodman et al., 2023; Zakar et al., 2015). As predominantly migrants, kiln workers also often lack access to state welfare provisions and labour protections.

India is already at high risk of excessive heat (Das & Umamahesh, 2022). In many places, the maximum temperatures already exceed 40°C on occasion. An additional 3–5°C will make outdoor physical work very difficult during the hottest periods (Kjellstrom et al., 2009; Venugopal et al., 2016). As the brick-making industry is traditionally unregulated with a large proportion of kilns not registered for production (Siddaiah et al., 2018), this may tempt kiln owners to push workers and the natural environment simultaneously to maintain production levels. For example, the combustion process of brick making produces carbon monoxide (CO), particulate matter (PM) and sulphur dioxide (SO_2) (Bhanarkar et al., 2002). Brick making accounts for 9% of black carbon emissions in India (Das &

Umamahesh, 2022; Office of International and Tribal Affairs, 2012) and uses an estimated 35 million tonnes of coal annually (Maheshwari & Jain, 2017). Due to the toxicity levels produced, brick making is one of the most polluting industries (Seay et al., 2021). The sector is also highly inefficient, with the same polluting technology requiring high amounts of manual labour (Raju & Kumar, 2015). Yet, the situation on air pollution is changing rapidly. Traditionally used Fixed Chimney Bulls Trench Kilns (FCBTK) are being replaced with Zig-Zag technology driven kilns, affording efficient manoeuvre of the air for heating purposes. Further, only approved fuel (e.g., coal, firewood and/or agricultural residues) are to be used, reducing the use of petroleum coke, tyres, plastic and hazardous waste. Any newly established kilns are mandated to use piped natural gas and be registered with their respective state governments.

In addition to heat and pollutant exposure, the furnaces themselves are another hazard, as workers experience high radiant heat from the kilns, which reach temperatures up to 1000°C, in addition to the extreme outdoor temperatures increasingly experienced in India (Lundgren-Kownacki et al., 2018). The combined effect of kiln heat exposure with outdoor temperatures affects both workers (e.g., personal OSH risks including dea'th) and value chains (e.g., worker productivity). This is particularly relevant to labourers in northern India, which currently averages at least five to six heatwaves a year (Kumar & Sharma, 2021), with global temperatures in 2023 breaking all records and India experiencing its second hottest year (Climate Change Service, 2024). Climate change-induced heatwave projections for India up to the end of the century show more intense, frequent and longer duration heatwaves, with previously unaffected regions in the south, northeast and west affected (Das & Umamahesh, 2022). Further, an increase of severe heat waves is projected to be unavoidable for northern India during the pre-monsoon season of March to July by 2100 (Murari et al., 2015). Outdoor workers in northern India are at highest risk of heat stress in June (Kumar & Sharma, 2021); during the brick production season. As a result, there is a need to understand how heat extremes will differ across different types of brick kilns, the effects on labour capacity and productivity, and the resultant implications for decent work. This need is amplified in the case of unregulated kilns.

A holistic approach is required to achieve this understanding of the vulnerabilities of brick kiln workers. Knowledge of which workers need protection—the where and when—is the first step in developing a framework for the generation of climate change adaptations under a decent work approach. In a significant step forward, this study aims to measure the future risk of heat stress in the brick kilns in India with three different indicators derived from the wet bulb globe temperature (WBGT): the number of days with extreme heat; loss of labour capacity; and impact on annual brick production. It does so across all of India, at scales never previously possible, to 2050. Using these data analyses and knowledge of current working conditions of those in brick kilns, the paper discusses possible trade-offs and complexities of climate change adaptation strategies in the context of an industry where decent work is not the norm and so where workers may have to choose getting paid (on a piece rate basis) and resting, for example.

This new understanding of how kilns will be impacted by climate change in the context of workers' heat stress vulnerabilities and the decent work agenda should be of interest to India's government, kiln owners, businesses that source bricks from India, and the ILO.

2 | METHODS

2.1 | Mapping kiln location and type

Boyd et al. (2021) established a methodology for estimating both the number of brick kilns and their locations using satellite Earth observation (EO) data captured across 2017/18. A convolutional neural network (CNN) was used to detect every brick kiln present in very high-resolution (VHR) satellite EO data across the 1.5 million km^2 area known as the Brick Belt, which includes northern Indian states (Boyd et al., 2018; Boyd et al., 2021; Foody et al., 2019). Key features of brick kilns used as part of the machine-learning approach adopted related to their size and shape (Nazir et al., 2020). They refer to brick kilns as "objects of UN SDG intersectionality" due to the number of negative externalities associated with brick kilns (i.e., sites of reported labour exploitation and non-decent work (SDGs 5.2 and 8.7); environmental impacts (SDG 12.2) and health issues (SDG 3.9)) and recommend using EO data to update mapping as required. For this pan-India study we adapted and extended the methodology, training the CNN to identify kiln type, in addition to location. Specifically, each brick kiln as seen in 2020 VHR Airbus (Neo)Pleiades and Maxar WorldView satellite data covering the whole of India (3.287 million km^2) was geolocated and classified according to two kiln types—the FCBTK and Zig-Zag kilns. Zig-Zag kilns are an improved version of the FCBTK—with lower energy consumption and savings on energy cost, better environmental performance and produce a higher percentage of class-I bricks (Yadav et al., 2019). After a period of consultation, in 2017 the Indian Pollution Control Board ordered all existing kilns to instal Zig-Zag technology (Kumar, 2017), but it is thought conversion has not been universally adopted (Kamyotra, 2015). Our mapping provides insight into uptake of the new technology.

In total 48,219 brick kilns were mapped with an overall accuracy of 96.3%. Where there was uncertainty in the classification it was assumed the kiln was still using FCBTK technology. The mapping was used to underpin climate and climate change modelling to estimate impacts of heat stress on kiln workers. Since brick production is seasonal (to avoid the monsoon) (Misra et al., 2020; Roy & Khanduri, 2018), findings tend to be for a brick production year of 7 months from December to June (212 days) instead of a full year (although heat stress indicators are calculated annually).

2.2 | Spatio-temporal patterns of climate (WBGT) in India to 2050

The WBGT is used in international and national standards for evaluating occupational heat stress exposure, thus is the most used indicator

TABLE 1 List of bias-adjusted general circulation models (GCMs) used in the modelling. Based on climate from ISIMIP3b.

GCM	Institute
1. GFDL_ESM4	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA
2. IPSL-CM6a_LR	Institut Pierre Simon Laplace, Paris 75,252, France
3. MPI-ESM1-2-HR	Max Planck Institute for Meteorology, Hamburg 20,146, Germany
4. MRI-ESM2-0	Meteorological Research Institute, Tsukuba, Ibaraki 305–0052, Japan
5. UKESM1-0-II	Met Office Hadley Centre, Fitzroy Road, Exeter, Devon, EX1 3 PB, UK

of occupational heat-stress in industry (Clusiault et al., 2022). The WBGT index is influenced by the environmental conditions of dry-bulb temperature, radiant heat, air movement, and relative humidity—the four basic elements of the thermal environment (Budd, 2008). Both the International Organisation for Standardisation (ISO) and the American Conference of Governmental Industrial Hygienists (ACGIH) provide adjustment constants for WBGT to account for the clothing worn and the metabolic rate of specific working conditions.

We use bias-adjusted, spatially downscaled global climate model (GCM) data from phase 3b of the Intersectoral Impact Model Intercomparison Project (ISIMIP3b; Lange, 2019; Lange & Büchner, 2021) to estimate thermal climate and its change across India for two reference periods: 1985–2014 and 2021–2050. We considered three future greenhouse gas scenarios consistent with the shared socioeconomic pathways (SSP) (Riahi et al., 2017): SSP-126, SSP-370 and SSP-585. Daily mean air temperature, maximum air temperature, relative humidity, wind speed and downwelling shortwave radiation, for five GCMs (Table 1), at 0.5° horizontal spatial resolution, was used to calculate the WBGT for each GCM cell. This affords the assessment of the thermal climate of India at resolutions meaningful to brick kiln distributions across the country, and its change over time.

Calculating the density of brick kilns across the corresponding 0.5° GCM grid cells produced climate statistics for 1122 cells across the landscape of India. The Indo-Gangetic plains of the north have much higher densities than the rest of India (Figure 1a,b). Figure 1c,d also displays the productivity of these mapped kilns—both by subdivision and cells—which is important for India's continuing economic growth (see Section 2.3: Thermal climate change impact assessment for details).

