Issue: JuLy - Dec 2024

IAS MAGAZINE

Indian Association of Sedimentologists

The CO_2 Problem: Climate Model vs Field Measurements

Courtesy: G. Shanmugam

The “IAS Magazine” is an online “fellowship magazine of the Indian Association of Sedimentologists (IAS) which publishes news about science, people, the society and articles of general interest science and achievements of sedimentologists / allied scientists of international repute and their contributions relevant to the society. The Magazine is being published online biannually in June and December. The authors may submit their articles to the Magazine online at journal.indiansedimentologists.com. The guidelines for the format of the articles are given on the same website.

Editor: G. M. Bhat

https://doi.org/10.51710/jias.v3i2

Publisher:

Bashir Ahmad Lone on behalf of the Indian Association of Sedimentologists
Wadia Museum of Natural History University of Jammu, Jammu (India)
bashir@jammuuniversity.ac.in, 91 9419168069 (M)

IAS MAGAZINE ISSN NO 2582 – 2020
Vol. 3, Issue II, 2024, pp. 1-33
DOI: https://doi.org/10.51710/jias.v3i2.401

2024 IAS Keynote Lecture
The CO_2 Problem: Climate Models vs. Field Measurements

G. Shanmugam
Department of Earth and Environmental Sciences
The University of Texas at Arlington, Arlington, Texas 76019, USA
Email: shanshanmugam@aol.com

ABSTRACT:

Developed countries (e.g., USA, Germany, and France) have the unfair advantage over developing countries (e.g., Republic of the Congo, Republic of Kenya, and Sri Lanka) in imposing climate rules that enforce the use of expensive renewable energy based on flawed climate models with inflated CO_2 concentrations. This review attempts to bring attention to this irregular practice by amassing empirical data from field measurements on CO_2 that contradict climate models. The content is presented in two parts, (1) the "PhanDA" model and (2) the CO_2─1,000 ppm limit.

The "PhanDA" model-derived CO_2 value by Judd et al. (2024) for the Present is ~220 ppm, which does not match the measured value of 420 ppm at the Mauna Loa Observatory in Hawaii for the Present in the Keeling Curve. During the past 50 years, the Keeling Curve shows a rapidly increasing CO_2 trend, whereas the PhanDA model shows a rapidly decreasing trend.

Equally important, the PhanDA model is inapplicable for the Mesozoic era ((252 Ma-66 Ma), which represents 35% of the Phanerozoic eon (539 Ma-0). There is no correlation between Temperature and CO_2 during the Mesozoic, which is the underpinning of the model. Therefore, the PhanDA model and the associated assertion on the importance of CO_2 on Climate Change are problematic.

During a Trump-Musk Conversation on X (2024), Elon Musk claimed that when Atmospheric CO_2 goes past 1,000 ppm from the current value of nearly 400 ppm at a rate of 2 ppm per year increase, it would cause headaches and nausea in humans. This is a consequential claim to human health. In addressing this vital issue, a rigorous examination of 80,302 empirical data points from 25 countries on CO_2 concentration values available from direct measurements and from publications related to classrooms, conference rooms, dwellings, and aircraft cabins was carried out. This robust dataset (i.e., 46 figures and 13 tables) suggests that humans are able to function normally without adverse health effects even when CO_2 concentration levels reach between 2,000 and 6,000 ppm. Further, the U.S. Government (USDA, 2024) does not consider the CO_2─1,000 6limit as a health threat. In fact, the CO_2 5,000 ppm is the U.S. Government's Permissible Exposure Limit (PEL) of the daily workplace exposure. For basic physiological reasons, the concentration of $\mathbf{CO_2}$ in ambient air is almost irrelevant as long as it is much smaller than about 40,000 ppm, where it is in equilibrium with the optimum $\mathbf{CO_2}$ concentration of human blood. According to NRC (2007), 20,000 ppm is an appropriate sub chronic NOAEL (No Observed Adverse Effect Level) for headaches. Therefore, the notion that headaches supposedly associated with the 1.000 ppm limit of CO_2 is a fallacy. There is no need for concern about indoor CO_2 levels in classrooms, conference rooms, dwellings, and aircraft cabins.

KEYWORDS:

CO_2, The "PhanDA" climate model, The Keeling Curve, Phanerozoic, Mesozoic, Climate Change, The Net Zero, "Climate: The Movie (The Cold Truth)", William Happer, Richard Lindzen, Patrick Moore, Steve Koonin, John Christy, Roy Spencer, Freeman Dyson, Fred Singer, Bjorn Lomborg, John Clauser, Judith Curry, Anthony Watts, Willie Soon, Alex Epstein, Martin Durkin, Tom Nelson, John Robson, The CO_2 Coalition, The Heartland Institute

CONTENTS:

INTRODUCTION:

This review is based on a Keynote Lecture, which was the third consecutive Indian Association of Sedimentologists (IAS) Keynote Lectures given by G. Shanmugam (Fig. 1).

a. 2022: University of Jammu: Sedimentary Basins (Shanmugam, 2022).

b. 2023: Annamalai University: Scientific Journey (1962-2023) (Shanmugam, 2024a).

c. 2024: Birbal Sahni Institute of Palaeosciences: The CO_2 Problem (The Keynote). The goal is to address the issue of the hegemonic western countries and their Environmental, Social, and Governance (ESG) (Fig. 2) over Developing Countries (e.g., Sri Lanka) through Climate models and CO_2 (Shanmugam, 2024a, b).

Fig. 1 Three consecutive IAS keynote Lectures by G Shanmugam

Contrary to popular belief that natural CO_2 is the primary controlling factor of Climate Change, hegemonic superpower, such as the United States, and other developed countries are the true powers, which not only manipulate climate models to exhibit

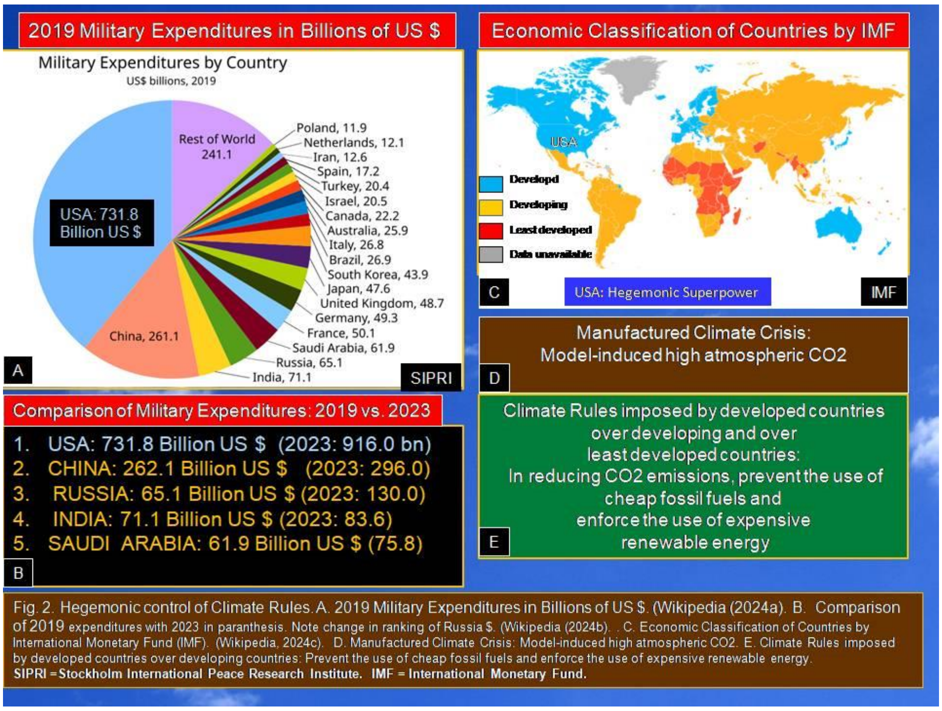


Fig. 2. Hegemonic control of Climate Rules. A. 2019 Military Expenditures in Billions of US $. (Wikipedia (2024a). B. Comparison of 2019 expenditures with 2023 in paranthesis. Note change in ranking of Russia $. (Wikipedia (2024b). . C. Economic Classification of Countries by International Monetary Fund (IMF). (Wikipedia, 2024c). D. Manufactured Climate Crisis: Model-induced high atmospheric CO2. E. Climate Rules imposed by developed countries over developing countries: Prevent the use of cheap fossil fuels and enforce the use of expensive renewable energy. **SIPRI = Stockholm International Peace Research Institute. IMF = International Monetary Fund.**

inflated CO_2 concentrations but also impose Climate Rules over developing countries unfairly (Fig. 2). The objective of this review is to illustrate the fallacy of climate models based on empirical data from field measurements on two fronts, namely (1) the

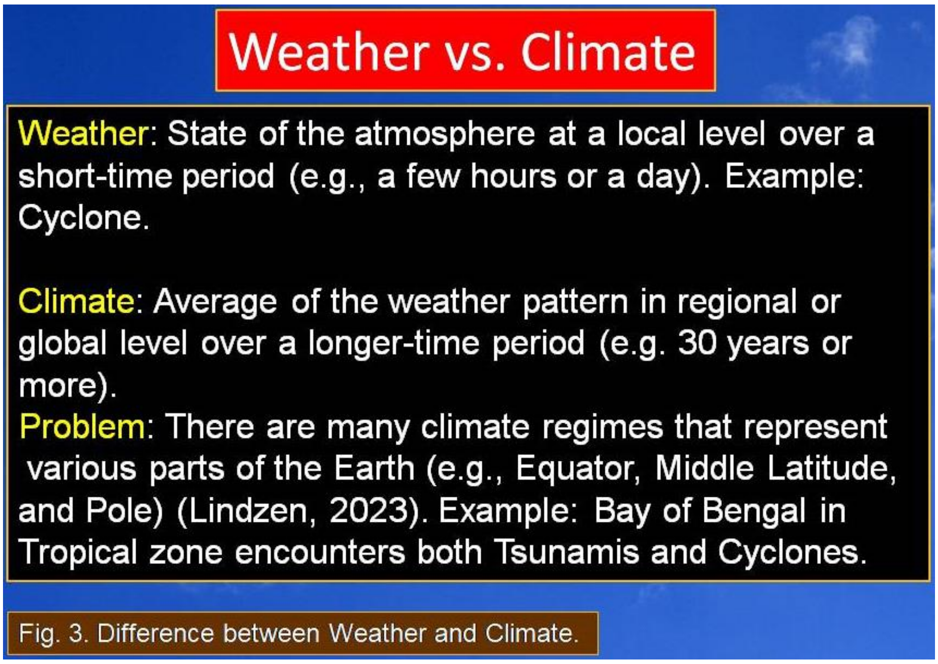


Fig. 3. Difference between Weather and Climate.

"PhanDA" model, and ((2) the CO_2 1000-ppm limit.

WEATHER VS. CLIMATE

In this discussion, it is imperative that we clarify the difference between Weather and Climate (Fig. 3).

1. Weather represents the state of the atmosphere at a local level over a short-time period (e.g., a few hours or a day). Example: Cyclone. <u>Climate</u> represents the average of the weather pattern in regional or global level over a longer-time period (e.g. 30 years or more). Example: Tropical climate. The problem is that there are many climate regimes that represent various parts of the Earth (e.g., Equator, Middle Latitude, and Pole) (Lindzen, 2023). For exam[le, Bay of Bengal is located in a Tropical zone, which encounters both Tsunamis (triggered by earthquakes) and Cyclones (triggered by seven meteorological factors) (Fig. 4).

2. Cyclones are meteorological phenomenon (AOML, 2007a, b, c; Shanmugam, 2008), not man-made events. For example, Cape Verde Island (a small country with minimum CO_2 emissions) triggers largest number of Cyclones in the North Atlantic (Fig. 5).

3. There is a major disparity in frequency of cyclones between Arabian Sea and Bay of Bengal with India in the middle (Fig. 6). Clearly, the Indian population in has nothing to do with triggering of Cyclones.

Importantly, there is a tendency to attribute a plethora of natural events, such as Tsunamis, Cyclones, Meteorite impacts, Wildfires, etc. to Climate Change (Fig. 7). This is false.

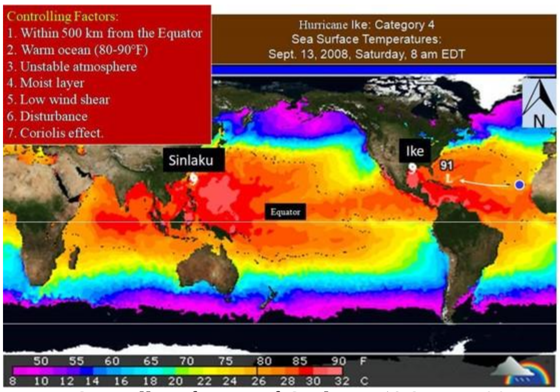


Fig 4. Controlling factors of Cyclones (AOML, 2007 a, b, c; Shanmugam 2008

Fig 5. Origin of North Atlantic Cyclones. Cape Verde Is. 177th in CO_2 emissions. Image credit Nilfanion NHC. NASA. Wikipedia. Public domain

Fig 6. Disparity in frequency of cyclones between Arabian Sea and Bay of Bengal image credit: Hurricane Alley

Fig 7. Climate (Consequence) cannot cause diverse weather and impacts events

PART 1: THE "PHANDA" MODEL

In understanding the role of CO_2 on Climate Change, Judd et al. (2024) published a model called "PhanDA" on September 20, 2024 in *Science*. This model is a reconstruction of Global Mean Surface Temperature (GMST) for the past 485 million years (Fig. 8A). Previously, Scotese et al., 2021) published similar temperature curves (Fig. 8B). However, the model by Scotese et al. (2021) did not predict the extreme high temperatures for the Early Paleozoic.

The PhanDA model was created using **Data Assimilation**, a method that statistically integrates

Geological data with climate model simulations. PhanDA indicates that Earth's Temperature has varied between 11° and 36°C over the past 485 million years. This range is larger than previous reconstructions. Judd et al. (2024) claim that CO_2 is the dominant driver of Phanerozoic climate, emphasizing the importance of this greenhouse gas in shaping Earth history. However, there are basic problems that are still unresolved. The purpose of this review is to bring attention to these fundamental issues.

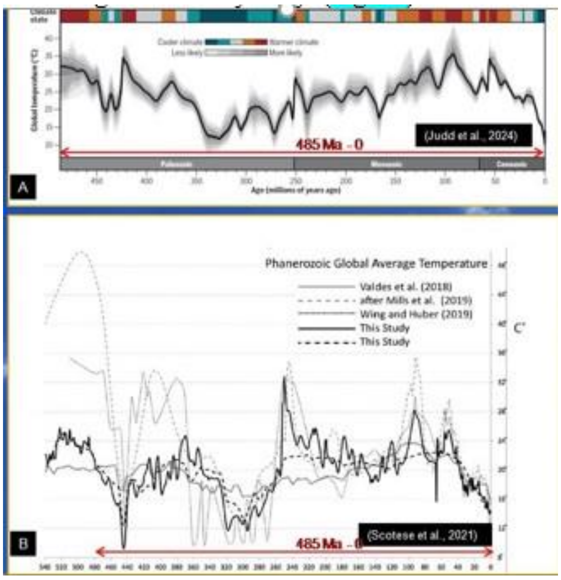


Fig 8. Comparison of global temperature curves, A). Temperature curve by Judd et al., 2024, B). Temperature curve by Scotese et al. Red arrow shows the interval covered in Fig. 8A (485 Ma-0). Note that the model by Scotese et al., did not predict the extreme high temperatures for the early Paleozoic

THE CO_2 PROBLEM

1.The "PhanDA" model shows a decreasing Temperature trend during the past 20 Ma (Fig. 9), whereas observations illustrate an increasing Temperature for the past 50 years (Fig. 10).

2. Christy (2022) noted out that IPCC model predicts a greater Global Warming than the measured Temperature data suggest (Fig. 10).

3. IPCC AR6 (2021) Climate model is problematic for three reasons (Fig. 11):

   a. Temperature anomaly is used, not absolute Temperature.

   b. Temperature varies with different baseline.

   c. The model has a large uncertainty range (Fig. 11).

Phanerozoic temperature history

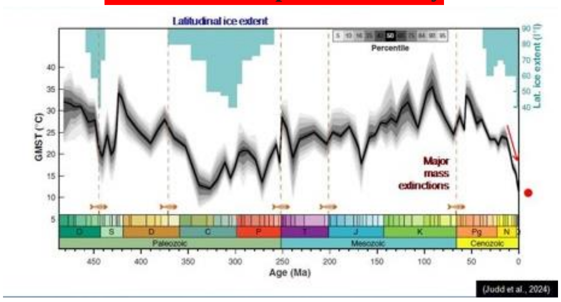


Fig 9. Phanerozoic temperature history. PhanDA constructed GMST for the past 485 Million years. Black line shows the median, shading corresponds to the ensemble percentile. Blue rectangles show the maximum latitudinal ice extent, and orange dashed lines show the timing of the five major mass extinctions of the Phanerozoic. Source Judd et al., (2024). Red arrow shows decline in temperature, which contradicts measured temperature data (see Christy, 2022).

Temperature Predictions vs. Observations

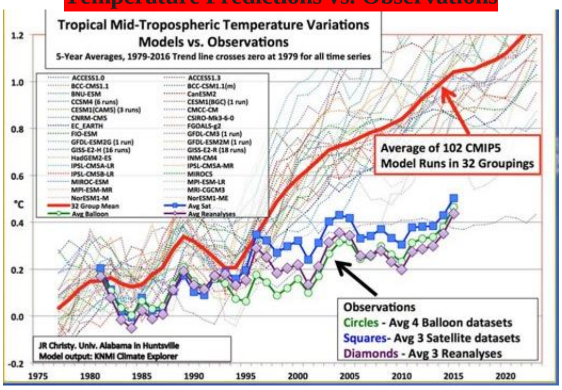


Fig 10. Exaggerated temperature prediction (Red line) vs Actual data by observation. Diagram source: Christy, (2022).

4. Contrary to the claim by Judd et al. (2024), here is no correlation between Temperature and CO_2 trends (Fig. 12) (Epstein, 2022).

5. In the PanDA models also, there is an absence of correlation between

Problems with Prediction of Global Surdace Air Temperature by IPCC AR6 (2021)

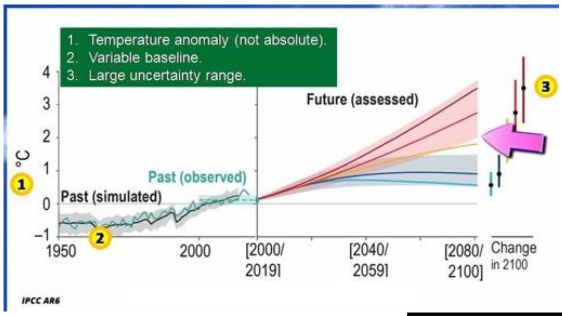


Fig 11. Three problems with IPCC Model. Source: IPCC AR 6 (2021). https://ipcc.ch/report/ar6/wg1/figures/technical-summary

Temperature and CO_2 during the Mesozoic era(Fig. 13C).

6. The high-altitude Mauna Loa site in Hawaii, used in constructing the Keeling Curve for atmospheric CO_2 concentrations (NOAA, 2024), is considered the Gold Standard for measured CO_2 concentrations in climate studies. The current measured value of CO_2 is 420 ppm in the Keeling Curve (Fig. 13A and B), but the PhanDA –reconstructed value is ~220 ppm (Fig. 13C). Judd et al. (2024) are conspicuously silent in explaining this discrepancy.

7. During the past 50 Years, CO_2 concentration has been steadily increasing in field observations ((Fig. 13A and B), but CO_2 concentration is decreasing in reconstructed values in the PhanDA model for the past 10 Ma (Fig. 13C). Judd et al. (2024) need to address this discrepancy.

8. In explaining the inapplicability of the PhanDA model to Mesozoic era, Judd et al. (2024) concede that "Although this may represent a true decoupling of CO_2 and GMST, it could also result from an incomplete knowledge of how different proxies encode past CO_2 information (11). Further work exploring both the CO_2 and temperature proxies is needed to resolve this "Mesozoic Conundrum." This is a major problem because the Mesozoic era ((252 Ma-66 Ma) represents 35% of the Phanerozoic eon (539 Ma-0).

9. From a critical scientific perspective, it makes no sense to claim that CO_2 is the primary control knob of climate for reasons ranging from lots of contradictory geological/climatological evidence (Berner, 2004; Dyson, 2007; Singer et al., 2009;

Watts, 2009; Soon et al., 2015; Christy, 2022; Epstein, 2022; Koonin, 2022; Curry, 2023; Lindzen, 2023; Moore, 2023; Plimer, 2023, Shanmugam, 2023, Durkin and Nelson, 2024) to basic radiation transfer physics (van Wijngaarden and Happer, 2020; Happer, 2022), which shows that radiation forcing from CO_2 is heavily saturated so huge changes, like "instantaneously" doubling CO_2, only diminish Earth's cooling radiation to space by about 1%.

Distribution of CO_2 and Temperature during the past 600 Million Years

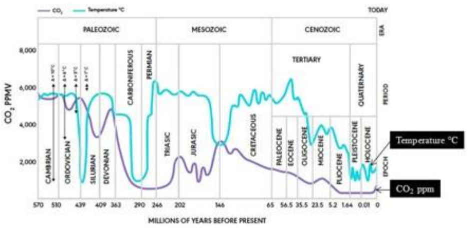


Fig 12. Absence of correlation between CO_2 and Temperature. Source: Epstein (2022). ***Additional labels by G. Shanmugam***

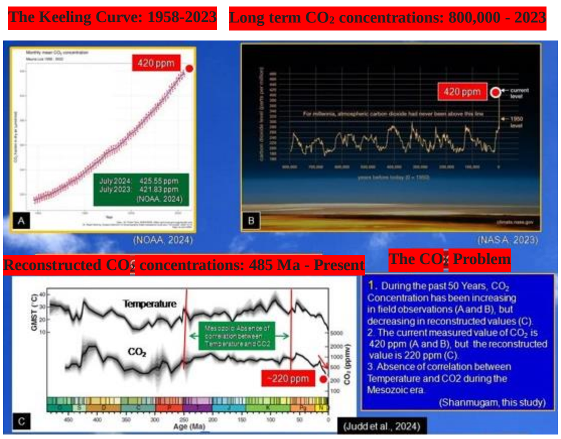


Fig 13. Problems with Climate Model ©. Red arrow in C shows declining CO_2 trend., which contradicts measurements (A & B)

PART 2: THE CO_2 1,000-PPM LIMIT

During a two-hour Trump-Musk Conversation on X (2024), Elon Musk claimed that when Atmospheric CO_2 goes past 1,000 ppm, it would cause headaches and nausea in humans. His conversation on August 12, 2024 was viewed by 1 Billion on Platform X (formerly known as Twitter). The current difference in CO_2 concentration between outdoor (atmospheric 420 ppm) and indoor (classroom 1,000 ppm) is 580 ppm.

DONALD JOHN TRUMP (born June 14, 1946) is an American politician, media personality, and businessman who served as the 45th President of the United States from 2017 to 2021. On November 5, 2024, Trump was elected as the 47th President of the United States.

ELON REEVE MUSK (born June 28, 1971) is a businessman and investor known for his key roles in the space company Space X and the automotive company Tesla, Inc. Other involvements include ownership of X Corp., the company that operates the social media platform X (formerly known as Twitter), and his role in the founding of The Boring Company, xAI, Neuralink, and OpenAI. He is one of the wealthiest individuals in the world; as of August 2024, *Forbes* estimates his net worth to be US$241 billion (Wikipedia, 2024).

Musk's influence and his Platform have the power to significantly affect public opinion. Although Musk was careful in making his comment with enough caveat (Fig. 14), some might overreact and believe that when the level of CO_2 goes past 1,000-ppm limit, it can have serious negative effects on people's health. I am particularly concerned about students and other followers of Musk who may be influenced by the Musk's magnetic message.

Trump – Musk Conversation on X August 12, 2024

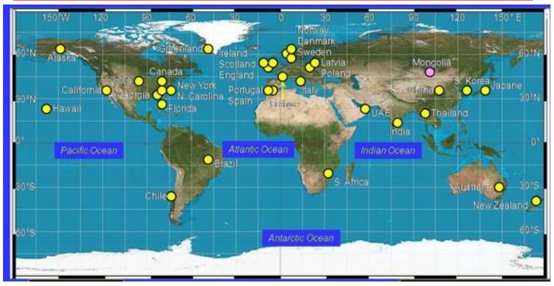
Musk states that:
[01:09:35] "But I think if you just keep increasing the plus per million in the atmosphere long enough, eventually it actually simply gets uncomfortable to breathe. People do not realize this. If you go past 1000 parts per million of CO_2 you start getting Headaches and nausea. We are now in the 400 range. We are adding, I think, about roughly two parts per million per year. It still gives us, what it means is we still have quite a bit of time."

Fig 14. Trump – Musk Conversation on X August 12, 2024
Source: Trump – Musk Conversation on X, 2024

In preventing this false narrative, the purpose of this article is to present empirical data from real-world examples, such as classrooms, conference rooms, aircraft cabins, and other indoor environments that already have over 1,000 ppm of

CO_2, without anticipated ill effects. I have considered a total of 80,302 empirical data points from 25 countries (Fig. 15), which include 79,372 classroom data points. I have also examined data from three U.S. conference rooms (i.e., Iowa, Georgia, and Florida) and 179 U.S. domestic flights among 770 global flights. Importantly, I provide the necessary geological and physiological details in establishing a sound scientific framework. Finally, I reiterate the U. S. Government policies, established by USDA, NRC, and OSHA, on this matter.

Global map showing CO_2 and CO Study Locations



CO Study Location *CO Study Location*

Fig 15. Global map showing CO_2 and CO Study Locations. *Data compiled by G. Shanmugam*

THE U.S. CO_2 STANDARD: 1,000 PPM LIMIT

The U.S. Guideline: ASHRAE (*American Society of Heating, Refrigerating and Air-Conditioning Engineers) (CO_2meter) considers that 1,000 ppm of CO_2* is the typical maximum value for indoor air quality (Table 1). In a recent article, Stumm (2022, p. 20) stated "…the indoor CO_2 level of 1,000 ppm reappears as a sensible, time–honored upper limit…"

Table 1. ASHRAE Carbon Dioxide Levels in the Classroom. From CO_2 meter (2024)

Serial Number	CO_2 (ppm)	Comments	Source
1	400	Normal outdoor air	ASHRAE
2	400-1,000	Typical CO_2 levels found indoors	ASHRAE
3	1,000-2,000	Common complaints of drowsiness or poor air quality	ASHRAE
4	2,000-5,000	Associated with headaches, fatigue, stagnant, stuffiness, poor concentration, loss of focus, increased heart rate, nausea	ASHRAE
5	> 5,000	Toxicity or oxygen deprivation may occur. This is the permissible exposure limit of the daily workplace exposure	ASHRAE
6	> 40,000	Immediately harmful due to oxygen deprivation	ASHRAE

ASHRAE = *American Society of Heating, Refrigerating, and Air-Conditioning Engineers*

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have developed ventilation guidelines that should maintain a comfortable environment for most occupants. The amount of fresh air that should be supplied to a room depends on the type of facility and room. For example, in elementary school classrooms, ASHRAE recommends 15 cubic feet per minute person of outdoor air (for a 1,000 square foot room occupied by 35 people). In office spaces, ASHRAE recommends 17 cubic feet per minute person (for a 1,000 square foot occupied by 5 people). In addition, a Minnesota Department of Labor and Industry (MNDOLI) Rule states that "outside air shall be provided to all indoor workrooms at the rate of 15 cubic feet per minute per person (MN Rule, 5205.110)".

These rates of ventilation should keep carbon dioxide concentrations below 1,000 ppm and create indoor air quality conditions that are acceptable to most individuals (MNDOH, 2024).

Carbon dioxide is not generally found at hazardous levels in indoor environments. The MNDOLI has set workplace safety standards of 10,000 ppm for an 8-hour period and 30,000 ppm for a 15-minute period. This means the *average* concentration over an 8-hour period should not exceed 10,000 ppm and the *average* concentration over a 15-minute period should not exceed 30,000 ppm. It is unusual to find such continuously high levels indoors and extremely rare in non-industrial workplaces. These standards were developed for healthy working adults and may not be appropriate for sensitive populations, such as children and the elderly.

Satish et al. (2012) have reviewed the Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance. Although typical outdoor CO_2 concentrations are approximately 380 ppm, outdoor levels in urban areas as high as 500 ppm have been reported (Persily 1997). Concentrations of CO_2 inside buildings range from outdoor levels up to several thousand parts per million (Persily and Gorfain 2008). Prior research has documented direct health effects of CO_2 on humans, but only at concentrations much higher than those found in normal indoor settings. CO_2 concentrations > 20,000 ppm cause deepened breathing; 40,000 ppm increases respiration markedly; 100,000 ppm causes visual disturbances and tremors and has been associated with loss of consciousness; and 250,000 ppm CO_2 (a 25% concentration) can cause death (Lipsett et al. 1994). Maximum recommended occupational exposure limits for an 8-hr workday are 5,000 ppm as a time-weighted average, for the Occupational Safety and

Health Administration (OSHA 2012) and the American Conference of Government Industrial Hygienists (ACGIH 2011).

The UK Guideline: Maximum CO_2 level is 2,000 ppm (Air Gradient, 2024a).

The Netherlands Guideline: Maximum CO_2 level is 1,200 ppm (Air Gradient, 2024a).

In short, there is no agreement among countries on the threshold limit of CO_2. For reference, I have inserted the ASHRAE's maximum indoor value of 1,000 ppm of CO_2 as the "U. S. Standard" in figures for reference purposes.

WHAT ARE THE SYMPTOMS OF DIFFERENT LEVELS OF CO_2 EXPOSURE?

According to the U.S. Government (USDA, 2024), the following are the symptoms of exposure to CO_2:

CO_2 is considered to be minimally toxic by inhalation. The primary health effects caused by CO_2 are the result of its behavior as a simple asphyxiant. A simple asphyxiant is a gas which reduces or displaces the normal oxygen in breathing air.

Symptoms of mild CO_2 exposure may include headache and drowsiness. At higher levels, rapid breathing, confusion, increased cardiac output, elevated blood pressure and increased arrhythmias may occur.

Breathing oxygen depleted air caused by extreme CO_2 concentrations can lead to death by suffocation.

5,000 ppm (0.5%) OSHA Permissible Exposure Limit (PEL) and ACGIH Threshold Limit Value (TLV) for 8-hour exposure

10,000 ppm (1.0%) Typically no effects, possible drowsiness

15,000 ppm (1.5%) Mild respiratory stimulation for some people

30,000 ppm (3.0%) Moderate respiratory stimulation, increased heart rate and blood pressure, ACGIH TLV-Short Term

40,000 ppm (4.0%) Immediately Dangerous to Life or Health (IDLH)

50,000 ppm (5.0%) Strong respiratory stimulation, dizziness, confusion, headache, shortness of breath

80,000 ppm (8.0%) Dimmed sight, sweating, tremor, unconsciousness, and possible death.

The response to CO_2 inhalation varies greatly even in healthy individuals. The seriousness of the symptoms is dependent on the concentration of CO_2 and the length of time a person is exposed. Since CO_2 is odorless and does not cause irritation, it is considered to have poor warning properties. Fortunately, conditions from low to moderate exposures are generally reversible when a person is removed from a high CO_2 environment.