2.3 | Thermal climate change impact assessment

Using the simulated climate for each of the 702 cells containing a brick kiln (the distribution of kilns follows resource requirements, such as clay and water), across the five GCMs and the three SSPs, three inter-related measures were calculated: (i) the number of days with extreme heat; (ii) loss of labour capacity and (iii) annual brick production. These were calculated to establish the possible impacts (direct and indirect) of climatically driven heat stress on brick kiln workers across India.

Internationally heat stress exposure thresholds for outdoor workers are commonly based on the WBGT, being adopted by both researchers and several international bodies, including the ISO (Dash & Kjellstrom, 2011; Lundgren-Kownacki et al., 2018). Days with extreme heat are defined by 1 day or more extended periods when WBGT is higher than an established threshold between 30 (Tuholske et al., 2021) and 34°C (Andrews et al., 2018). Human physiology encompasses both physiological and behavioural responses that sustain a reasonable core body temperature (CBT) that ranges from 35 to 40 °C despite being exposed to a broad range of ambient temperatures (Karthick et al., 2023). We established multiple limits on extreme heat ranging from 30 (moderate) to 34°C (extreme) to measure the sensitivity of the threshold concerning the number of days with extreme heat. Moreover, we used 30 and 34°C as thresholds to establish the categories of heat stress according to the frequency and intensity of days with WBGT above the ISO 7243 threshold limit values (TLV); these categories allow for definition of adaptations to each condition.

The ISO 7243 TLV was also used to establish the maximum time that can be worked under certain heat conditions. Working above the TLVs has adverse effects on the worker's health (Matthews et al., 2017), and thus is negatively related to labour productivity and capacity (Dunne et al., 2013). This analysis uses the HeatStress package (Casanueva, 2019; Casanueva et al., 2020), developed in the framework of the Horizon2020 HEAT-SHIELD project, with an average from three WBGT methods (using monthly and annual means): Stull (2011), Bernard (1999) and Liljegren et al. (2008). Equation (1) was used to estimate the number of working hours available based on the WBGT and the intensity of the physical activity (Dunne et al., 2013). Additionally, a similar function was built (Equation 2) using a TLV associated with acclimatised workers with very heavy work (general situation of workers in brick kilns). Both functions, integrated with the actual brick production, were used to determine productivity change due to heat stress impacting the calculated labour capacity.

$$\text{labour}_{\text{capacity}}(\text{LC}) = 100 - 25 \times \max(0, \text{WBGT} - 25)^{\frac{2}{3}}, \quad (1)$$

$$\text{labour}_{\text{capacity}}(\text{LC}) = 100 - 26 \times \max(0, \text{WBGT} - 26)^{0.6478}. \quad (2)$$

To understand the effect of the modelled WBGT climate change outputs and change in labour capacity on total brick production across India, we estimated the annual brick production in 2020 using the same VHR EO satellite data from the kiln mapping. The size of each kiln was measured and used as a proxy for production capacity. First, a random sample of brick kilns ($n = 678$) was used to establish a linear relationship between the perimeter and the trench width, which is often used to estimate the daily production (this was, 47 ± 5 m of

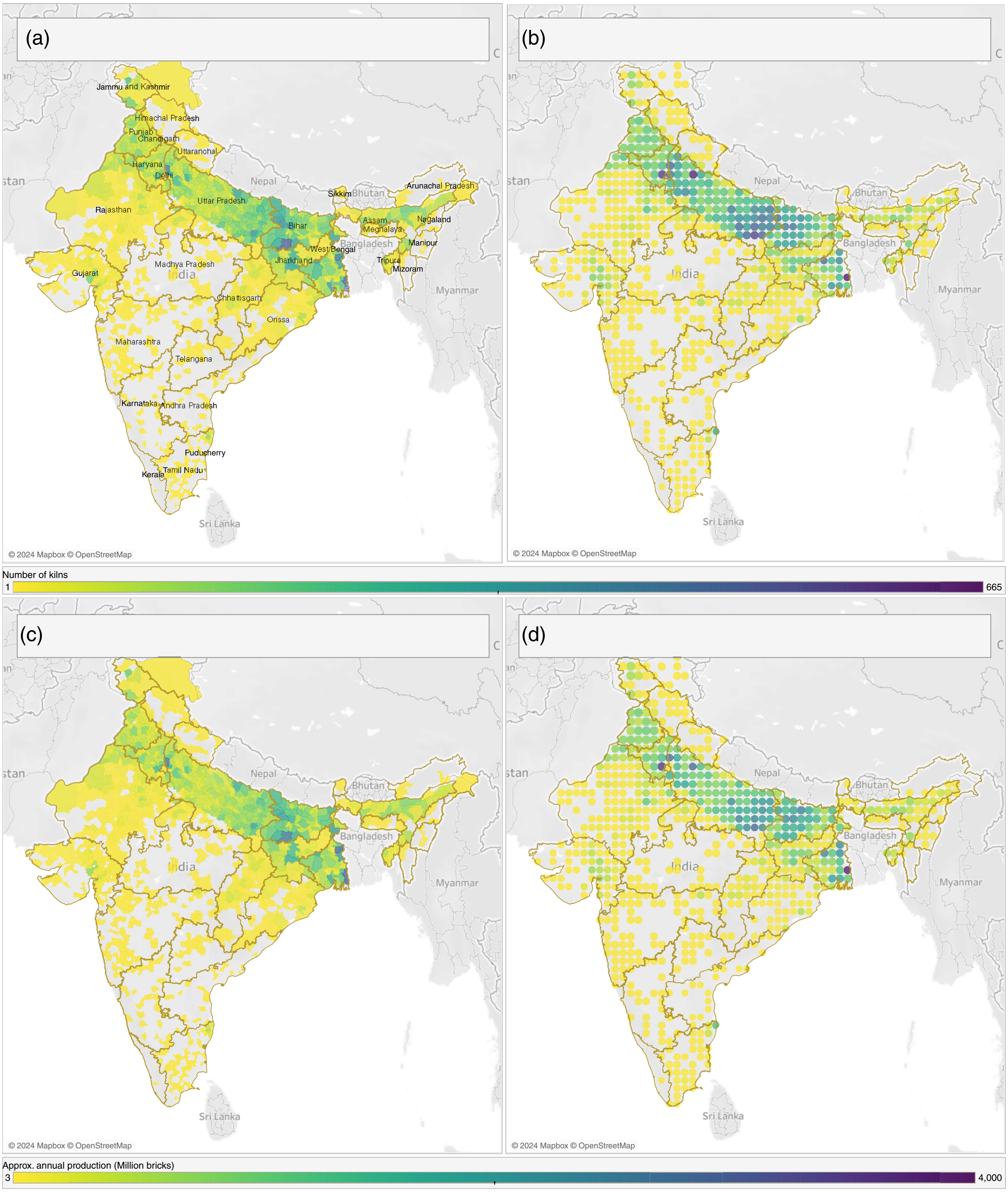

FIGURE 1 (a) Location of brick kilns in India by sub-division (admin level 3); (b) Location of brick kilns in India mapped as density of brick kilns in India at grid resolution of 0.5° × 0.5° (to match climate data used in analyses); (c) Annual production estimated by sub-division and (d) Annual brick production by grid. (See Section 2.3 for calculating (c, d).)

perimeter per 1 m of trench width for FCBTK, and 46 ± 4 m perimeter per 1 m of trench width for Zig-Zag). The trench width was linked to daily production estimates (Rana & Kumar, 2017), factoring a reduction of 75% for FCBTK as these kilns have a lower efficiency (Kamyotra, 2015). Our estimation of 253 ± 39 billion bricks is similar with other analyses which estimate an annual production between

240 and 260 billion bricks per year (Kamyotra, 2015; Tibrewal et al., 2023). The calculation accounts for an estimated annual growth of around 6%, represents the production of more than 1300 billion bricks by 2050 (Eil et al., 2020).