CO_2 CONCENTRATION IN CLASSROOMS

As mentioned before, ASHRAE has established Carbon Dioxide Levels in the Classroom (Table 1).

CALIFORNIA, USA

In a comprehensive study of CO_2 concentrations in California schools, Chan et al. (2020) visited 104 classrooms from 11 schools that had recently been retrofitted with new heating, ventilation, and air-conditioning (HVAC) units. CO_2 concentration, room and supply air temperature and relative humidity, and door opening were measured for four weeks in each classroom. Field inspections identified HVAC equipment, fan control, and/or filter maintenance problems in 51% of the studied classrooms. Across 94 classrooms with valid data, average CO_2 concentrations measured during school hours had a mean of 895 ppm and a standard deviation (SD) of 263 ppm. However, in all 11 schools, measured CO_2 concentration in classrooms exceeded 1,100 ppm (Fig. 16).

Indoor CO_2 concentrations measured during school hours in 94 classrooms indicate classrooms frequently had **CO_2** at or above the sensor limit of 2,000 ppm (Fig. 17). There is no evidence that these students had suffered adverse health problems from exposure to excess **CO_2**.

All 11 Schools have classrooms where measured CO_2 concentration exceeded 1100 ppm in California (Yellow bar)

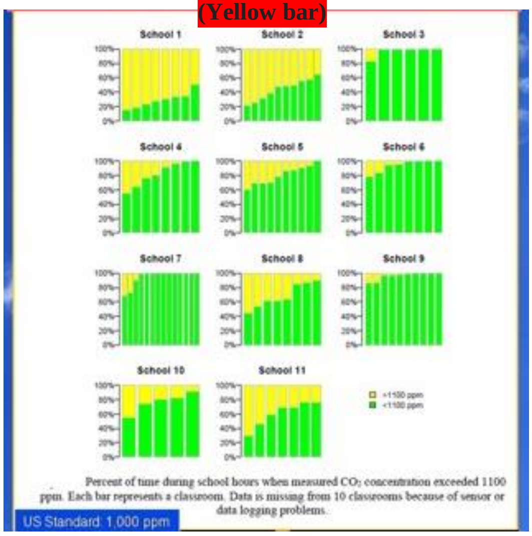


Fig 16 Source: Chan et al., (2020)
Additional labels by G. Shanmugam

Classrooms with CO_2 concentrationat or above2000 ppm in California (Yellow bar)

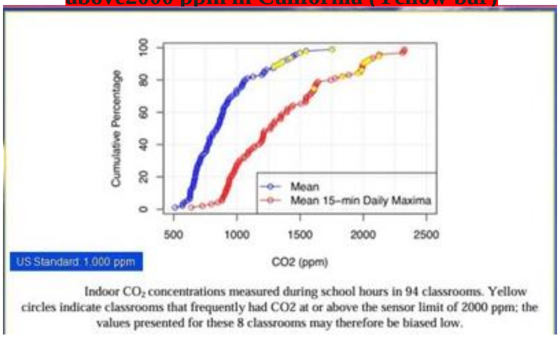


Fig. 17 CO_2>2000 ppm in California
Source: Chan et al., (2020) *Additional labels by G. Shanmugam*

NEW YORK, USA

Muscatiello et al. (2015) studied Classroom conditions and **CO_2** concentrations in 10 New York State Schools. They assessed the relationship between teacher-reported symptoms and classroom carbon dioxide (**CO_2**) concentrations. Previous studies have suggested that poor indoor ventilation can result in higher levels of indoor pollutants, which may affect student and teacher health. Ten schools (9 elementary, 1 combined middle/high school) in eight New York State school districts were visited over a 4-month period in 2010. Carbon dioxide concentrations were measured in classrooms over 48-h, and teachers completed surveys assessing demographic information and self-reported symptoms experienced during the current school year. Data from 64 classrooms (ranging from 1 to 9 per school) were linked with 68 teacher surveys (for four classrooms, two surveys were returned). Overall, approximately 20% of the measured classroom CO_2 concentrations were above 1,000 parts per million (ppm), ranging from 352 to 1,591 ppm.

Happer (2014) reported that in classrooms of colleges and universities, **CO_2** Levels average about 1,000 ppm.

NORTH CAROLINA, USA

Wilson (2022) reported that Higher than normal levels of CO_2 detected in a classroom in Wake County in North Carolina. Using a chart, she pointed out that how the carbon dioxide levels go up and down throughout the day. At 9:00 am the reading shows the CO_2 levels around 800 ppm but then climbs throughout the day, reaching the highest level of CO_2 around 2:00 pm at 3,200 ppm (Fig. 18).

CO_2 concentrationat measured at 3200 ppm in North Carolina Classroom

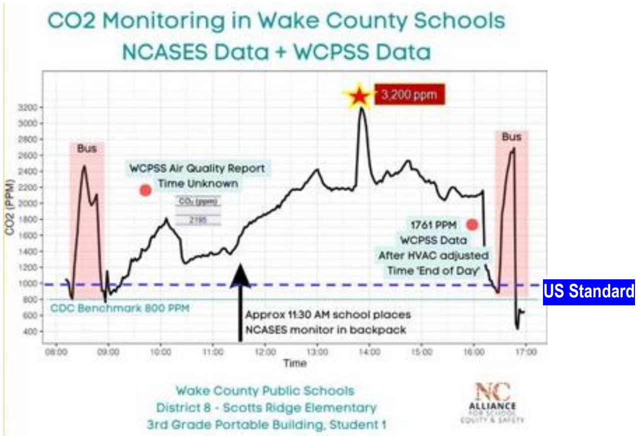


Fig. 18 CO_2 3200 ppm in North Carolina Classroom
Source: Wilson (2022) *Additional labels by G. Shanmugam*

HAWAII, USA

HIDOE (2022) reported that three classrooms out of 1,339 in Hawaii measured over 2,000 ppm of CO_2 (Table 2).

Table 2. Measured Maximum CO_2 concentration of over 2000 ppm in three classrooms in Hawaii

Tier	No. of Rooms
1 (< 800 ppm)	337
2 (800 - 1100 ppm)*	525
3 (1100 - 1500 ppm)	304
4 (1500 - 2000 ppm)	70
5 (> 2000 ppm)	3

US Standard

*1100 ppm approximates ASHRAE 62.1 HVAC design guidelines for 700 ppm above ambient carbon dioxide; ASHRAE 62.1 is used to guide the improvement of indoor air quality in existing buildings

Source: HIDOE (2022) *Additional labels by G. Shanmugam*

CANADA

The Quebec Government has released data from 76,122 classrooms across 3,246 schools in Quebec, Canada (CBC News, 2023). In the week before Christmas, 5,090 classrooms (6.7 per cent) exceeded the 1,500 ppm threshold. The most recent data also shows nearly a third of classrooms (33.2 per cent) recorded an average weekly CO_2 concentration of more than 1,000 ppm — the optimal limit according to Health Canada.

LONDON, ENGLAND, UK

Hama et al. (2023) studied CO_2 concentrations in 30 classrooms of primary schools in London, England, UK. Their study showed that CO_2 Concentrations exceeded the U.S. Standard of 1,000 ppm in many London classrooms (Fig. 19).

CO_2 Concentrations Exceed the US Standard of 1000 ppm in London Classroom, UK

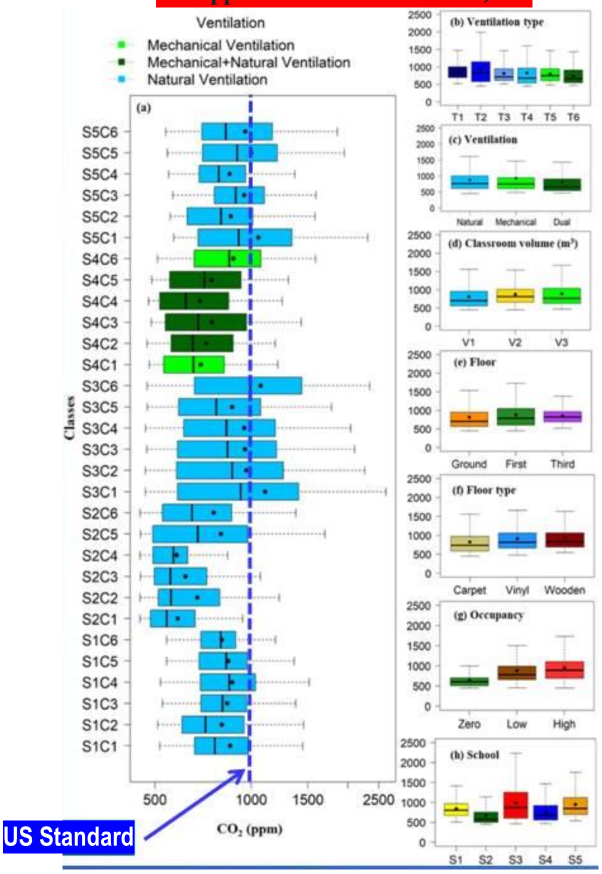


Fig. 19 Source: Hama et al., (2023)
Additional labels by G. Shanmugam

A LECTURE ROOM, UK

Greene et al. (2022) described the effects of high CO_2 concentration on the thermal comfort and academic performance of students during winter and summer in a large occupied lecture room. A large lecture room was chosen as the sample. This room was typical of other lecture rooms on the university's campus and similar to the other Universities within the UK. The results showed that CO_2 Concentrations exceeded 2,500 ppm in a Lecture Room for December 5th, 2008, UK (Fig. 13). This study also revealed that there is a positive correlation between the number of participants and the level of CO_2 concentration (Fig. 20).

On Wednesday May 6th, 2009, this study confirmed that high CO_2 concentration did affect the student's academic performance from 10am to 11am, when only 51%obtained higher than the passing 50% score on the test with CO_2 concentration ranging from 2,500 to 3,000 ppm.

SCOTLAND, UK

Bain-Reguis et al. (2022) studied indoor CO_2 and Thermal Conditions in 20 Scottish Primary School Classrooms with different ventilation systems during the COVID-19 Pandemic.

These classrooms are labeled A1, A2, A3, A4, A5, B1, B2, B3, B4, B5, C1, C2, C3, C4, C5, D1, D2, D3, D4, and D5. The recommended thresholds for room occupancy as provided by Scottish Government advice were 1,500 ppm for normal teaching classrooms. By comparison, the U.S. has 1,000 ppm limit. Surprisingly, CO_2 Concentrations exceed the Scottish Standard of 1,500 ppm in 11 out of 19 classrooms during the COVID-19 Pandemic in Scotland (Fig. 21). This observation is perhaps the most convincing evidence that humans can and do function normally when the CO_2 concentration exceeds the 1,000 ppm limit.

CO_2 Concentrations Exceed 2500 ppm in a Lecture Room, UK

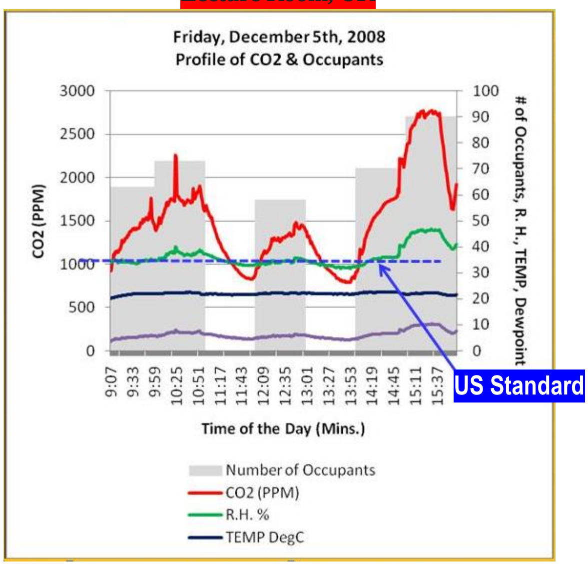


Fig. 20 Source: Greene et al., (2012)
Additional labels by G. Shanmugam

CO_2 Concentrations Exceed Scottish standard of 1500 ppm in 11out of 15 Classrooms during school hours in Scotland

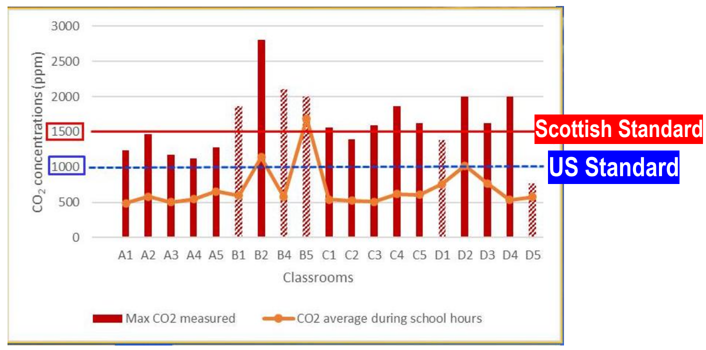
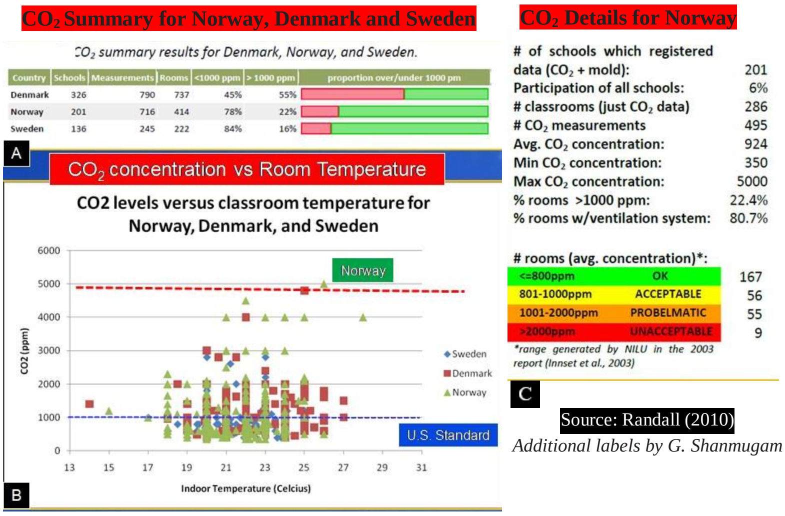


Fig. 21 Source: Bain-Reguis et al., (2022)
Additional labels by G. Shanmugam

IRELAND

As part of the AMBER (Assessment Methodology for Building Energy Rating) project, IES (2024) has developed a monitoring and control system for ensuring adequate ventilation in spaces to minimize the risk and spread of COVID-19 in Ireland. The project had already identified the importance of monitoring CO_2 and had highlighted a number of serious issues with respect to the CO_2 levels in both homes and schools. In some instances, the CO_2 levels in schools were rising <u>to over 6,000 ppm. This is the highest value reported among 80,302 classrooms considered from 25 countries in this study.</u>



Country	Schools	Measurements	Rooms	<1000 ppm	> 1000 ppm
Denmark	326	790	737	45%	55%
Norway	201	716	414	78%	22%
Sweden	136	245	222	84%	16%

Fig. 22 A). CO_2 Summary for Norway, Denmark abd Sweden, B). CO_2 concentration vs Room Temperature, C). CO_2 Details for Norway from Randall (2010)

NORWAY, DENMARK, AND SWEDEN

Randall (2010) studied CO_2 concentration in 1,373 classrooms from Norway, Denmark, and Sweden in 2009.