The estimation of the effect of climate change carries several uncertainties (Mehta et al., 2019); such as the choice of data source, parameter definition, downscaling methods, climate models, as well as GCM selection and emissions scenarios (Gosling et al., 2017). We present the standard uncertainty (u), considered to be the standard deviation from the mean, calculated by the square root of the sum of the squares of the differences between the result of each GCM, SSP or WBGT estimation methods x_i (depending on the case) and the general average $\bar{x}$, divided by one less than the number of measurements N (Equation 3) (Giorgi & Mearns, 2002).

$$u=\left[\frac{\sum_i^n (x_i-\bar{x})^2}{N-1}\right]^{1/2}. \tag{3}$$

3 | RESULTS

3.1 | WBGT: Spatio-temporal patterns of thermal in India (to 2050)

As a country, between the two reference periods (1985–2014 and 2021–2050), the annual mean of daily WBGT for India was simulated to increase for each SSP scenario (taking an average across the GCMs and WBGT methods used) by 0.86 (± 0.26°C) for the SSP-126 scenario, 0.83 (± 0.49°C) for the SSP-370 and 0.90 (± 0.38°C) for the SSP-585 scenario, representing an increase between 3.66% (± 1.09%), 3.37% (± 1.92%), and 3.84% (± 1.61%) respectively (Table 2).

Across India, the WBGT modelled is heterogeneous in its spatio-temporal pattern, with the magnitude of WBGT increase simulated vary across all SSPs (Figure 2). Practically all kilns will have workers in a higher annual mean WGBT by 2050 than present. For the SSP-126 and SSP-370 scenarios, 96% and 83% of kilns will see at least a 1.0°C temperature increase, respectively. Whilst, for SSP-585, 86% of the kilns will see an increase of at least 1.0°C, including an increase of more than 1.5°C for 24% of kilns.

The modelled WBGT increase most in the areas where the brick kiln production is concentrated: the northern belt of India. As brick production requires certain resources, present siting of kilns should prevail. There is a high spatial coincidence between kiln density and intensity of increase in WBGT (Figure 3) exposing a high number of workers to this increase in heat.

3.2 | Days of moderate and extreme heat stress

For the workers at all brick kilns, a daily WBGT of above 30°C (i.e., of moderate heat stress TLV) is expected for 45 (±5) days for SSP-126, 44 (±8) days for SSP-370 and 46 (±8) days for SSP-585 across the

TABLE 2 Changes in annual mean of daily WBGT (1985–2014 vs. 2021–2050) for season production (December to June) in India. Changes in mean WBGT per each GCM, scenario and WBGT model. Absolute values and % of change. Colour ramp corresponds to % of change.

		Δ WBGT (°C) (1985–2014 vs 2021–2050)			Δ WBGT (%) (1985–2014 vs 2021–2050)		
GCM	WBGT model	SSP-126	SSP-370	SSP-585	SSP-126	SSP-370	SSP-585
MPI-ESM1-2-HR	Bernard	0.55	0.09	0.33	2.36%	0.38%	1.42%
MPI-ESM1-2-HR	Stull	0.70	0.38	0.56	2.99%	1.60%	2.39%
MPI-ESM1-2-HR	Liljegren	0.55	0.08	0.30	2.30%	0.33%	1.26%
GFDL_ESM4	Bernard	0.54	0.60	0.57	2.31%	2.51%	2.44%
GFDL_ESM4	Stull	0.54	0.64	0.65	2.30%	2.66%	2.77%
GFDL_ESM4	Liljegren	0.56	0.56	0.57	2.34%	2.29%	2.39%
MRI-ESM2-0	Bernard	0.95	0.75	1.14	4.08%	3.12%	4.89%
MRI-ESM2-0	Stull	1.03	0.83	1.18	4.40%	3.42%	5.04%
MRI-ESM2-0	Liljegren	0.96	0.71	1.11	4.02%	2.89%	4.65%
IPSL-CM6a_LR	Bernard	1.02	1.03	1.00	4.36%	4.22%	4.27%
IPSL-CM6a_LR	Stull	0.98	1.04	1.01	4.16%	4.23%	4.29%
IPSL-CM6a_LR	Liljegren	1.01	1.00	0.98	4.21%	4.00%	4.09%
UKESM1-0-II	Bernard	1.15	1.53	1.35	4.92%	6.14%	5.78%
UKESM1-0-II	Stull	1.22	1.71	1.48	5.19%	6.78%	6.30%
UKESM1-0-II	Liljegren	1.17	1.50	1.34	4.89%	5.90%	5.60%
Multi-model average		0.86	0.83	0.90	3.66%	3.37%	3.84%
Uncertainties of climate projection and WBGT model (±)		0.26	0.49	0.38	1.09%	1.92%	1.61%

Abbreviations: GBC, global climate model; WBGT, wet bulb globe temperature.

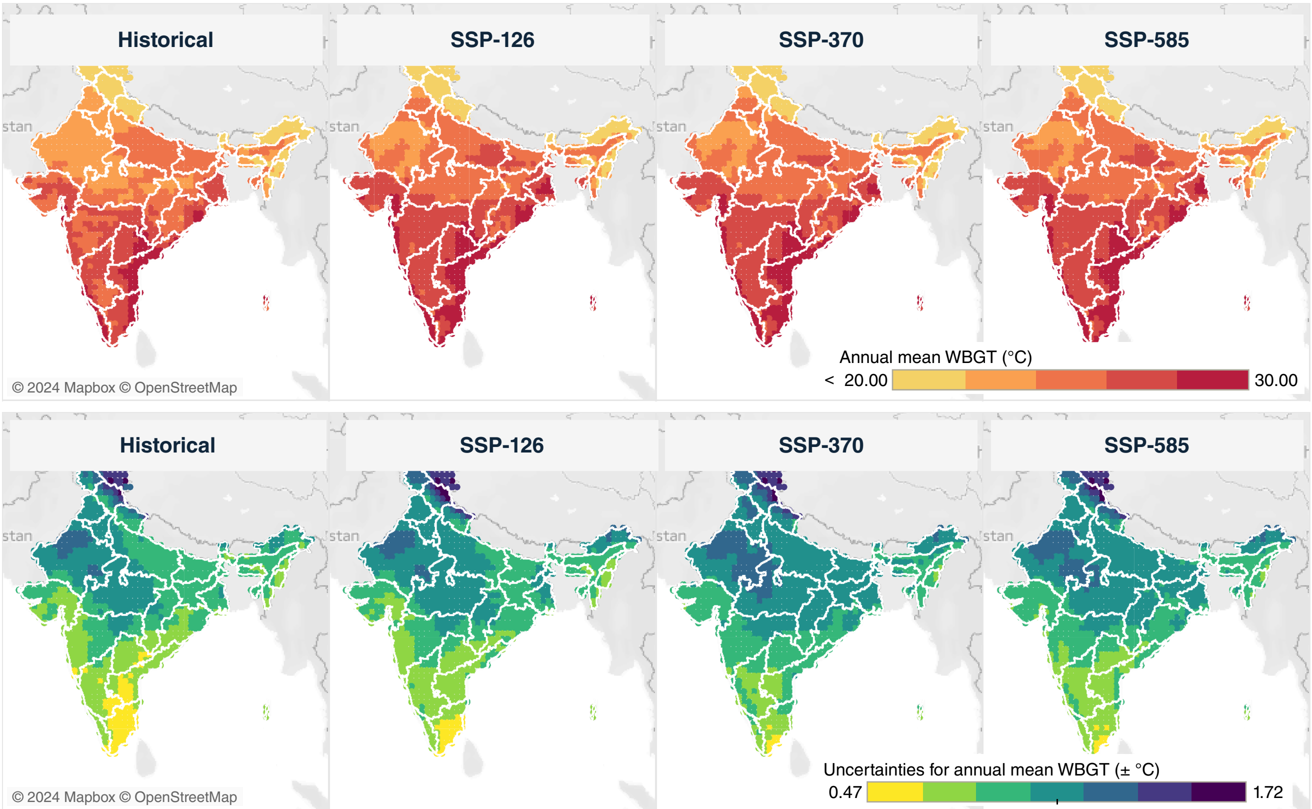

FIGURE 2 Top: distribution of annual mean (December to June) of daily WBGT for multi-model average across historical reference period (1985–2014) and SSPs (2021–2050). Bottom: uncertainties for annual mean of daily WBGT (±°C). WBGT, wet bulb globe temperature.

brick production period defined of 212 days, this represents 21% of the days of work at a kiln. (Supporting Information (SI) Figure 1). This assumes that kiln workers work 7 days a week as the kiln is operational 24/7 from start-up to close (Kubasiewicz et al., 2023). The workers at more than 40% of kilns (>19,000 kilns) will face more than 50 days of moderate heat stress in all SSP scenarios, including kilns in Odissa, Tamil Nadu and Andrha Pradesh; some kilns in these states will see WBGT above 30°C for at least 100 days. A bivariate map combining the density of kilns per analysis cell and the number of days with moderate heat stress (Figure 4), illustrates that the areas of highest kiln concentration in India are those most vulnerable to moderate heat stress.