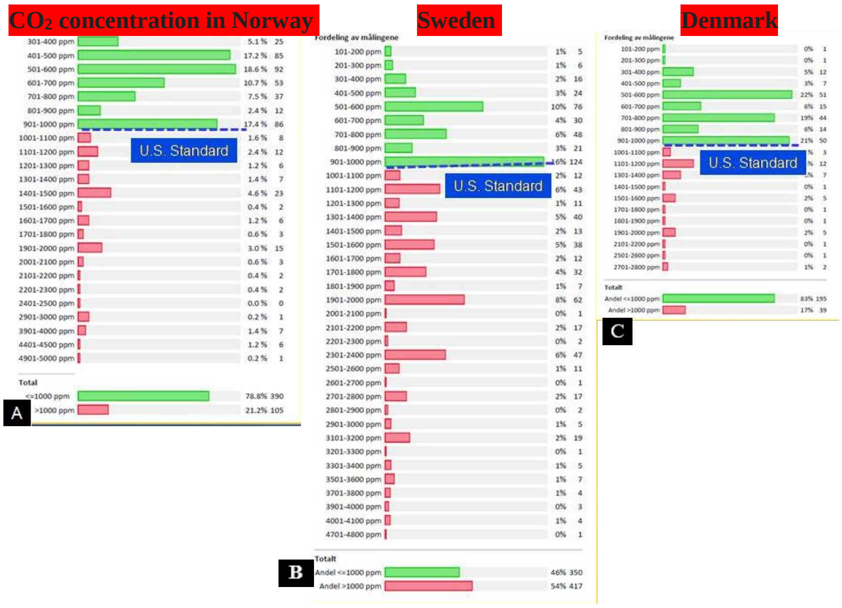


Fig. 23 Norway, Denmark and Sweden Source: Randall (2010) *Additional labels by G. Shanmugam*

<u>Summary</u>

Project: 2009 Scandinavian student-based research campaign Institution: Institute for Air Research (NILU) Countries: Norway, Denmark, and Sweden

Total Number of Classrooms: 1,373

Total Number of students: 12,000

Maximum CO_2 concentration measured: 5,000 ppm in Norw (Fig. 22B)

Maximum % rooms with CO_2 concentration: >1000 ppm: 54% Denmark (Fig. 23B)

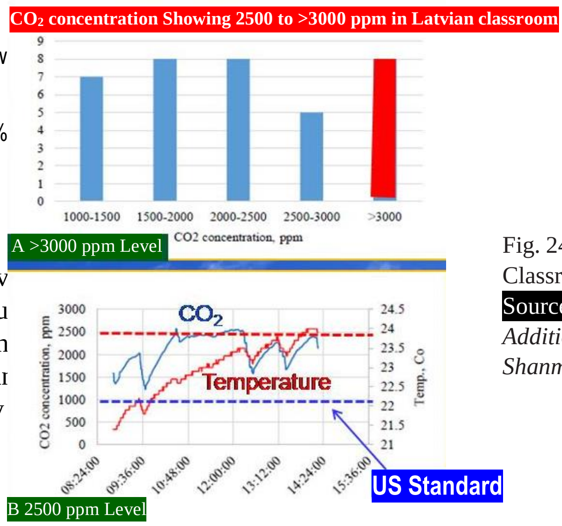


Fig. 24 > 3000ppm in Latvian Classroom

Source: Zemitis et al., (2021)

Additional labels by G. Shanmugam

LATVIA

Zemitis et al. (2021) studied 9 classrooms Latvia. They reported that CO_2 concentration lev averages of about 2,380 ppm and the absolu maximum of 4,424 ppm. The field results show th >3,000 ppm level of CO_2 is common (Fig. 24A), ar that the CO_2 concentration (blue line) consistently above 1500 and reaches 2,500 ppm (Fig. 24B).

At the start of the year 2019, there were 707 educational institutions and 214,002 pupils in Latvia, according to information from the Ministry of Education and Science. Bogdanovica et al. (2020) documented CO_2 concentration values above 2,000 ppm in a Latvian classroom (Fig. 25). They have also reported a weak positive correlation between CO_2 concentration and the percentage of pupils with headache. The correlation coefficient is r = 0.31 (Fig. 26b) The results of the survey show that indoor IEQ, overheating and fatigue ratings, as well as headaches per hour, have a moderate correlation with CO_2 concentration in the classroom, so CO_2 concentration may have the potential to influence student well-being at school, but the correlation is not strong because well-being is affected by many other factors. The occurrence of headaches in the learning process is not direct evidence of their correlation with the increase in CO_2 concentration in the room, as the period of non-compliance with the CO_2 concentration standard may be too small for pupils to suffer from headaches. Headaches can also be caused by other factors, such as sickness or sleep deprivation in students, and difficulties in understanding the class subject.

CO_2 concentration values above 2000 ppm in Latvian classroom

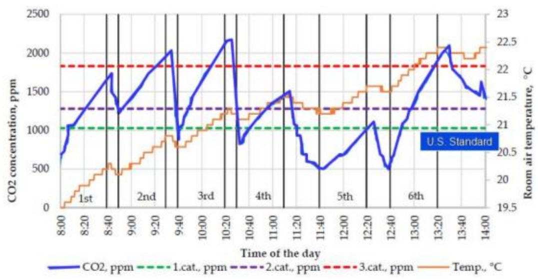


Fig. 25 > 2000ppm in Latvian Classroom

Source: Bogdanovica et al., (2020) *Additional labels by G. Shanmugam*

A weak positive correlation between CO_2 concentration and the percentage of pupils with headache in a Latvian classroom. The correlation coefficient is r = 0.31

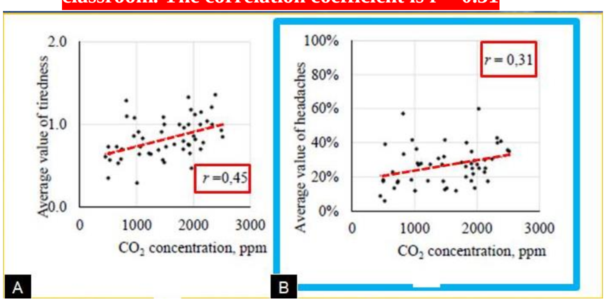


Fig. 26 A weak positive correlation between CO_2 concentration and the percentage of pupils with headache in a Latvian classroom. The correlation coefficient is r = 0.31.

Source: Bogdanovica et al., (2020) *Additional labels by G. Shanmugam*

COIMBRA, PORTUGAL

Ferreira and Cardoso (2013) studied air quality in 51 elementary schools (81 classrooms) in the city of Coimbra, Portugal, both inside and outside of the rooms was evaluated during the four seasons, from 2010 to 2011. In 47 schools, the average CO_2 concentrations were above the maximum reference concentration (984 ppm) mentioned in Portuguese legislation. The maximum concentration values found inside the rooms were critical, especially in the fall/winter (5,320 ppm). This is the second highest value reported among 80,302 classrooms considered from 25 countries in this study.

POLAND AND SPAIN

Krawczyka et al. (2016) compared CO_2 concentration values in 8 classrooms from Poland and Spain. Carbon dioxide concentration was in the range between +0 and +5,000 ppm with precision ±50 ppm (±2%); between5,000 ppm and 10,000 ppm with precision ±100 ppm (±3%); and atmospheric pressure was in the range between +600 and +1150 hPa with precision ±5 hPa. (Krawczyka et al. (2016) compared CO_2 concentration values in 8 classrooms from Poland and Spain. Carbon dioxide concentration was in the range between +0 and +5,000 ppm with precision ±50 ppm (±2%); between5,000 ppm and 10,000 ppm with precision ±100 ppm (±3%); and atmospheric pressure was in the range between +600 and +1150 hPa with precision ±5 hPa. Concentration of CO_2 in classroom 2 in Białystok (Poland) exceeds the U.S. Standard (Fig. 27A). Concentration of CO_2 in classroom 5 in Belmez (Spain) is below the U.S. Standard (Fig. 27B).

CO_2 concentration in Poland and Spain with reference to US Standard

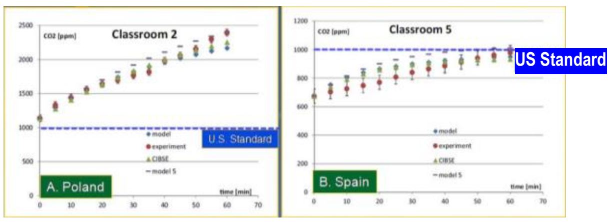


Fig. 27 CO_2 concentration in Poland and Spain.

Source: Krawczyka et al., (2016) *Additional labels by G. Shanmugam*

FRANCE

Canha et al. (2016) reported that the French Departmental Health Regulations mandate that concentrations do not exceed 1,300 ppm at any time in rooms in which smoking is prohibited. However, the studied classrooms presented CO_2 concentration above 1000, 1300, and 1500 ppm during 65%, 46%, and 35% of the occupied period, respectively.

Table 3. Distribution of the CO_2 concentrations (ppm) in French Classrooms.

Distribution of the CO_2 concentrations (ppm) during the occupied period over the sampling week (n = 50 classrooms)

CO_2 concentration (ppm)	Mean	Min	P5	P25	Median	P75	P95	Max
Weekly mean	1290	530	730	970	1250	1670	1900	2220
Minimum	440	360	380	410	430	460	570	600
Maximum	2440	580	1080	1880	2320	3180	3890	4310

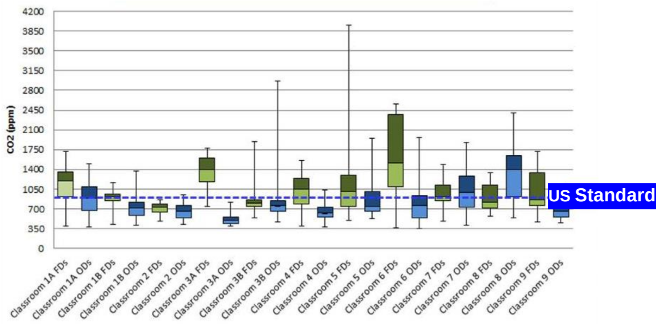
Source: Source: Canha et al. (2016) *Additional labels by G. Shanmugam*

They also documented the overall results of the CO_2 concentration measurements for the studied Classrooms during the period of occupancy. The mean CO_2 concentration in the 50 studied classrooms was 1,290 ppm during the occupied period, with a median of 1,250 ppm and a maximum of 2,220 ppm. The absolute measured maximum was 4,310 ppm (Table 3).

ITALY

Di Gilio et al. (2021) studied CO_2 concentration inside 9 schools (11 classrooms) located in Apulia Region (South of Italy) during the reopening of schools after the lockdown due to COVID-19 pandemic. Although, during the first evaluation stage, air ventilation through the opening of windows and doors was guaranteed, 6 (54%) classrooms showed mean values of CO_2 higher than 1,000 ppm and almost all classrooms exceeded the recommended CO_2 concentration limit value of 700 ppm (Fig. 28). In one case, CO_2 concentration exceeded 2,300 ppm (Fig. 28).

CO_2 concentration value exceeds 2300 ppm in an Italian classroom



First Stage evaluation (FDs green color Second Stage evaluation (Other days blue

Fig. 28. > 2300 ppm in an Italian Classroom.
Source: Di Gilio et al., (2021) *Additional labels by G. Shanmugam*

UNITED ARAB EMIRATES

In their annual indoor air quality assessment for the Abu Dhabi National Oil Company (ADNOC) Schools, the Abu Dhabi Education Council has reported hazardous levels (~3000 ppm) of carbon dioxide in 15 classrooms. In their study of indoor air quality in 15 classrooms in the United Arab Emirates, Abu-Rahmah et al. (2021) reported that CO_2 concentration ranged between 2,625 and 3,382 ppm under "Precleaning AC filters" conditions (Table 4). Even after cleaning of AC filters, CO_2 concentration exceeded 1,000 ppm in these 15 classrooms (Table 4).

Table 4. Measured CO_2 concentrations in 15 schools in the United Arab Emirates

: Indoor air-quality parameters precleaning and postcleaning the AC filters.

Location	Code	Vol. (m^3)	No. of occupants	Grade level	Precleaning AC filters: CO_2 levels (ppm)	T (°C)	RH (%)	CO_2 indoor/ outdoor	Postcleaning AC filters: CO_2 levels (ppm)	T (°C)	RH (%)	CO_2 indoor/ outdoor
Arabic classroom	G138	238	12	9	2,893	27	63	6.90	1,048	25	38	2.50
Arabic classroom	G132	238	17	7	3,098	26	67	7.40	1,318	24	42	3.15
Math classroom	G009	253	7	12	2,897	25	63	6.91	1,189	24	37	2.84
English classroom	G008	156	8	12	3, 311	25	64	7.90	1,308	24	38	3.12
Chemistry lab	G123	140	10	10	2,792	24	69	6.66	1,033	23	43	2.47
Cafeteria	G106	756	44	6–12	3,381	25	66	8.00	1,087	24	41	2.60
Physics lab	G083	349	13	12	2,778	25	65	6.63	971	24	39	2.32
Hum. classroom	G074	196	10	8	3,009	24	65	7.18	1,272	23	41	3.00
Hum. classroom	G075	196	13	8	2,625	25	62	6.26	1,330	24	34	3.17
Arabic classroom	G134	238	17	7	3,117	25	61	7.44	1,286	24	32	3.07
Art lab	G087	349	21	10	3,107	25	65	7.42	1,046	24	39	2.50
Math classroom	G014	253	9	11	2,822	25	60	6.74	920	24	32	2.20
Physics lab	G080	349	19	11	2,897	25	61	6.91	1,167	24	32	2.80
Hum. classroom	G072	196	19	6	3,275	24	60	7.82	1,014	23	31	2.42
English classroom	G020	156	20	10	2,993	25	61	7.14	763	24	34	1.82
Time-based averages					~3000	~25	~63	~7.2	~1,117	~24	~37	~2.7

Source: Abu-Rahmah (2021) *Additional labels by G. Shanmugam*

INDIA

Soomro et al. (2018) studied five classrooms in Hyderabad City in India. Three of them had CO_2 concentration over 1,000-ppm limit (Table 5).

SOUTH AFRICA

van der Walt et al. (2024) studied CO_2 and temperature every 11 min in 24 classrooms at two schools in Stellenbosch, South Africa. Container classrooms with and without insulation, mobile (prefabricated) classrooms, and brick classrooms of different configurations were included. Measurements were concurrently sampled over

Table 5. Measured CO_2 concentrations over 1,000 ppm in 3 schools in Hyderabad City in India

Institute	Time	Average Temperature (°C)	Average Humidity (%)	Average atmospheric pressure (hpa)	Average wind speed (m/s)	CO_2 concentration (ppm)	Occupancy	Gender	
								Male	Female
CR1	9:30	36	23	1012	4.44	1378	40	40	00
	10:00	32	24	1012	4.44	1231	40	40	00
	10:30	38	22	1012	4.44	1298	40	40	00
CR2	9:30	36	32	1013	4.44	478	20	10	10
	10:00	32	24	1012	4.44	498	20	10	10
	10:30	34	20	1012	4.44	518	20	10	10
CR3	8:00	33	15	1012	3.88	1058	37	22	15
	8:30	34	16	1012	4.16	1178	37	22	15
	9:00	35	11	1012	4.16	1198	37	22	15
CR4	5:30	35.5	30	1012	2.22	798	14	8	6
	6:00	35.5	28	1013	4.16	848	14	8	6
	6:30	35.5	20	1012	4.16	896	14	8	6
CR5	5:30	30.4	42.6	1010	2.22	1318	53	53	00
	6:00	32	45	1011	2.77	1413	53	53	00
	6:30	33	40	1012	4.16	1428	53	53	00

Source: Soomto et al., (2018) *Additional labels by G. Shanmugam*

twelve months, across multiple seasons with relevant metadata, including ambient weather conditions. They analyzed temperature and CO_2 concentrations for classroom types and classroom categories and compare school days with non-school days. The results show that temporary classrooms (container and mobile) have substantially worse thermal environments, even when air conditioning is available. The CO_2 concentrations in container classrooms were substantially worse with CO_2 concentration values above 1,000 ppm during all seasons (Fig. 29).