In addition, by using the minimum and maximum values established for TLVs (i.e., at 30 and 34°C), we can estimate the increase of days in both limits that the kilns will be exposed to. Applying both indicators (> = 30°C as a measure of length, and > =34°C as a measure of intensity) to days with heat stress provides insight into personalised adaptation plans. As illustrated in Figure 5, the workers in 31,288 kilns would have more than 10 additional days with WBGT > = 30°C for SSP-126, 8988 for SSP-370 and 33,394 (more than 70%) for SSP-585. Similarly, an increase in the number of additional days of WBGT > = 34°C (extreme), especially for SSP-585 are expected, where 940 kilns would have workers exposed for 8 additional days with extreme WBGT (> = 34°C). For SSP-585, 9% of total kilns will be in areas with high vulnerability in both frequency and intensity, being Uttar Pradesh with 1391 kilns, followed by West Bengal (1090 kilns) and Gujarat (849 kilns) the states with highest exposure.

3.3 | Labour capacity and associated productivity

When comparing labour capacity for the periods 1985–2014 and 2021–2050 using the multi-model average (Equation 1), a reduction in labour capacity in India by 5.54% (±1.7%) for SSP-126 and 5.95% (±3.1%) and 6.32% (±2.5%) for scenarios SSP-370 and SSP-585 is seen. When applying the same principles to Equation 2 labour capacity reduces slightly less in all three scenarios: 5.27% (±1.26%), 5.65% (±2.8%) and 6.05% (±2.4%) (Tables S1 and S2).

As a result of the modelled reduced labour capacity, it follows that there will be an impact on brick production. Based on production estimates of 253 billion bricks (see Section 2.3: Thermal climate change impact assessment) we assumed a linear relationship between labour capacity and brick production only. When applied to Equation (1), this determined a (mean) decline in production by 7.42% (for SSP-126), 6.76% (for SSP-370) and 7.79% (for SSP-585), which is equivalent to between 17,122 and 19,722 million bricks. For the application of Equation (2), the reduction is less, with production decreasing between 15,794 and 18,212 million bricks (Tables S3–S5).

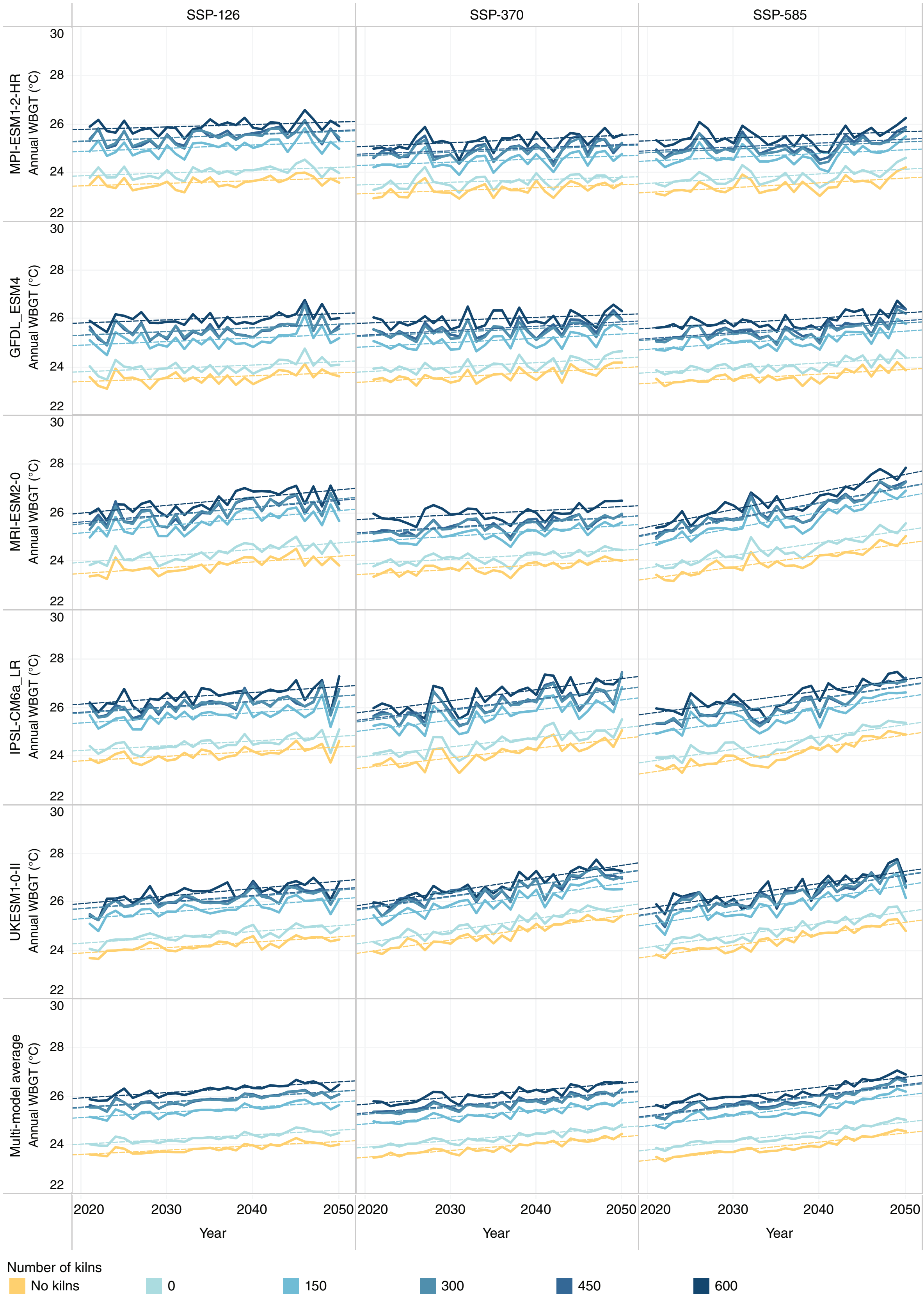

FIGURE 3 Annual mean of daily WBGT (December to June) using average for WBGT method across GCM and SSPs grouped by number of kilns in each location. GCM, global climate model; SSPs, socioeconomic pathways; WBGT, wet bulb globe temperature.