CO_2 concentration value aboves 1000 ppm in Container schools during all seasons in South African Primary School classrooms

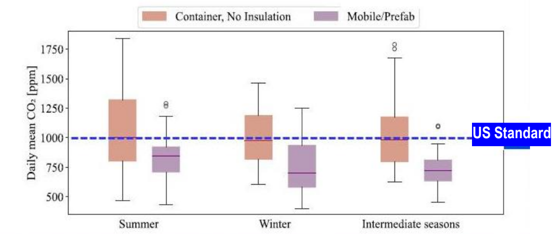


Fig. 29 South Africa Source: Van der Wall et al., (2024) *Additional labels by G. Shanmugam*

SOUTH KOREA

Han et al. (2022) studied CO_2 concentration in Elementary School Classrooms in Seoul, South Korea. They published an example of CO_2 concentration changes over time in three classrooms, one each with no air cleaner, one air cleaner and two air cleaners, used for 27–28 students in the second grade at S school. Regardless of the presence of an air cleaner, the initial CO_2 concentration in all three classrooms was approximately 500 ppm, and it increased to 2,500–3,000 ppm during class, decreased by approximately 100–700 ppm during playtime, and then increased again to 3,000 ppm (Fig. 30). During lunchtime, the initial CO_2 concentration decreased to 1,500–2,000 ppm and then increased again to 3,000 ppm during afternoon class. Most of the classrooms were closed environments because measurements were taken during early winter, and thus CO_2 levels continued to increase during class time due to lack of ventilation. Nevertheless, students attended these classes during class hours with >1,000 ppm of CO_2.

Increase in CO_2 concentration to 3000 ppm during class hours in Elementary School Classrooms, Seoul, South Korea

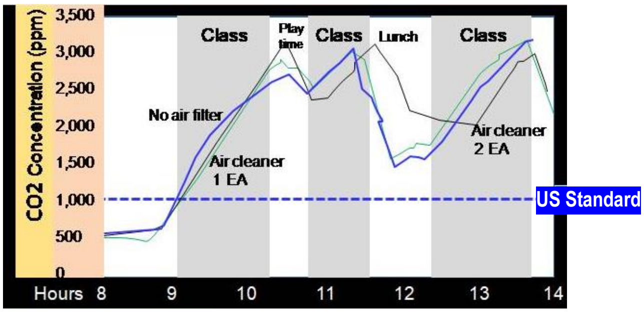


Fig. 30 Increase in CO_2 concentration to 3000 ppm during class hours in Elementary School Classrooms, Seoul, South Korea

Redrawn from Han et al.,) *Additional labels by G. Shanmugam*

AUSTRALIA

Andamon et al. (2023) reported on pre-pandemic field measurements of CO_2 concentration levels conducted for an academic year in 10 classrooms from four primary and a secondary schools in Victoria, Australia. Measured CO_2 concentrations across the 10 classrooms which were operated with a mix of intermittent natural ventilation and air-conditioning for cooling or heating, on average ranged between 657 ppm and 2,235 ppm during school hours with median over 1,000 ppm in 70% of classrooms.

Across the four seasons, which approximately corresponds to the four school terms, all classrooms exceeded 1,000 ppm for the median peak concentration levels and showed similar median levels ranging from a narrow band of 1169 ppm–1,359 ppm for average CO_2 concentration levels, exceeding 2500 ppm with wider range of 2655 ppm–3558 ppm for peak median maximum CO_2 concentrations and 2121 ppm–2,397 ppm for the 95% of 15-min moving average. The maximum values for peak maximum CO_2 concentrations ranged from 3,799 ppm to 5,000 ppm recorded in 3 classrooms (Fig.31). During all seasons, maximum measured concentrations of CO_2 range between 2,000 and 4,200 ppm (Fig. 31).

Peak Maximum CO_2 concentration values range from 3799 ppm to 5000 ppm in three Australian Schools

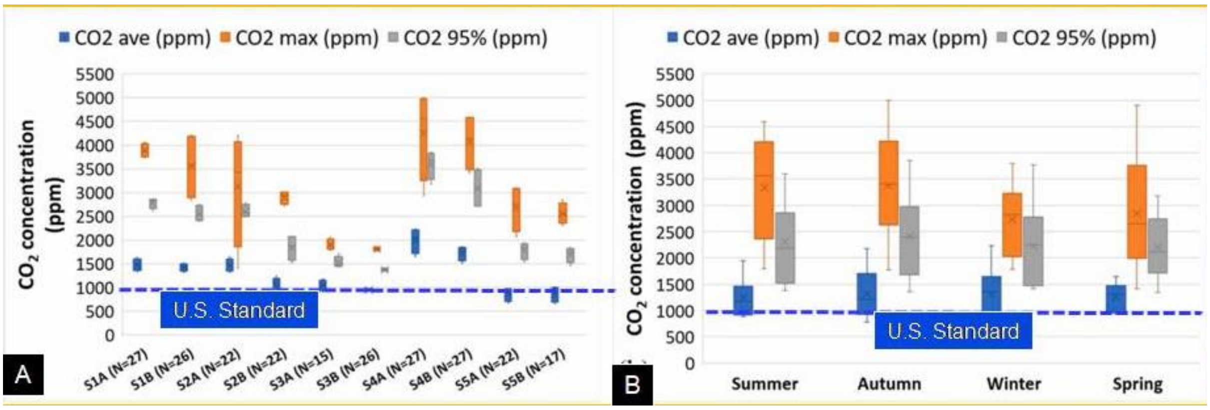


Fig. 31 Peak Maximum CO_2 concentration values range from 3799 ppm to 5000 ppm in 3 Australian School Classrooms
Source: Andamon Rajagopalan & Woo (2023) *Additional labels by G. Shanmugam*

NEW ZEALAND

BRANZ (2019) conducted a study of air quality in 28 classrooms in 10 schools in New Zealand. In New Zealand new school buildings, the Ministry of Education requires that the average concentration of CO_2 should not exceed 1,500 ppm. By comparison, the U.S. Standard is 1,000 ppm.

- Inside the Wellington classroom, the CO_2 average concentration in school hours was almost 900 ppm.
- In the Auckland schools of the SKOMOBO trial, CO_2 in one classroom exceeded 1,000 ppm for 66% of school time and 1,500 ppm for 40% of the day in winter. In spring, CO_2 rates were mostly below 1,000 ppm.
- In Hawke's Bay, weekly average CO_2 measurements were consistently over 1,000 ppm year round. Students in one classroom experienced high CO_2 levels the whole year, with summer levels around 2,000 ppm. Windows were not being opened.
- In Christchurch, over half of the averages were above 1,200 ppm, with one room reaching 2,800 ppm in winter and another 3,800 ppm in autumn. In one classroom, students were exposed to CO_2 levels of 2,000–3,000 ppm for a whole week in winter. In another, CO_2 levels were above 2,000 ppm for most of the year.
- In Dunedin, 53% of the weekly averages were below (or around) 1,000 ppm. No students were exposed to CO_2 above 2,000 ppm.

According to BRANZ (2019), these CO_2 concentrations, although exceeds 1,000 ppm in some cases, are unlikely to be a significant health risk but are more likely to have a temporary impact on performance.

JAPAN

Senseair (2024) studied CO_2 concentrations in 13 classrooms on a daily basis at Tagoura Junior High School in Japan. CO_2 concentrations exceeded the U.S. Standard limit of 1,000 ppm (Fig. 32).

CO_2 concentration in 13 Classrooms at Tagoura Junior High School, Japan

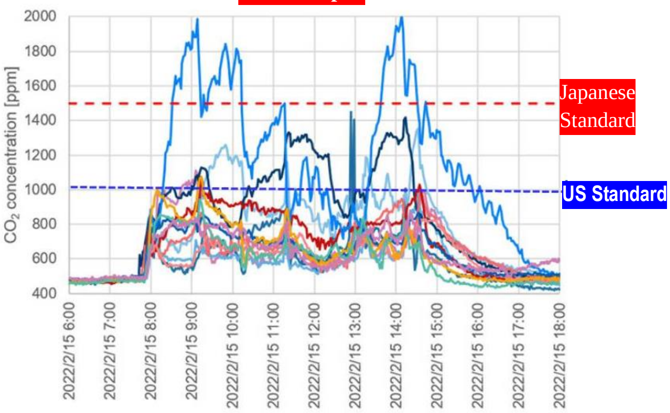


Fig. 32 CO_2 concentration in 13 Classrooms at Tagoura Junior High School, Japan
Source: Senseair (2024) *Additional labels by G. Shanmugam*

CHINA

Lee and Chang (2000) examined five classrooms in Hong Kong (HK), air-conditioned or ceiling fans ventilated, for indoor and outdoor air quality. They found that maximum indoor CO_2 level reached 5,900 μl/l during class at the classroom with cooling tower ventilation.

The subsample of the CIEHS 2018 study was performed in 66 classrooms of 22 primary schools nationwide in China by Zhu et al. (2021). This study found that CO_2 levels exceeded the recommended limit of CO_2. All these examples suggest that students worldwide are attending schools where CO_2 concentration values are often above 1,000 ppm.

THAILAND

AirGradient (2024b) studied CO_2 levels in 30 classrooms in the city of Chiang Mai in Northern Thailand. They analyzed the high CO_2 values of 2,000 to 3,000 ppm as follows (Fig. 33).

- When the school opens at 8 am, CO_2 levels began to rise from the initial amount of 1,000ppm (and not the typical outside CO_2 of around 400ppm).
- By 10 am, CO_2 levels skyrocket to over 2,000ppm.
- By 12 pm, the amount of CO_2 peaks beyond 3,000ppm.
- After 12 pm, CO_2 levels drop by a normal rate. This is perhaps due to students going out of the room for their lunch break, allowing fresh air to circulate.
- By 3 pm, CO_2 levels drop below 1,000ppm as students go home

The average during the school day in this particular classroom is approximately 2,080 ppm CO_2. But there are no observed effects of high CO_2 levels on students from this study.

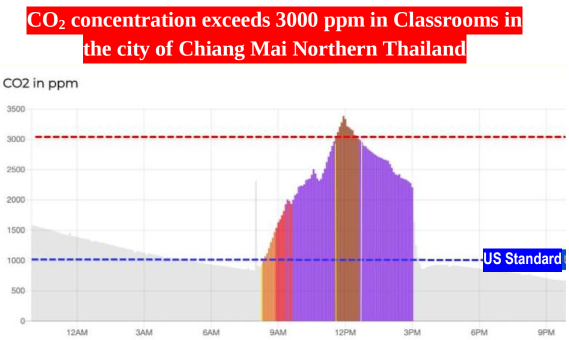


Fig. 33 CO_2 concentration exceeds 3000 ppm in Classrooms in the city of Chiang Mai Northern Thailand

Source: AirGradiant (2024b) *Additional labels by G. Shanmugam*

BRAZIL

Jurado et al. (2014) evaluated the indoor air quality in Brazilian universities by comparing thirty air-conditioned (AC) (n = 15) and naturally ventilated (NV) (n = 15) classrooms. The levels of CO_2 in the AC rooms were significantly higher than CO_2 in the NV rooms (1,433.62 ± 252.80 and 520.12 ± 37.25 ppm, respectively).

CONCEPCIÓN, CHILE

Rivera (2020) conducted field studies in 9 schools and 28 classrooms in the city of Concepción, Southern Chile. CO_2 concentrations average 1600 ppm in fall and 1900 ppm in winter, exceeding the maximum threshold of 1,000 ppm in densely occupied spaces according to EPA and ASHRAE Standard 62.1-2016. Indoor Air quality profile measurements of CO_2, during one school day school in the fall, shows a maximum of 5,000-ppm

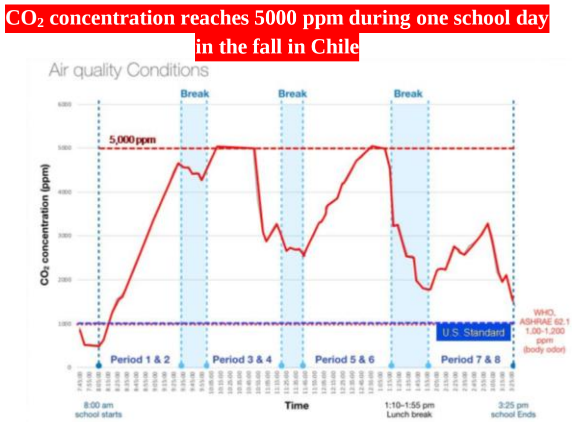


Fig. 34 CO_2 5000 ppm in Chile

Source: Rivera (2020) *Additional labels by G. Shanmugam*

concentration value (Fig. 34)

Data gathered for this study show that in indoor classrooms and other settings, CO_2 concentration commonly range between 2,000 and

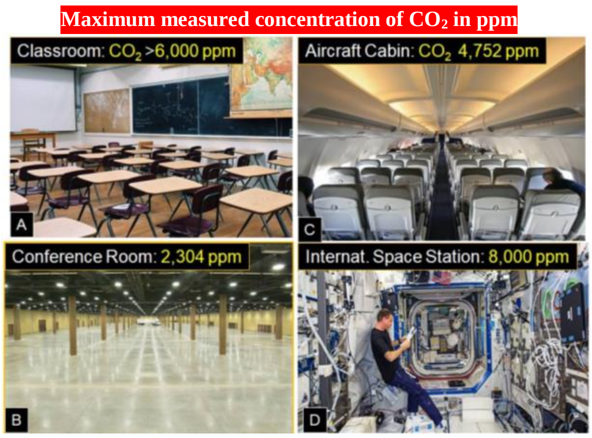


Fig. 35 Maximum measured concentration of CO_2 in ppm in various settings. A). Clasroom CO_2 >6000 ppm (IES, 2024) B). Conference room 2304 ppm (Teleszewski et al., 2019) C). Aircraft Cabin 4752 ppm (COT, 2022) D). International Space Station 8000 ppm (Moser 2023).

6,000 ppm (Fig. 35).

CO_2 CONCENTRATION IN CONFERENCE ROOMS, USA

We have examined data from three conferences held in three different States in the US, namely Iowa, Georgia, and Florida in 2024 (Fig. 29). The 2024 Florida Homeschool Convention was the largest of the three in terms of attendees with measured value of CO_2 at 1,248 ppm (Fig. 36). There is no evidence that these conference attendees had suffered from exposure to excess **CO_2**.

We found that there is a general increase in **CO_2** concentration values with increasing number of attendees (Table 6).

Increase in CO_2 concentration in ppm with increase in number of Conference Attendees

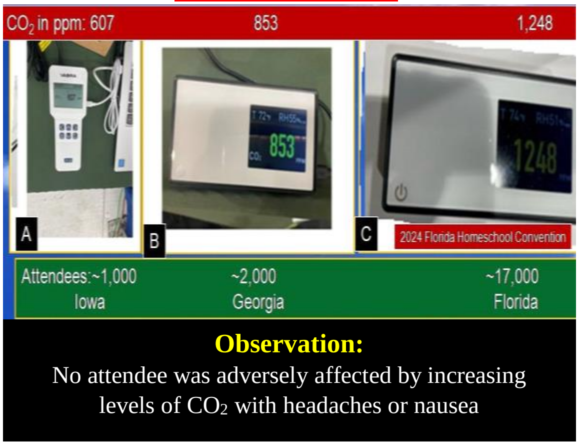


Fig. 36 Increase in CO_2 concentration in ppm with increase in number of Conference Attendees in the US

Table 6. Number of attendees and measured CO_2 in three conferences in the USA (Fig. 29). Courtesy of Angela Wheeler, The CO_2 Coalition

Serial Number	State (USA)	Number of Attendees	Measured CO_2 (ppm)
1	The Homeschool Iowa Convention West Des Moines, Iowa June 14 and 15, 2024	~1,000	107
2	The Southeast Homeschool Convention Atlanta, Georgia July 26 and 27, 2024	~2,000	853
3	The Florida Homeschool Convention Kissimmee, Florida May 23-25, 2024	~17,000	1,248

CO_2 CONCENTRATION IN A CONFERENCE ROOM, POLAND

Carbon dioxide levels were measured in a conference room in the building of the Faculty of Civil and Environmental Engineering at Białystok University of Technology by Teleszewski et al. (2019). This building is located in the city of Białystok, Poland, Maximum CO_2 concentration was 2,304 ppm (Table 7).