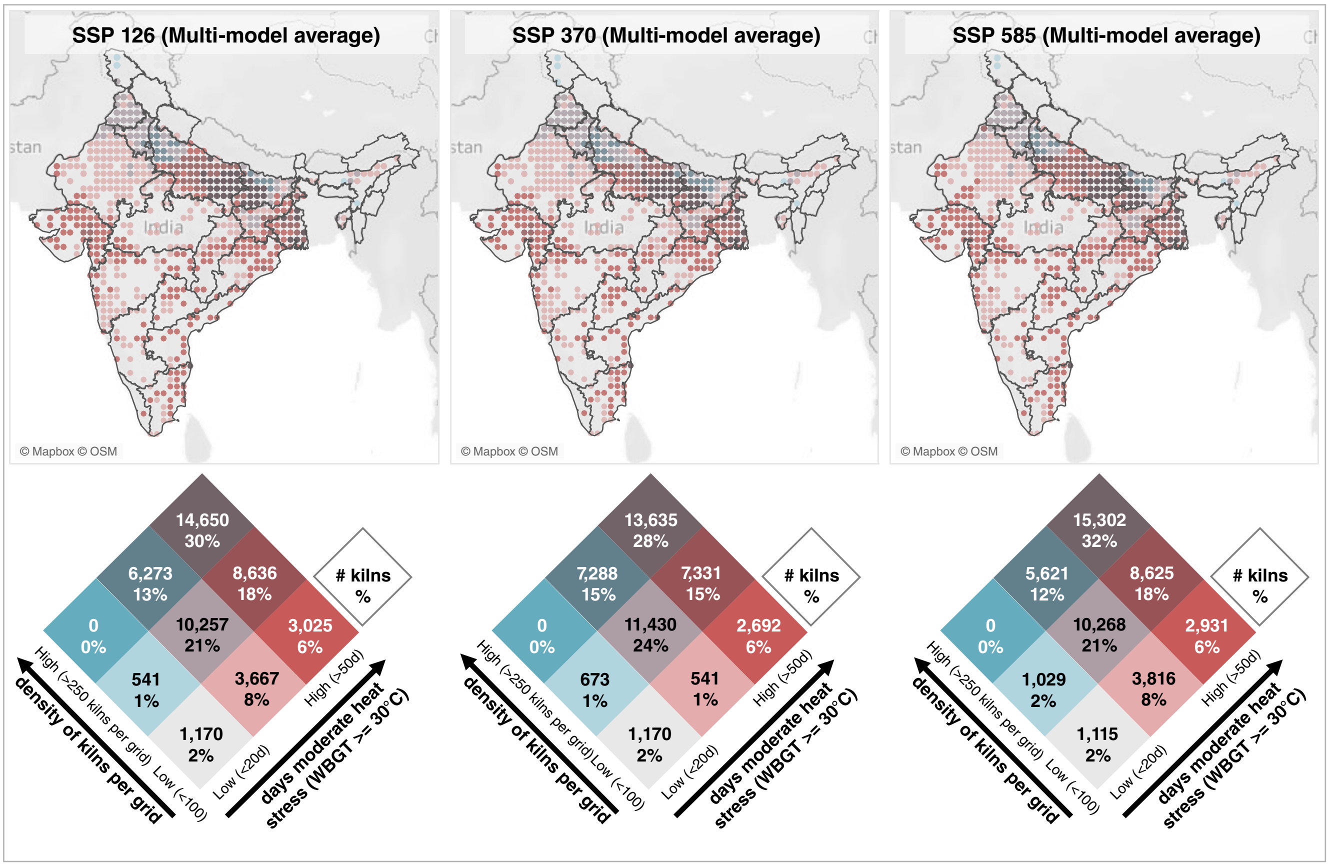

FIGURE 4 Bivariate map number kilns per grid and days with moderate heat stress in multi-model average (WBGT > = 30°C). High-High values represent locations with high concentration of kilns and highest number of days with WBGT > = 30°C. WBGT, wet bulb globe temperature.

As already noted, the locations in India with the highest brick production are also among the most vulnerable to the increase in WBGT and consequently to the reduction of labour capacity (and associated reduced brick production). This is especially evident for Uttar Pradesh (Central zone), Bihar, West Bengal (Eastern zone), Haryana, Punjab and Rajasthan (Northern zone), where some 80% of India's bricks are produced (Figure 6).

4 | DISCUSSION

The increase in India's annual mean daily WBGT over the next 25 years modelled here concurs with that of other studies (e.g., Azhar et al., 2017; Dasgupta et al., 2021). India is one of the "Critical 9" countries identified to experience sustained high temperatures, which also have significant populations at high risk from a lack of access to cooling due to poverty and electricity access gaps (SE for All, 2022) and has been modelled to experience the largest population-weighted labour losses and associated economic productivity impacts under future warming projections. Although this study has not sampled the full range of climate model uncertainty using just five GCMs and one labour capacity function (which is not calibrated specifically for brick kiln workers, hence the use of the Dunne model), it is the first time that modelled outputs of a changing climate have been examined with maps of brick kiln locations—an industry reliant on migrant workers who are particularly vulnerable to externalities such as climate change. Critically, spatially intersecting simulated changes in WBGT with the EO mapped brick kiln locations, affords a unique insight into brick making in India; the pan-India perspective overcoming the challenge of the climatic diversity of the Indian subcontinent (Kumar & Sharma, 2021). No matter the GCM and SSP pathway used in the modelling, the high spatial co-occurrence of increases in both moderate and extreme heat (as per TLV of 30°C and 34°C, respectively) with the (current) location of brick kilns indicates that climate change scenarios by 2050 will present a material risk to those working in brick production in India. This finding has direct implications for workers, the Indian economy and global value chains (Parsons et al., 2024), particularly as the current labour regime—reliant on extraction of resources and the presence of debt—encourages social-ecological exploitation. The circulation required in the global value chain of brick manufacturing in India is central to this exploitation, and reduction of the compounding climate change risk is one that requires combined redress (Baglioni et al., 2022).

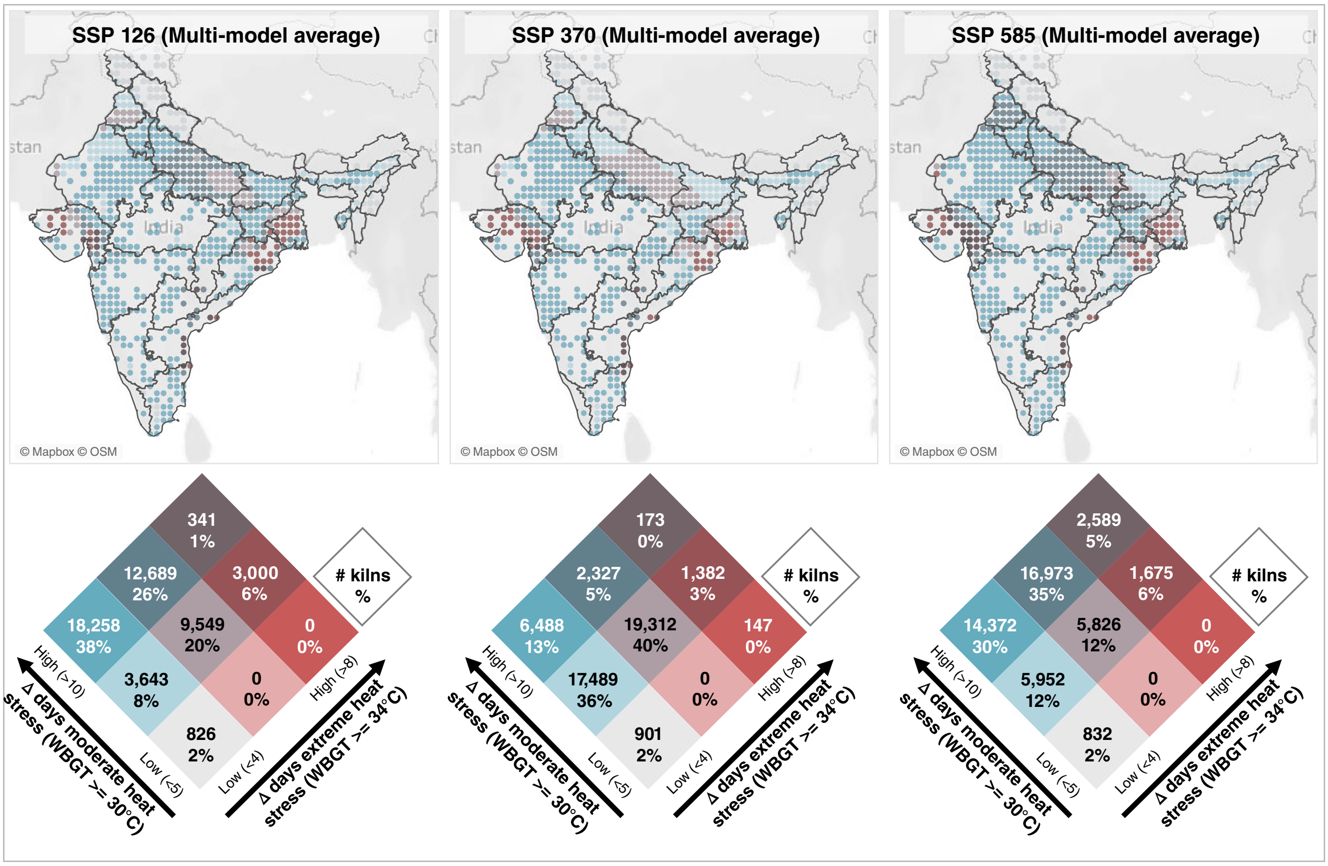

FIGURE 5 Bivariate map of increase of days moderate heat (WBGT > = 30°C) and days with extreme heat stress (WBGT > = 34°C) comparing reference period (1985–2014) versus 2021–2050, using multi-model average for GCM and WBGT method. High-High values represent highest exposure in frequency and intensity of heat stress. GCM, global climate model; WBGT, wet bulb globe temperature.

India's brick production is predicated on construction and real estate booms that are expected to continue to grow as India's GDP increases (CWW, 2024). This economic development gives rise to an increased demand for bricks both locally and overseas, where the global value chains requirement for cheap goods often overlooks and outweighs labour and environmental rights, rooting the dual issues in places far from sites of final consumption (Parsons, 2023). As such, approaches for climate adaptions are required in production activities that do not further impact on the reduction in the productivity modelled here. The country's migrant economy has increased because of climate change impacts at source (for example, consistent drought or flood), providing a population that is eager to work but vulnerable to the impacts of climate change. Migrant workers need effective and economically sustainable heat stress mitigation at the kilns. However, due to the advance-payment business model of kilns, migrant workers are less likely to choose adaptation options like increased rest hours. This business model begins with recruitment in workers' home states. Migrant workers are approached by someone known in their village with an offer of work in the brick kilns. Most accept an advance on their wages (Guérin et al., 2007; Nanjunda & Venugopal, 2021), from which migration costs and then food/living expenses are deducted during the work season. This system of advances is a pervasive working model of the kiln industry. Workers are paid an advance and then bound to the workplace for the duration of the work season. Their final wages are settled at the end of the season, and may show a negative settlement, forcing them back into work the following season. This system of advances, deductions and debt-based work can tie workers to a piece-rate payment structure that equates to less than the minimum wage (Kumari, 2018; PCLRA, 2020). Risks of being trapped in this bonded labour are particularly acute for interstate migrant workers, who may not speak the local language, have higher levels of debt due to migration costs, and may not be registered for state social protection schemes.

Thermal inequality or inequity linkages of health and decent work in the brick manufacturing industry of other countries (e.g., Parsons, 2021) share similarities with our presented example, exacerbating precarity for workers, compounding risks, and limiting response options. The twinned impacts of heat stress and decreasing labour productivity, modelled in this paper, further exacerbate the vulnerability of already precarious brick kiln workers: the reduction in productivity due to heat stress will reduce workers' income and therefore increase the period of indebtedness against their wage advance (Anti-Slavery International, 2017; Dash & Kjellstrom, 2011). Because workers are paid by bricks made, long working hours that could be

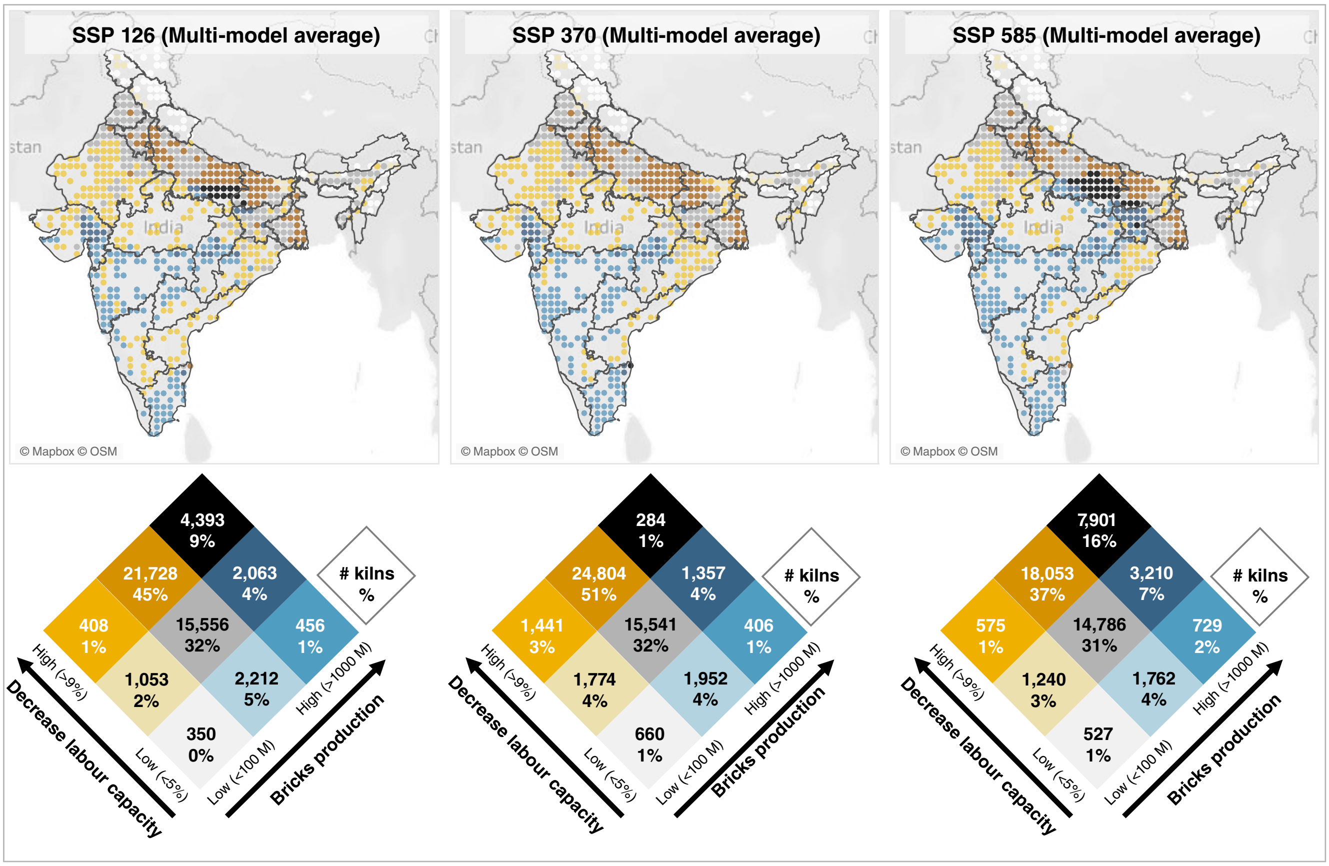

FIGURE 6 Bivariate heatmap showing mean change of labour capacity between reference periods (1985–2014 vs. 2021–2050) using Equation (1) and brick production per grid (Million).

dangerous in a hotter climate are incentivised. At the same time, air pollution and heat create health impacts—pollution impacts on health are worse during heatwaves (Rahman et al., 2022)—and as productivity declines so too may working conditions. The limited evidence from other sectors points towards this sort impact due to a drop in a worker's productivity being likely—Jessoe et al. (2018) reports a reduction of non-farm employment shares, such as in Mexico, as well as reduced paid agricultural workdays. And this has a disproportionally larger impact on female workers, for example in India (Afridi et al., 2022).

As the brick industry begins to engage with climate change adaption and mitigation processes (Jajal et al., 2019, all measures will need to accommodate the migration status of kiln workers and the current piece-rate system, to avoid the unintended impact of further reducing access to work. It is already the case that crop failures have forced rural populations and landless migrant workers to travel from the poorest Indian states, such as Bihar, Orissa, Uttar Pradesh and West Bengal, into low-tech jobs, such as brick making (Nanjunda et al., 2021). This movement of people into the industry is likely to accelerate over the next 25 years. There is an urgent need for the kiln industry and government labour and environmental inspectorates to understand and design comprehensive labour policies and workplace interventions to avert health risks for these millions of workers in the 48,000+ kilns. Workers are outside, exposed to the heat, at every stage of the brick production process—procurement of the clay, its tempering and moulding, drying of the constructed bricks, firing (which exposes the worker to yet more heat) and sorting of the bricks.

However, association between heat exposure and physiological response is not straightforward. Ioannou et al.'s (2022) meta-analysis of 38 post-2000 field studies monitored experienced and acclimatised outdoor workers in 21 countries, including India. It concluded that labour productivity is projected to remain at levels higher than the workers' physical work capacity. Further, it pointed to people resorting to working more intensely than they should to meet financial obligations (e.g., payment for medical treatment taken on as a debt). This is pertinent for migrant brick kiln workers, given the pattern of work in kilns of indebted labour against an advance. As temperatures increase and productivity decreases, brick workers may need to increase their hours of work to maintain production levels, putting them at greater risk of unsafe working environments and exposing themselves to heatstroke, dehydration, fatigue, and long-term diseases (Venugopal et al., 2023). Such conditions have already been reported in brick kilns leading to organ failure and death (Kovats & Hajat, 2008; Kumar & Sharma, 2021). Brick kiln workers already try to work longer hours when it is cooler (Misra et al., 2020; Saha et al., 2020), and if they respond to reduced productivity by working more hours each day and/or at hotter times of the day, this may add further indicators of forced labour—"excessive overtime"—alongside the existing forced labour indicator (from the ILO's (2012a) list of 11) of "debt bondage", as well as further exacerbating the forced labour indicator of "abusive working and living conditions." Workers may also need to increasingly deploy their children to help meet targets of brick production. An estimated 70% of the children of migrating kiln workers accompany them to live in the kilns, and children (age 0–14 years) comprise an estimated 34% of the population in kilns (PCLRA, 2020). Levels of child labour may increase as families attempt to maintain production levels, with resulting impacts on children's health and education.