Table 7. Measured maximum CO_2 concentration of 2304 ppm in a Conference room at Bialstok University technology, Poland

Series no.	Date	Number of persons n	$\gamma = n/V$	Average relative humidity	Initial concentration of CO_2	Air change rate m	Time of prior airing with open windows
–	–	person	person/m^3	%	ppm	h^{-1}	min
1	12/04/2017	53	0.17	44.46	607	0.1	720
2	17/05/2017	48	0.16	48.82	457	0.001	720
3	05/07/2017	54	0.17	55.71	754	6.7	60
4	15/11/2017	59	0.19	45.84	553	2	720
5	13/12/2017	53	0.17	41.73	536	1	720
6	17/01/2018	56	0.18	42.90	1658	8.2	0
7	14/02/2018	53	0.17	40.15	549/2304	0/7.5[a]	720

Source: Teleszewski et al,. (2019) *Additional labels by G. Shanmugam*

CO_2 CONCENTRATION IN A CONFERENCE ROOM, CHINA

Wang et al. (2022) studied four conference rooms in China using both measurements and simulations of CO_2 concentration (Fig. 37). Measured values exceeded 1,800 ppm (Fig. 30A). In simulations, with the doors and windows closed, in winter the peak value of CO_2 concentration in ROOM D could reach 3200 ppm, while in summer, was up to 3500 ppm (Fig. 37 B). The CO_2 concentration at 12:00 (three hours after the meeting) reduced to 1000 ppm in winter.

Measured and Simulated CO_2 concentration values in Conference Rooms China

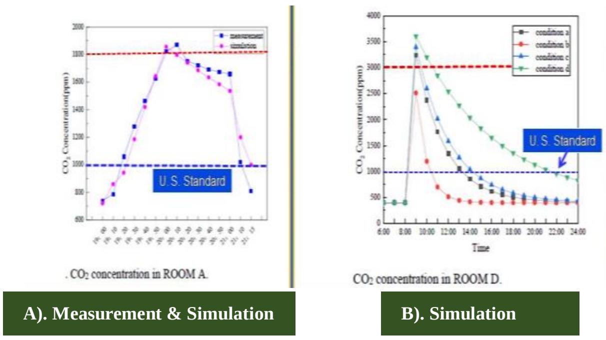


Fig. 37 Conference Rooms, China Source: Wang et al., *Additional labels by G. Shanmugam*

CO_2 CONCENTRATION IN GREENLANDIC DWELLINGS

A comprehensive study of indoor air quality was performed by Kotol et al. (2014) in Sisimiut, Greenland in 2011/2012. A cross sectional study in 79 dwellings was performed. In summer, the average CO_2 concentrations ranged from 467 ppm to 877 ppm and in winter from 438 ppm to 2368 ppm. The highest concentrations appeared in bedrooms with the absolute measured maximum of 4,687 ppm. The CO_2 concentrations were above 1370 ppm for 2% of time in the summer and for 30% of time in the winter. The CO_2 concentrations we measured in Greenlandic bedrooms were generally higher compared to CO_2 concentrations measured in other studies conducted in Denmark and Alaska. This may likely be due to lower ventilation rates in Greenlandic dwellings.

CO_2 CONCENTRATION IN STUDENT HOUSES, FAIRBANKS, ALASKA

Kotol (2014) studied four student houses for indoor air quality in Fairbanks, Alaska. He reported thatCO_2 concentration reached a maximum of 2,500 ppm (Fig. 38).

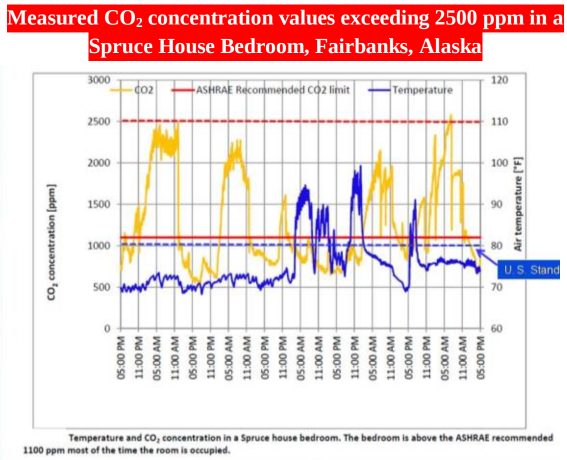


Fig. 38 Spruce House Bedroom, Fairbanks, Alaska

Source: Kotol (2014) *Additional labels by G. Shanmugam*

CO CONCENTRATION IN MONGOLIAN HOUSEHOLDS

Cowlin et al. (2006) studied CO concentration, but not CO_2, in 58 households in Ulaanbaatar, Mongolia (Fig. 39). In homes with all stove types, the average level of indoor concentrations of PM and CO exceeded Mongolian national standards for 24-hour concentrations, and in the case of PM, the excess exposure was large. The Mongolian national standard for 24-hour CO is 2.6 parts per million (ppm), and the average of 24-hour CO concentrations over all households was 9.5 ppm. The Mongolian national standard for 24-hour average total suspended particles is 150–200

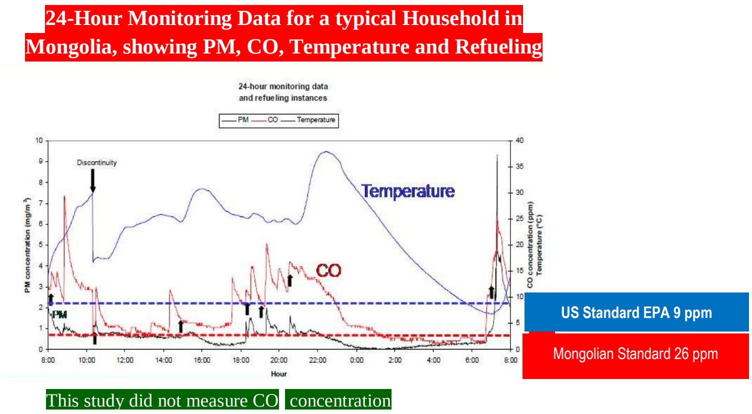


Fig. 39 24-Hour Monitoring Data for a typical Household in Mongolia, showing PM, CO, Temperature and Refueling

Source: Cowlin et al,. (2006) *Additional labels by G. Shanmugam*

micrograms per cubic meter (µg/m3), and the average 24-hour observed PM concentration was 730 µg/m3 over all households.

CO_2 CONCENTRATION IN AIRCRAFT CABINS

U.S. DOMESTIC AND INTERNATIONAL FLIGHTS

COT (Committee on the Toxicity) (2022) reviewed approximately 770 U,S. Domestic and International flights for in-flight cabin air quality.

REVIEW SUMMARY

- The highest mean value of CO_2 reported in aircraft was 1903 ppm and the maximum value was 4,752 ppm (Table 8, Fig. 40).
- Levels of CO and CO_2 in aircraft were collated and compared with regulatory values in aircraft, air quality standards as well as levels that cause adverse health effects.
- For CO_2 measured in aircraft worldwide, many mean and maximum concentrations exceed the ASHRAE aircraft standard (1100 ppm) and maximum concentrations exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm).
- In EU flights, maximum concentrations also exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm), but mean and maximum concentrations are lower than CS aircraft standards (5000 ppm).
- For CO, mean and maximum concentrations measured in aircraft worldwide are below all regulatory values for aircraft and air quality standards, with the exception of the World Health Organization (WHO) Air Quality Guideline (AQG) of 4 mg/m^3 (2.2 ppm). No mean data are available for EU flights but maximum concentrations are below regulatory values for aircraft and air quality standards, with the exception of the WHO AQG.
- Following the ban on smoking in commercial flights in 1997, CO_2 and CO concentrations showed a slight decreased

trend or appeared largely unaffected, respectively.

- All concentrations of CO_2 and CO reported are below levels that are reported to cause adverse health effects. Therefore, no adverse health effects are anticipated following exposure to the reported levels of CO and CO_2 in aircraft.

Table 8. Mean, minimum and maximum concentrations of Co 2 in Airbus 330 and Boeing 747 -400

Flight	Mean conc. (ppm)	Min conc. (ppm)	Max conc. (ppm)
A	1.170	629	2195
B	906	612	1565
C	686	642	1492
D	1557	855	2900
E	1052	1052	2368
F	1097	863	2043
G	716	479	1826
H	728	423	1911
I	967	760	1491
J	701	538	1347
K*	884	418	4752
L*	868	530	4088
M	683	509	2303
N	733	427	1489
O*	1024	624	1994
P	1000	702	1946

**Flight in which smoking was permitted. It should be noted that smoking was prohibited in all flights in 1997*

Source: COT (2022) *Additional labels by G. Shanmugam*

Mean and maximum concentration of CO_2 in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

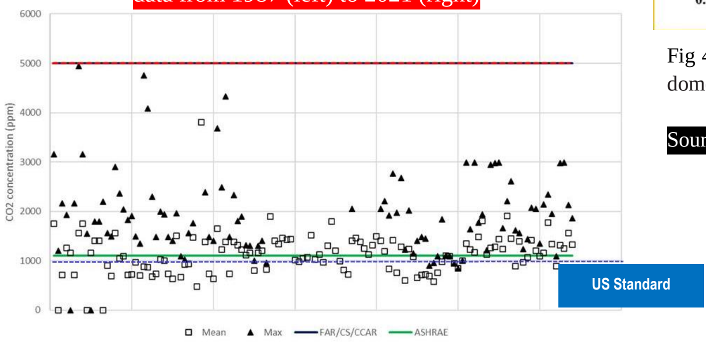


Fig 40. Mean and maximum concentration of CO_2 in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

Source: COT (2022) *Additional labels by G. Shanmugam*

A CASE STUDY OF THE U.S. DOMESTIC FLIGHTS

Cao et al. (2019) measured real-time CO_2 concentrations, an indicator of ventilation rates, and cabin pressure in the passenger cabins of 179 U.S. domestic flights from boarding through deplaning. This dataset was considered by COT (2022). The average CO_2 concentrations were 1,353 ± 290 ppm (mean ±SD) and the estimated outside airflow rates were 5.77 ±2.09 L/s/p across all flights (Fig. 41). The results indicated that 96% of observations met the minimum recommended outside airflow rates for acceptable air quality (3.5 L/s/p), but only 73% met the rate required in FAA design requirements (4.7 L/s/p), during flying phases. The CO_2 levels on all flights were well below the occupational exposure limit of 5000 ppm. However, all maximum and most mean and median CO_2 concentration values are more than 1,000 ppm (Table 9). There is no data on passengers who had suffered from exposure to excess **CO_2**.

According to COT Meeting (2023), "Most aircraft and occupational standards for CO_2 are set

Measured CO_2 Concentration and pressure during a typical flight

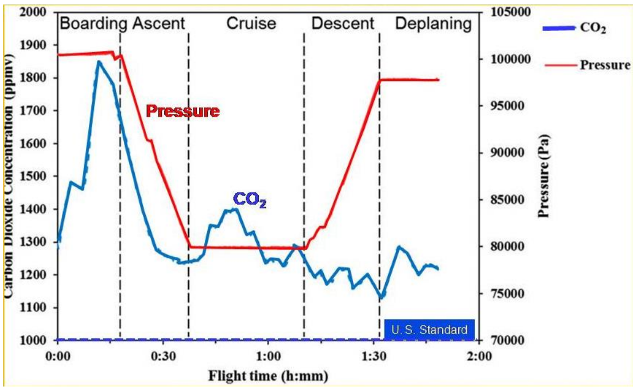


Fig 41. Measured CO_2 Concentration and pressure during a typical domestic flight in the US

Source: Cao et al., (2019) *Additional labels by G. Shanmugam*

at 5,000 ppm" (Table 10), The Committee on Toxicity (COT) is an independent scientific committee that advises the UK government on the toxicity of chemicals in food, consumer products, and the environment. Clearly, this UK government entity does not consider even the 5,000 ppm of CO_2 is harmful to humans.

Measured CO_2 Concentration and estimated outside air flow rates on all the flights

Measured CO_2 concentrations and estimated outside airflow rates on all the flights. US Standard: 1,000 ppm

Aircraft series	Aircraft types	Aircraft numbers	CO_2 concentration (ppmv) Min	Max	Mean	Median	SD	Outside ventilation rate (L/s/p) Min	Max	Mean	Median	SD
Airbus 319/320	A319	2	1003	1635	1228	1211	112	4.05	8.19	6.11	6.13	0.82
	A320	3	682	2990	1175	1235	382	1.94	17.08	8.15	5.95	4.04
Boeing 737	B737-300	4	1032	1773	1479	1497	111	3.64	7.83	4.68	4.55	0.54
	B737-400	1	1656	1937	1808	1804	65	3.26	3.98	3.56	3.57	0.16
	B737-500	1	1000	1220	1124	1142	49	6.06	8.23	6.88	6.69	0.49
	B737-700	7	850	2947	1261	1272	188	1.97	10.90	6.05	5.71	1.40
	B737-800	6	661	2976	1288	1355	316	1.95	18.38	6.73	5.22	3.62
Boeing 757	B757	67	703	2992	1438	1421	284	1.94	15.95	5.19	4.88	1.52
Boeing 767	B767-300	5	756	1662	1234	1238	160	3.96	13.66	6.25	5.93	1.65
Bombardier	CR-7	1	1094	2209	1903	1911	160	2.77	7.14	3.38	3.32	0.48
	CR-9	5	658	2616	1451	1427	265	2.27	18.59	5.04	4.86	1.32
	CRJ-100	2	620	1620	889	878	160	4.10	21.60	10.61	10.25	2.91
	CRJ-140	1	1264	1566	1398	1384	79	4.28	5.76	5.02	5.07	0.39
	CRJ-150	1	793	1233	969	976	127	5.97	12.42	9.07	8.58	1.88
	CRJ-200	2	721	1442	1070	1049	173	4.79	15.09	7.90	7.63	2.14
Embraer	E-135	1	1143	2077	1417	1381	185	2.99	6.68	5.04	5.08	0.79
	E-145	1	682	2054	1201	1070	403	3.03	17.08	7.86	7.40	3.85
	E-170	1	855	1352	1097	1083	160	5.23	10.78	7.49	7.25	1.73
	E-175	8	686	2137	1162	1120	200	2.89	16.85	6.91	6.89	1.69
	E-190	1	1392	2340	1771	1717	233	2.59	5.03	3.75	3.80	0.60
MD	DC-9	3	934	1951	1340	1159	320	3.23	9.23	5.82	6.54	1.59
	MD-80	1	659	1094	897	891	111	7.14	18.52	10.41	10.01	2.45
	MD-88	53	514	2979	1321	1318	264	1.95	39.50	5.89	5.42	1.98
	MD-90	2	656	2993	1251	1265	416	1.94	18.72	6.97	5.75	2.83
Summary		179	514	2993	1353	1333	290	1.94	39.50	5.77	5.34	2.09

Note: All maximum and most mean and median CO_2 concentration values are more than 1,000 ppm

Source: Cao et al., (2019) *Additional labels by G. Shanmugam*

Table 10. Aircraft regulatory values for CO_2 in Europe, US, and China. Source: COT Meeting (2023). (Cited in Chen et al., 2021).