Climate change mitigation and adaptation measures should be explored now for India's brick-making industry, with implementation imminently, and should be undertaken within a decent work framework—one that factors in what the ILO calls "conditions of freedom, equity, security and human dignity", to help avoid these potential future scenarios of forced labour, child labour and worsening conditions of work. The current precarity faced by workers in brick kilns suggests that incremental occupational health interventions may not be effective. Instead, although India does not currently have any legal framework for protection of workers from rising heat (Maloo, 2022), it would be in the vanguard if it did introduce such a framework (as very few countries have done so). Worker protection legislation could accompany and support India's existing deployment of new strategies for climate adaption (World Bank, 2022)—in 2019 it launched the India Cooling Action Plan to provide sustainable cooling measures, and since the National Disaster Management Authority (NDMA) categorised 23 of India's 28 states, along with about 100 cities and districts, as being at risk of suffering extreme heat, states have developed heat action plans (NRDC, 2022). The national and state-level plans could provide the impetus for a state-by-state roll-out of climate mitigation and decent work policies and guidelines targeting the millions of brick kiln workers.

If decent work action plans included a transition for the kiln industry to time-based wages, this would improve the economic security of kiln workers, lessen the need to take advance payments, remove the incentive to work excessive hours within a piece-rate system and enable workers to change their employment. There is precedent for this level of change in the industry, albeit from the angle of environmental and health regulation rather than labour and decent work. Brick kilns are already the focus of new legislation from the central government with respect to their emissions contributing to poor air quality (Bashir et al., 2023). The reason for this government attention is the kilns' impacts on the health outcomes of populations residing in close proximity. A new focus on decent work may further help this effort: our mapping shows that uptake of a change in kiln firing technology remains low, likely because the brick kilns are hard to regulate as they are small industries in vast numbers, spread across large geographies of the Indo-Gangetic plain. The use of process-based modelling to quantify the potential joint effects of exposure to air pollution and heat stress (e.g., cardiovascular and respiratory mortality and morbidity) to project future occupational health effects may further galvanise action from government stakeholders on regulation and policies where climate change adaptation, public health and decent work intersect. Here, brick kilns are clear objects of sustainable development goal (SDG) intersectionality (Boyd et al., 2021)—a site where multiple of the SDGs and associated targets meet, and where achieving one can help achieve another; for example SDG 8.7 (end forced labour), SDG 13.3 (improve capacity on climate change adaptation) and SDG 3.9 (reduce death and illness from air pollution). The kiln industry illustrates the UN's own observation that many of the SDGs and their targets can be achieved in ways that would enable adaptive responses to climate change (UN, 2024).

Outside of specific government policies to protect kiln workers from the rising heat, owners/managers of kilns could explore how adaptation measures such as self-pacing, hydration, adequate shade areas, work-rest regimes, and mechanisation can be adopted to protect workers from the rising heat. Workers can physiologically acclimatise to performing physical tasks in the heat; however, these adaptations take at least 4 days to occur (Tyler et al., 2016). Accordingly, a period of reduced work intensity and/or duration should be given to workers when first exposed to heat stress. This period will not be the same for all workers, as heat stress does not impact individuals to the same extent or in the same manner (inter-individual differences), and its impacts may change at different times even for the same person (intra-individual differences) (Deshayes et al., 2024). The different demographics of workers and their varied roles in brick making mean that kiln owners/managers must understand the potentially different impacts of heat stress across the kiln population.

Any reduction of a worker's capacity will impact the current business model in the kilns—already subject to changes in value chains and climate adaptation planning (Parsons et al., 2024). Owners of brick kilns face economic challenges, including high interest rates, land rent and delayed payments from construction agencies (Naveen, 2016). As part of the informal economy, brick kiln owners are vulnerable to the demands of construction companies, who set prices and establish demand and delivery times (John, 2018). Brick kilns are typically notified of the total brick requirement at the initiation of a construction project, but this does not guarantee a committed demand, as construction companies determine their actual purchases based on brick quality and production speed (Naveen, 2016). Construction companies do not regulate manufacturing practices, further reducing the incentive on the part of kiln owners to ensure decent working conditions (Naveen, 2016). Access to credit for brick kiln owners with the condition of formalising their kiln as a manufacturing site and registering it as a factory under India's Factories Act would give owners more significant margin to negotiate delivery times with construction companies and mitigate time restrictions caused by heat stress. It would reduce the uncertainty of supply to construction companies, facilitate the upgrading of the value chain and allow investment in living and working conditions. It also would enable better regulation of current environmental and labour standards, as kilns registered as factories are placing under the Directorate General, Factory Advice Service and Labour Institutes, with its factory inspection services across states. This increased ability to regulate and inspect kilns, where caste-based division of labour and seasonal migration (inter-state or intra-state) from the poorest locations (John, 2018) perpetuates vulnerable labour conditions, would support decent work conditions in an otherwise informal sector.

There are currently several initiatives within India that may further support efforts at the nexus of decent work and climate change adaptation. One is specific to the brick kiln industry. The UNDP India Accelerator Lab administers the GeoAI platform (Boyd et al., 2021; BPCB et al., 2023). This platform contains the mapping of all kilns and drives inspections to ensure all kilns are registered with the appropriate state government department. The platform is currently supporting unprecedented data collection efforts at kilns to capture the demographics of the different types of workers in kilns and details on workers' conditions—social, economic and environmental. In the state of Bihar, one of the policy recommendations reported by UNDP because of the surveys is the improvement of working conditions and provision of social security and social protection services to brick kiln workers. The second initiative, which targets workers beyond the brick kiln industry, is the Government of India's (Ministry of Labour and Employment, 2024) eShram portal. Launched in August 2021, this is a National Database of Unorganised Workers. Upon registration, it records the worker's name, occupation, address, educational qualification, and other details, and extends social security benefits to the registered worker. The Government describes it as the "first-ever national database of unorganised workers including migrant workers, construction workers, gig and platform workers," and its aim as achieving "portability of the social security and welfare benefits to the migrant and construction workers" (see above). As of March 2024, 294,775,463 unorganised workers had registered with eShram. There are 33 broad occupation sectors and, according to civil society organisations who have supported workers to register, brick kiln workers are registered under Construction, and subcategory "Bricklayers and Related Workers" (occupation code 29).

However as of March 2024, only 821,367 workers had been registered in this category: a small proportion of the estimated 10 m kiln workers in India (8.2%). By comparison, 28,444,456 domestic workers had registered—a number higher than most existing estimates of domestic workers in India (ILO, 2022). By 2022, the Government had acknowledged issues with registering kiln workers (Ministry of Labour and Employment, 2022). In addition, 32.5% of domestic workers had registered through self-registration, as compared to 11.38% of brick kiln workers. Instead, kiln workers were largely registered through CSCs (88.6%)—Common Service Centres that are access points for the delivery of Government-to-Citizen services (numbering 596,247 across India as of January 2024). The low rates of self-registration suggest low rates of access to mobile devices and data among kiln workers, low rates of literacy, high rates of migrant labour (where information campaigns and registration drives have missed these workers during kiln off-seasons), and potentially low rates of penetration by government (national and state-level) awareness-raising and instructions about eShram registration due to kiln workers' isolation. The sector remains largely undocumented, its workers unregistered for the benefits enabled by eShram. The low rates of registration may indicate high levels of vulnerability, including to forced labour—characterised for example by restriction of movement (of the kind required to access a CSC); excessive overtime (of the kind that would prevent time spend registering); and retention of identity documents including the documents required for eShram registration (see ILO, 2012a, for the list of 11 forced labour indicators). However, new data on the scale and location of the kilns, as gathered and used in the GeoAI Platform, may enable eShram registration drives to focus on specific areas, including in those states with the highest exposure to heat stress in both frequency and intensity (Uttar Pradesh, West Bengal and Gujarat).

This sort of initiative would then allow a much more complete analyses of the geographical and socio-economic situations that exist in each kiln, in order to inform what decent work could look like in kilns. The analyses undertaken in this paper provide evidence-based guidance on where to focus the effort in data capture via the GeoAI platform and eShram portal. Once coverage is expanded, this will move understanding of the likely pathways for kiln workers and which kilns are likely to be most at risk of the worst impacts from rising heat. An increase in data per kiln would afford further quantitative analyses, such as production of a risk index. Such indices usually pool data on factors that make populations (and/or areas) more or less at risk to climate change, by accounting for the climate hazard (heat) alongside demographic and socio-economic variables that represent a population's ability (or lack thereof) to cope with climate change, and/or their vulnerability. Indices like the INFORM Risk Index and the WorldRiskIndex aim to do this at a national level (e.g. see Birkmann, Jamshed, et al., 2022; Birkmann, Liwenga, et al., 2022) and similar calculations can be done at a sub-national level (e.g. Mysiak et al., 2018). Such an index would allow us to show which brick kilns are more at risk from climate change than others, based on socio-economic factors like workplace policies and decent work frameworks.

Currently, available data in the GeoAI platform are restricted to a few kilns in Bihar (BPCB et al., 2023) and these early results report the majority of the workforce as male (86.8%) and that 85% all workers belong to poorest Dalit communities (Schedule Caste and Schedule Tribe) facing extreme poverty and social marginalisation. The provision of shaded areas for resting or eating is limited, with only a small percentage of kilns offering this amenity, availability of clothing for workers is limited, although the availability of potable water is widespread. With this (albeit limited) data, in conjunction the knowledge generated by the analyses and modelling of this paper, consideration by all stakeholders (economic-, environmental-, rights-focused) as to the operation of the brick industry in India should commence right away. This would avoid the most likely pathway (at present) in the future where within piece-rate systems, such as India's brick kilns, any reduction in productivity generates proportionally lower wages for workers (ASI, 2017).

At present, clear cause-and-effect is not available in further analyses of the likely impacts and consequences of heat-induced productivity reductions within the sector. However, early indications from a number of anecdotal sources (e.g., as small-sample survey responses, civil society organisations (CSO) feedback, and media reports) indicate that workers already rearrange their time to work through the cooler parts of the day. While this allows them to maximise productivity (though not necessarily to previous levels), a range of costs have been identified by CSOs compounding the financial pressures of reduced wages (pers. comm. Volunteers for Social Justice, 2024). Workers may have to pay for additional water to keep cool, or for electricity to provide artificial light to enable work to continue in the cooler hours after daylight (ibid). In this latter case, workers are then required to rest during the hottest part of the day, in shelter/accommodation that may concentrate rather than alleviate the heat. Adequate rest may not be possible, exacerbating the risk of exhaustion, hindering recovery, and leaving workers more susceptible to the impacts of heat stress. Alternatively, they may push through and work during hotter parts of the day, again endangering their health and wellbeing. For example, most workers live in accommodations on site of the kilns which are inadequate and often have roofs made of materials (e.g., metal sheets) that keep the ambient indoor temperatures high (Tasgaonkar et al., 2022; Vellingiri et al., 2020). Further, there is little opportunity for rest to escape the heat in any shaded areas, as stopping work prevents income being earned (Rahman et al., 2022). CSO reports (pers. comm. Volunteers for Social Justice, 2024) have noted that some owners do not attend their kilns through the hottest part of days with extreme heat. It is not yet clear if, or to what extent, the reduced levels of production are accepted as a necessary consequence of extreme heat or workers are pressured to make up the discrepancy.

Reduced profits for kiln owners come within a context of increasing regulatory costs, such as the requirement to convert to Zig-Zag technology. Where support to transition is available to kiln owners, kiln owners regard it insufficient and some have sought opportunities within the production process to recover costs, adversely impacting conditions for workers (Nagaraj et al., 2024). For others, particularly those closer to the capital where additional air quality regulations apply, the combined costs of regulatory compliance proved too great, and many kilns have closed. The expected positive effect on air quality in Delhi was achieved, and thus far workers are reporting that they have been able to find work in other kilns (Roy, 2024). However, the extent to which this can continue to be the case is highly uncertain, particularly when considered alongside the climate change impacts predicted for the main brick producing regions. The informal, seasonal nature of the kiln sector means that alternative employment schemes that would be available to other types of factory workers are inaccessible by kiln workers (ibid.).

For those remaining in kiln work, the Indian Government's National Disaster Management Authority (NDMA 2024) provides advice for communities during extreme heat events including avoiding strenuous activities outdoors during the hottest part of the day (12–3 pm), drinking sufficient water, and wearing adequate clothing to provide shade, or seek shelter from the sun. However, these recommendations whilst useful, place the onus on the individual worker where in fact systems-change is needed across the brick manufacturing sector. Structurally, the overall response to heat stress is beyond the worker's control. A multifaceted approach to support workers is thus required when responding to an increase in the likelihood of heat stress. A more considered approach between State Governments and Kiln Owner Associations needs to be had which requires better working conditions to be supplied to the workers without the costs of improvements to accommodations, water supplies, and changing work patterns being passed onto the workers themselves in the form of additional debt. These clear-cut moves towards decent working standards would benefit all stakeholders in the brick manufacturing.

Should stakeholders not respond appropriately, a pathway for workers is to raise an income in alternative employment sectors, either replacing brick making entirely or to supplement any losses resulting from reduced productivity. However, this is unlikely as income-generation opportunities outside of kilns are significantly constrained by a range of factors. This group is largely comprised of poor, non-land-owning families, from socially marginalised Dalit communities, who are actively excluded from many kinds of employment. During the monsoon, when brick making is not possible, workers would previously have sought daily wages in agriculture, often in their home villages. This has been negatively impacted in recent decades by huge shifts away from agrarian livelihoods, due to factors including crop loss, increased indebtedness, and mechanisation (Choithani et al., 2021). Many agricultural and construction activities cease during the monsoon, and international migration is out of the reach of kiln workers due to high up-front costs, leaving a limited range of intra- and inter-state opportunities. Worker support organisations have consistently identified significant issues in developing an understanding of the medium- and longer-term realities for kiln workers (pers. comm. Volunteers for Social Justice, 2024). As workers migrate to their home states out of season, most change their mobile phone numbers so they lose contact with support organisations. Together with the large numbers and highly dispersed nature of this population, the difficulty in maintaining contact has meant that reliable data on the experiences of workers outside an individual kiln season is extremely challenging (ibid.). This is also means there is a low likelihood of these workers accessing government welfare schemes pushing them back to brick making. The future-casting presented here suggests that mitigation of the rising heat via a raising of working standards at kilns, along with a fuller consideration of worker welfare—as per decent work definitions—is a pathway of necessity.

5 | CONCLUSION

Vulnerable populations, such as migrant and poor workers, will bear the heaviest burdens of climate change (Lundgren-Kownacki et al., 2018). This is particularly acute in growing economies such as India (Venugopal et al., 2021). This paper provides new evidence that workers in India's brick kilns are particularly vulnerable to the projected rising heat. They would be particularly vulnerable to failures to achieve climate change adaptation strategies or failures to build those strategies alongside a decent work framework. Our method of mapping vulnerable populations with climate change scenarios affords a nuanced understanding of what climate change could mean for the brick making industry in India and helps to identify where interventions should be targeted. The geographies of greatest increase in heat match those of the majority of kiln workers and because the physiological effects of the heat means that workers tend to slow down and take more frequent and longer breaks, this impacts their working time and productivity. There is a need to protect these workers whose status in society is marginalised. However, there is still limited and outdated knowledge of brick kiln worker characteristics.

The insight across the geographies of brick kilns of this paper and further work through data collection at kilns of workers should afford more nuanced and tailored mitigation strategies, moving the future of these workers away from one of dangerous work. By filling the evidence gap on the informal economy of brick kilns, including how and where workers are made more vulnerable by environmental and health damage, exacerbated by climate change (Watts et al., 2017), research can support industry transformations towards decent work standards. By designing a climate mitigation plan through the lens of decent work, government and business actors can avoid increased worker vulnerability to bonded, forced and child labour as a result of worsening work conditions, reduced productivity, lower piece-rate payments and increased household debt. There is the potential for kilns to become more environmentally sustainable, monitored and regulated, and for labour and health conditions for kiln workers to improve—demonstrating through these objects of SDG intersectionality that decent work in the face of climate change is achievable (Ghosh & Roy, 2023), that the SDGs are integrated and indivisible (Lyytimäki, 2019; Nilsson et al., 2016).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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