Serial Number	Allowed CO_2 (ppm)	Aircraft/Workplace	Country / Continent
1	5,000	FAR (Federal Aviation Regulations)	US
2	1,000	ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, withdrawn)	US
3	30,000	JAR (Joint Airworthiness Requirements)	EU
4	5,000	EASA (European Aviation Safety Authority} CS (Certification. Specifications}	EU
5	20,000; 15 min 5,000; peak 2,000	BS-EN4618 on Aerospace series (withdrawn)	EU
6	5,000	CCAR (Chinese Civil. Aviation Regulations)	China
7	5,000; 8-hour PEL (Permissible Exposure Limit) (Workplace exposure limit.)	EH40/2005 Workplace exposure limits	

Since 1970, I have taken hundreds of international flights, some lasting 15 hours, around the world. I have never had any incidents of adverse health effects caused by CO_2 exposure during flights. I must conclude that the 1,000-ppm CO_2 concern is unwarranted.

CO_2 CONCENTRATION IN SUBMARINE NAVAL VESSELS AND INTERNATIONAL SPACE STATION

Data collected on nine nuclear-powered ballistic missile submarines indicate an average CO_2 concentration of 3,500 ppm with a range of 0-10,600 ppm, and data collected on 10 nuclear-powered attack submarines indicate an average CO_2 concentration of 4,100 ppm with a range of 300-11,300 ppm (Hagar 2003).

It is also worth mentioning that astronauts operate in the International Space Station (ISS) for a period of 3 years under **CO_2** levels of 8,000 ppm (Fig. 35) (Moser, 2023). Almost all of the CO_2 on board the ISS is produced by the astronauts' breathing. Carbon dioxide levels are monitored and controlled on the ISS (International Space Station) by the Atmosphere Revitalization (AR) subsystem of the Environmental Control and Life Support System **(ECLSS)**. NASA has set the maximum allowable 24-hour average CO_2 on board the ISS at 5,250 ppm (4.0 mmHg). Let's Talk Science (2024). Although ISS is an unusual environment, the fact that these astronauts operate for a period of three years with CO_2 concentrations much higher than 1,000 ppm is worth emphasizing in this response to Musk, who founded Space X. On September 15, 2021, SpaceX made history when Elon Musk launched four private passengers into orbit on the first mission to space with an all-civilian crew.

CO_2 DISTRIBUTION (FORECAST) IN 2100

Forecast values of CO_2 concentration in 2,100 varies from 672 to 1,142 ppm (Fig. 42 and Table 11). As mentioned before, ASHRAE (*American Society of Heating, Refrigerating and Air-Conditioning Engineers) (2010, 2023) has established that 1,000 ppm of CO_2* is the typical value for indoor air quality in the USA. Therefore, there is no need for health concerns due to 1,000 ppm of CO_2 in 2100.

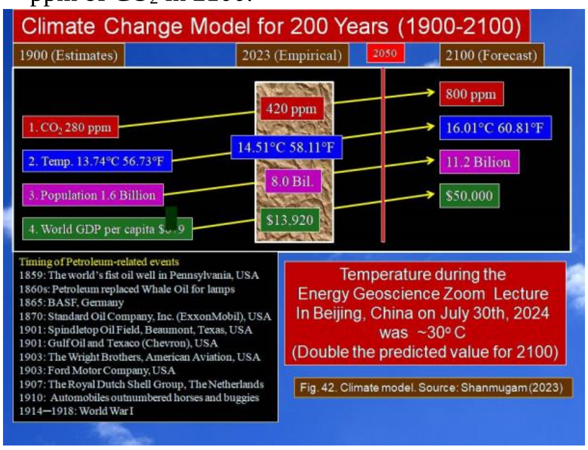


Fig. 42. Climate model. Source: Shanmugam (2023)

Table 11. Forecast values of CO_2 concentration in 2100.

Serial Number	Forecast levels of CO_2 (ppm) in 2100	Method	Source
1	572	By calculating CO_2 in 2100 by estimating at 2 ppm, increase in CO_2 per year from 2024 to 2100 (using 76 years and 152 ppm and 420 ppm for 2024). At this rate, 1,000 ppm will be reached by 2314.	This study
2	800	Forecast	Lindsey (2022); Happer and Lindzen (2022); Scripps CO_2 Program (2023). van Wijngaarden and Happer (2020)
3	1,000	~Forecast	IPCC (2000) Meehl et al. (2007)
4	1,142	Forecast	AWI (2019)

CO_2 AND HUMAN PHYSIOLOGY

Finally, the above discussion on CO_2 must be framed into a coherent human physiological network. For basic physiological reasons, the concentration of **CO_2** in ambient air is almost irrelevant as long as it is much smaller than about 40,000 ppm, where it is in equilibrium with the optimum **CO_2** concentration of human blood. According to Messina and Patrick (2022) of the U.S. National Institute of Health (NIH), "The partial pressure of carbon dioxide (PCO_2) is the measure of carbon dioxide within arterial or venous blood. It often serves as a marker of sufficient alveolar ventilation within the lungs. Generally, under normal physiologic conditions, the value of PCO_2 ranges between 35 to 45 mm Hg or 4.7 to 6.0 kPa." To put this into perspective, the partial pressure of CO_2 at sea level is 0.3 mm Hg. The difference in **CO_2** between inhaled (0.3 mm Hg) and exhaled air (40 mm Hg) confirms the fact that the inside of our lungs has 100 times more CO_2 than the air going into our lungs (Fig. 43). Our lungs have to keep breathing out this excess **CO_2** to avoid **CO_2** build up in our lungs. Normally, our lungs have about 40,000 ppm of CO_2 by comparison to the atmospheric CO_2 of about 400 ppm.

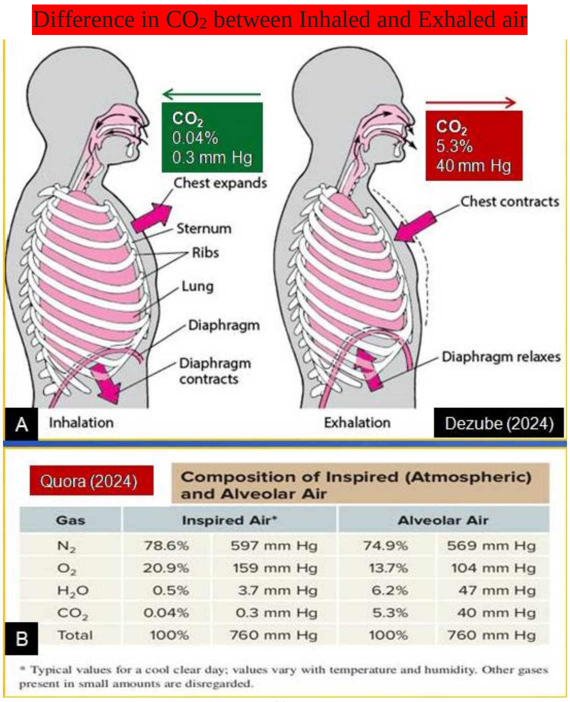


Fig 43. A). Diagram showing difference [n CO_2 between Inhaled and Exhaled Air during breathing. Diagram without CO_2 values from Dezube (2024). Merck Manual. Consumer Version. Additional CO_2 values from Quora (2024) added by G. Shanmugam. B). Composition of Inspired (Atmospheric) and Alveolar Air (Quora, 2024). *Additional labels by G. Shanmugam*

Our breathing reflex is driven by the **CO_2** concentration in the blood, not by a lack of blood oxygen. Our blood becomes too acidic when it has too much **CO_2** and it becomes too alkaline with too little **CO_2**. Our breathing rate adjusts automatically to maintain the optimum **CO_2**

In this context, we must discuss two related phenomena; one on alkalosis (too little **CO_2** in the blood) and one on the breathing reflex (triggered by too much **CO_2** in the blood). Respiratory alkalosis is caused by a low carbon dioxide level in the blood (MedlinePlus, 2024). This can be due to:

- Fever
- Being at a high altitude
- Lack of oxygen
- Liver disease
- Lung disease, which causes you to breathe faster (hyperventilate)
- Aspirin poisoning.

Breathing is usually automatic, controlled subconsciously by the respiratory center at the base of the brain (Dezube, 2024). Breathing continues during sleep and usually even when a person is unconscious. People can also control their breathing when they wish, for example during speech, singing, or voluntary breath holding. Sensory organs in the brain and in the aorta and carotid arteries monitor the blood and sense oxygen and carbon dioxide levels. Normally, an increased concentration of carbon dioxide is the strongest stimulus to breathe more deeply and more frequently. Conversely, when the carbon dioxide concentration in the blood is low, the brain decreases the frequency and depth of breaths. During breathing at rest, the average adult inhales and exhales about 15 times a minute.

EFFECTS IN HUMANS DUE TO HIGH LEVELS OF CO_2

The U. S. National Research Council (NRC, 2007) has documented the effects in humans due to high levels of CO_2. Selected examples are as follows:

- Dyspnea (i.e., shortness of breath) is a commonly reported end point and can be induced by acute exposures to CO_2 at >30,000 ppm (NRC 1996). Hyperventilation without dyspnea occurs at exposure concentrations as low as 10,000 ppm (NRC 1996). Dyspnea attributable to CO_2 is aggravated by increasing the level of exertion.

- White et al. (1952) studied humans exposed to CO_2 at 60,000 ppm for 16 minutes and reported that 19 of 24 subjects exhibited slight or moderate dyspnea and 5 of 24 exhibited severe dyspneic sensations. At 40,000-50,000 ppm for 17-32 minutes, 16 subjects reported dyspnea (Schneider and Truesdale 1922). In contrast, no dyspnea was reported in five subjects exposed at 32,000 ppm or at 25,000-28,000 ppm for several hours (Brown 1930).

- In the most modern protocol to examine dyspnea, Menn et al. (1970) reported that eight subjects exposed to CO_2 at 11,000 ppm exhibited no increase in dyspnea or intercostal pain during 30 minutes of maximal exercise. The same study reported that exposure to CO_2 at 28,000 ppm during 30 minutes of maximal exercise produced increased dyspnea in three of eight subjects and intercostal pain in two of eight subjects, but subjects did not show increased dyspnea at one-half or two-thirds maximal exercise. Sinclair et al. (1971) reported that a 1-h exposure to CO_2 at 28,000 ppm in four subjects caused no dyspnea or intercostal pain during steady strenuous exercise. Thus, the bulk of the data indicate a no-observed-adverse-effect level (NOAEL) for CO_2 of about 28,000 ppm on the basis of the findings on dyspnea and intercostal pain.

- Neither dyspnea nor intercostal pain occurred in four subjects exposed to CO_2 at 28,000 ppm for 15-20 days and made to do 45 minutes of exercise twice daily at up to a heavy level, although the chronic portion of this protocol was not fully described (Sinclair et al. 1971). Similarly, there were no symptoms reported in six subjects exposed to CO_2 at 20,000 ppm for 30 days or 29,000 ppm for 8 days and made to do 10 minutes of exercise twice a week at a workload of 150 watts (Guillerm and Radziszewski 1979; Radziszewski et al. 1988). Thus, 28,000 ppm is an appropriate chronic NOAEL for dyspnea and intercostal pain.

- Headaches are commonly associated with increased CO_2 concentrations in inspired air, but there is conflicting data on the concentrations reliably associated with that end point. There may also be an effect of exertion, because CO_2 seems to cause more headaches at lower concentrations during exercise than it does during rest. In particular, Schneider and Truesdale (1922) reported that for 16 resting subjects exposed to CO_2 at 10,000-80,000 ppm for 17-32 minutes, headaches developed only at concentrations that were ≥50,000 ppm; however, the headache could be intense. At 28,000 ppm for 1 h of strenuous steady-state exercise, occasional mild headaches were noted among four subjects (Sinclair et al. 1971). At 39,000 ppm for 30 minutes of exercise at two-thirds maximal exertion, Menn et al. (1970) found mild-to-moderate frontal headaches in six of eight subjects near the end of the exposure period. The headaches resolved after about an hour. At 28,000 ppm and 11,000 ppm for 30 minutes of exercise, no headaches were reported (Menn et al. 1970). Thus, there is inconsistent modern evidence for mild headaches resulting from CO_2 exposures at 28,000 ppm during exercise. Some level of increased exertion among submarine crew might be likely during 1-24 h emergency episodes; however, headaches induced by CO_2 are both mild and reversible and therefore were not used as a primary end point for setting the 1-h and 24-h EEGLs.

- Sub chronic CO_2 exposures at 30,000 ppm or higher are known to produce headaches. Glatte et al. (1967) reported that CO_2 at 30,000 ppm for 5 days led to mild to moderate throbbing frontal headaches on the first day in four of seven subjects. The headaches disappeared on day 3 and were not severe enough to interfere with normal activities, including 1 h of moderate exercise daily, although three of the four subjects with headaches requested analgesics. During 30-day exposures at 20,000 ppm, six subjects rarely developed headaches, and exposures at 29,000 ppm led to slight headaches (Radziszewski et al. 1988). Eight subjects, four exposed to CO_2 at 28,000 ppm for 15-30 days and four exposed to CO_2 at 39,000 ppm for 11 days, reported occasional mild headaches during exertion that disappeared after the first day of exposure (Sinclair et al. 1969, 1971). Thus, 20,000 ppm is an appropriate sub chronic NOAEL for headaches.
- In summary, it takes an exposure concentration of at least 10,000 ppm to increase minute-volume after a plateau in the hyperventilatory response has been reached, usually after a few hours. It is not clear from the data whether the hyperventilatory response diminishes with time, although in a study at 10,000 ppm, it resolved completely after 8 days of a 44-day exposure (Pingree 1977). Data from Radziszewski et al. (1988) showed a 60% increase in minute-volume during a 2-h exposure at 20,000 ppm. The increase was reduced to 45% after 24 h. There is no indication in the literature that hyperventilation constitutes an adverse response.

CONCLUDING REMARKS

We really do not know what will happen when the Atmospheric CO_2 exceeds 1,000 ppm limit in 2314 (Table 11). However, we do know that the “Evolution” in itself creates / modifies / erases the living being with appropriate physiology that is suited to such new atmospheric conditions. This global study, with robust datasets from 25 countries, has revealed that we can indeed adapt to hiher levels of CO_2 exposure (Table 12).

The U.S. Government (USDA, 2024) does not consider the CO_2─1,000 limit as a health threat (Fig. 44). A total of 80,302 empirical indoor data points from 25 counties (i.e., classrooms, conference rooms, and aircraft cabins) suggest that humans are able to function normally without adverse health effects even when CO_2 concentration levels reach between 2,000 and 6,000 ppm (Table 12). Although the authors of research articles are willing to advocate the adverse health risks associated with the artificial CO_2─1,000 ppm limit, they are conspicuously silent in documenting empirical evidence for headaches associated with the 1.000 ppm limit of CO_2. Also, there is no experimental evidence for such a relationship. According to NRC (2007), 20,000 ppm is an appropriate sub chronic NOAEL (No Observed Adverse Effect Level) for headaches. All datasets lead to the conclusion that humans can function normally without adverse health effects even at 10,000 ppm of CO_2 (Fig. 44). Therefore, the notion that headaches supposedly associated with the 1.000-ppm limit of CO_2 is a fallacy.

Table 12. Summary of empirical data points showing that millions of humans can and do function normally everyday under CO_2 concentrations much higher than 1,000 ppm worldwide in classrooms, conference rooms, dwellings in cold climate, aircraft cabins, submarine naval vessels, and International Space Station.

Serial Number	CO_2 (ppm)	Setting	Data Points	Location / Country / Region	Reference
1	>1,100	Classroom	104	California, USA	Chan et al. (2020)
2	1,591 Max	Classroom	64	New York, USA	Muscatiello et al. (2015)
3	3,200 Max	Classroom	1	North Carolina USA	Wilson (2022)
4	>2,000 in 3 Classrooms	Classroom	1,239	Hawaii, USA	HIDOE (2022)
5	>1,500 (6.7%)	Classroom	76,122	Canada	CBC News (2023)
6	>1,000	Classroom	30	London, England, UK	Hama et al. (2023)
7	>2,500	Lecture Room	1	UK	Greene et al. (2022)
8	>1,500	Classroom	20	Scotland, UK	Bain-Roguis et al. (2022)
9	>6,000 (Highest)	Classroom	1	Ireland	IES (2024)
10	5,000 Max (Norway)	Classroom	1,373	Norway, Denmark, and Sweden	Randall (2010)
11	2,500 Max	Classroom	10	Latvia	Zemitis et al. (2021)
12	5,320 Max (2nd Highest)	Classroom	81	Portugal	Ferreira and Cardoso (2013)
13	>1,000 (Poland) <1,000 (Spain)	Classroom	8	Poland and Spain	Krawczyka et al. (2016)
14	4,310 Max	Classroom	50	France	Canha et al. (2016)

15	>2,300	Classroom	11	Italy	Di Gilio et al. (2021)
16	~3,000	Classroom	15	United Arab Emirates	Abu-Rahmah et al. (2021)
17	>1,000	Classroom	5	India	Soomro et al. (2018)
18	>1,000	Classroom	24	South Africa	van der Walt et al. (2024)
19	3,000 Max	Classroom	3	South Korea	Han et al. (2022)
20	4,200 Max	Classroom	10	Australia	Andamon et al. (2023)
21	3,000 Max	Classroom	28	New Zealand	BRANZ (2019)
22	>1,000	Classroom	13	Japan	Senseair (2024)
23	>1,000	Classroom	71	China	Zhu et al. (2021)
24	>3,000	Classroom	30	Thailand	AirGradient (2024b)
25	1,433 Max	Classroom	30	Brazil	Jurado et al. (2014)
26	5,000 Max	Classroom	28	Chile	Rivera (2020)
27	1,248 Max	Conference Rooms	3	Iowa, Georgia, and Florida. USA	Angela Wheeler, The CO_2 Coalition
28	2,304 Max	Conference Room	1	Bialystok University of Technology, Poland	Teleszewski et al. (2019)
29	>1,800	Conference Room	4	China	Wang et al. (2022)
30	4,687 Max	Dwellings	79	Greenland	Kotol et al. (2014)
31	2,500 Max	Student houses	4	Fairbanks, Alaska, USA	Kotol (2014)
32	CO exceeded Mongolian Standard. CO_2 not measured.	Households	58	Mongolia	Cowlin et al. (2006)
33	4,752	Aircraft Cabins	770	U.S. Domestic and International	COT (2022)
34	11,300	Submarine Naval Vessels	10	Global	Hagar (2003)
35	8,000	International Space Station	1	Global	Moser (2023)
SUMMARY	**2,000-5,000 Common**	—	**80,302**	**25 Countries**	—

In all indoor air-quality case studies considered in this review, CO_2 concentration is not a problem. In fact, other studies have also illustrated with empirical data that there is no climate crisis (Shanmugam, 2024a) (Fig. 45).

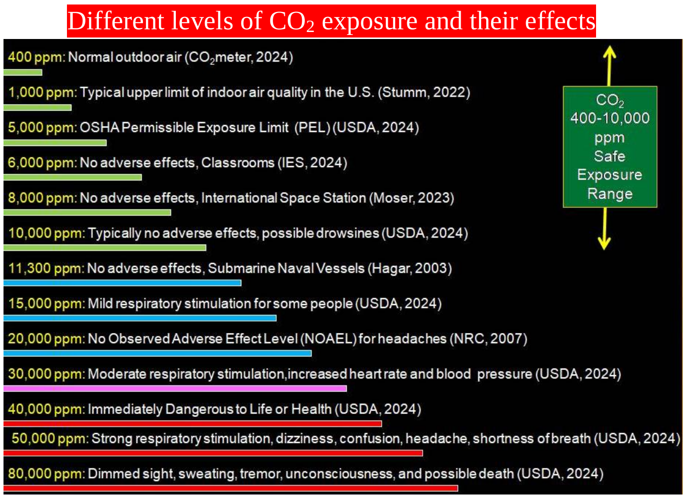


Fig 44. Different levels of CO_2 exposure and their effects
Data compiled by G. Shanmugam

Fig 45. Conclusions Source: *G. Shanmugam (2024b*
Image Credit: NASA

Finally, the developing countries should be allowed freely to flourish by using cheap fossil fuels without the "Climate Scam" exerted by the hegemonic western countries (Fig. 46).

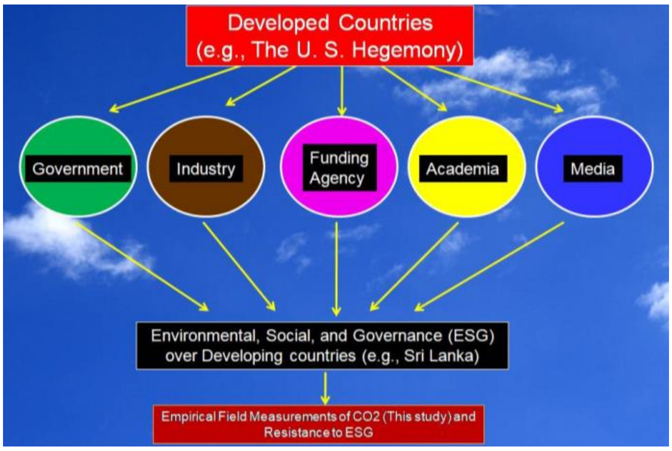


Fig 45. Implications of this study for ESG and Developing countries

Table 13. Problems associated with CO_2 and Temperature concerning Climate Change.

Serial Number	Problem	Detail	Reference
1	Conceptual	Absence of extreme high Temperatures for Early Paleozoic (Fig. 8B)	Scotese et al. (2021)
2	Conceptual	Absence of correlation between Temperature and CO_2 during the Mesozoic era (Fig. 13C)	Judd et al. (2024)
3	Conceptual	Absence of correlation between Temperature an CO_2 during the Phanerozoic (Fig. 12)	Berner (1991, 2004); Epstein (2022)
4	Conceptual and Empirical	Contradiction between PanDA model and the Keeling Curve on CO_2 trends (Fig. 13)	Judd et al. (2024)
5	Conceptual	Exaggerated Temperature Prediction (Climate models) vs. Actual Field Observation (Fig. 10)	Christy (2022)
6	Conceptual	Use of Temperature anomaly, not absolute Temperatures in Climate models (Fig. 11)	IPCC AR6 (2021)
7	Conceptual	Use of baseline in Climate models (Fig. 11)	IPCC AR6 (2021)
8	Conceptual	Use of large uncertainty range in Climate models (Fig. 11)	IPCC AR6 (2021)
9	Empirical	Tsunamis are oceanographic phenomena, not anthropogenic (Fig. 7)	Shanmugam (2006, 2008, 2012)
10	Empirical and meteorological	Cyclones are meteorological phenomena, not anthropogenic (Figs. 4, 5, 6, and 7)	Shanmugam (2008)
11	Empirical	Field measurements of CO_2 defy conventional model of 1,000 ppm upper limit (Fig. 44)	This study
12	Empirical	There is no Climate Crisis (Figs. 42 and 45)	Shanmugam (2024b)
13	Empirical, and political	Field measurements of CO_2 undermine the power of hegemonic western countries over developing countries (Fig. 46)	This study
14	Physiological	Breathing and CO_2 (Fig. 43)	Dezube (2024)
15	Empirical	Wind and solar energy options are unreliable and expensive	Epstein (2022)
16	Empirical, and political	Problems with EV	Robson (2024)
17	Political	Destruction of Nord Stream pipeline in the Baltic Sea	Putin (2024)
18	Hypocritical	Global Elites arrived at Davos in Switzerland (January, 2023) to attend the World Economic Forum In Private Jets, by emitting enormous amounts of CO_2 from burning Jet fuels, to discuss Climate Change.	Shanmugam (2024b)
19	Analytical	Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters	Koonin (2021)
20	Analytical	Climate Uncertainty and Risk: Rethinking Our Response	Curry (2023)
21	Physical	Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases	Van Wijngaarden, and Happer (2020)
22	Analytical	Bridging the Gap Between Data and Climate Policy.	Lindzen (2023)
23	Analytical	Is Climate Change Fake?	Moore (2021)
24	Analytical	Cool It: The Skeptical Environmentalist's Guide to Global Warming	Lomborg (2007)
25	Analytical	Freeman Dyson on Global Warming 1of 2 Bogus Climate Models.	Dyson (2007)
26	Political	Net Zero emissions	Fankhauser et al. (2022)
27	Analytical	200 Years of Fossil Fuels and Climate Change (1900-2100)	Shanmugam (2023)
28	Analytical	). Fossil fuels, climate change, and the vital role of CO_2 plays in thriving people and plants on planet Earth	Shanmugam (2024b)
29	Analytical	The "Climate: The Movie (The Cold Truth)"	Durkin and Nelson (2024)
30	Analytical	"CO_2 , The Gas of Life"	Happer (2023)
31	Analytical	Climate Change Reconsidered: The Report of the 1368 Nongovernmental International Panel on Climate Change (NIPCC)	Singer and Ids (2009)
32	Empirical	Is the US surface temperature record reliable?	Watts (2009)
33	Analytical	Reevaluating the role of solar variability on Northern Hemisphere temperature trends since the 19th century	Soon (2015)
34	Empirical	Declining tropical cyclone frequency under global warming	Chand et al. (2022)
35	Analytical	The NZE tamasha and the CoP	Chandrasekharam (2021)

Despite the vast number of contributions on Climate Change, critical problems are yet to be solved (Table 13).

ACKNOWLEDGEMENTS

I thank the Convener Dr. Arvind Kumar Singh and the IAS President Prof. G. N. Nayak for inviting me to deliver a Keynote at the IAS@BSIP-2024. As always, I am grateful to my wife, Jean

Shanmugam, for her general comments. I am grateful to Prof. G. M. Bhat, current Editor-in-Chief of IAS Magazine for inviting me to submit this review. I am a Member of the CO_2 Coalition.

My research interests cover not only Climate Change but also other domains, such as Landslides, Submarine fans, Seismites, Hyperpycnites, among others (Shanmugam, 2024b). This article is an expanded version of the manuscript entitled "Elon Musk's cautionary claim "When Atmospheric CO_2 concentration exceeds 1,000 ppm limit, it would cause headaches and nausea": All the 76,874 empirical data points of CO_2 from classrooms (>6,000 ppm), conference rooms, and aircraft cabins, assuage such a claim." My sincere thanks to Dr. S. Asokan (Ph.D., University of Cambridge, UK) for his insightful review. I thank William Happer (Cyrus Fogg Bracket Professor of Physics, Emeritus, Princeton University, and a Co-Founder of **CO_2** Coalition), for providing helpful comments on CO_2 and human physiology. I also thank Angela Wheeler, Vice President Marketing and Multimedia, The CO_2 Coalition, for providing images of **CO_2** meters used in this article (Fig. 36). As always, I am grateful to my wife, Jean Shanmugam, for her general comments.

I acknowledge with gratitude the following individuals, institutions, and entities for their contributions to our understanding of CO_2**.**

Abu Dhabi National Oil Company (ADNOC)

Alex Epstein

Alfred Wegener Institute (AWI)

Alice.ai

American Airlines

American Conference of Governmental Industrial Hygienists (ACGIH)

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

Angela Wheeler

Assessment Methodology for Building Energy Rating (AMBER)

Aviation Safety Authority)

Boeing

BS-EN4618 on Aerospace series

CBC (The Canadian Broadcasting Corporation) News

Chinese Civil. Aviation Regulations (CCAR)

CO_2 Coalition

CO_2meter

Committee on the Toxicity (COT)

Donald Trump

European Aviation Safety Authority (EASA)

EH40/2005 Workplace exposure limits

Elon Musk

FAR (Federal Aviation Regulations)

Florida Homeschool Convention

Gaylord Palms Resort & Convention Center, Kissimmee, Florida

George devries Klein

Ghulam Bhat

Greg Wrightstone

Homeschool Iowa Convention

Intergovernmental Panel on Climate Change (IPCC)

International Monetary Fund (IMF)

Jean Shanmugam

Joint Airworthiness (JAR)

MedlinePlus

Merck Manual

Minnesota Department of Health (MINDOH)

Minnesota Department of Labor and Industry (MNDOLI)

National Aeronautics and Space Administration (NASA)

National Institute of Health (NIH)

National Oceanic and Atmospheric Administration (NOAA)

National Research Council (NRC)

Norwegian Institute for Air Research. (Norwegian: NILU – Norsk Institutt for luftforskning)

Occupational Safety and Health Administration (OSHA)

Quora

Scripps CO_2 Program

Southeast Homeschool Convention

Stockholm International Peace Research Institute (SIPRI)

Sundaresan Asokan

United States Department of Agriculture (USDA)

U. S. Geological Survey (USGS)

William Happer

World Health Organization (WHO)

REFERENCES

Abu-Rahmah, Ali, Rasheed Ahmad, Abdelmaoula Haboub, and Yasmin Abu-Rahmah (2021). Towards Healthy Levels of Carbon Dioxide in Schools of theNational Oil Company of Abu Dhabi. Advances in Meteorology, Volume 2021, Article ID 6680476, 11 pages https://doi.org/10.1155/2021/6680476

ACGIH (American Conference of Governmental Industrial Hygienists). (2011). TLVs and BEIs. Cincinnati, OH:American Conference of Governmental Industrial Hygienists. Report

AirGradient (2024a). Classroom and indoor CO_2 Standards compared; A Look around the World. https://www.airgradient.com/blog/classroom-CO_2-standards/ Retrieved August 16, 2024

AirGradient (2024b). We Measured the CO_2 Level in a Classroom. This is What We Found Out. https://www.airgradient.com/blog/we-measured-the-CO_2-level-in-a-classrooms-this-is-what-we-found-out/ Retrieved August 28, 2024

Allen, M.R., Dube, O. P., Solecki, W., Aragón─Durand, F., Cramer, W., Humphreys, S., Kainuma, M.,Kala., J., Mahowald, N., Mulugetta, Y., Perez, R. M., Wairiu, M., Zickfeld, K. (2018). Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre─industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of Climate Change, sustainable development, and efforts to eradicate poverty [Masson─Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 49-92.

Andamon, Mary Myla, Rajagopalan, Priyadarsini, Woo, Jin, (2023). Evaluation of ventilation in Australian school classrooms using long-term indoor CO_2 concentration measurements. Building and Environment, 237, 1 June 2023, 110313 https://www.sciencedirect.com/science/article/pii/S036013232300340 Retrieved August 21, 2024

AOML (Atlantic Oceanographic and Meteorological Laboratory), (2007a). What is a hurricane, typhoon, or a tropical cyclone: http://www.aoml.noaa.gov/hrd/tcfaq/A1.html Retrieved February 15, 2023.

AOML (Atlantic Oceanographic and Meteorological Laboratory), (2007b). What is an extra-tropical cyclone: http://www.aoml.noaa.gov/hrd/tcfaq/A7.html Retrieved February 15, 2023.

AOML (Atlantic Oceanographic and Meteorological Laboratory), (2007c). How do tropical cyclones form: http://www.aoml.noaa.gov/hrd/tcfaq/A15.html Retrieved February 15, 2023.

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). (2010). ANSI/ASHRAE Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality. Atlanta, GA:ASHRAE.

AWI (Alfred Wegener Institute) {2019). New climate model for the IPCC. https://phys.org/news/2019-09- climate-ipcc.html Retrieved May 4, 2023.

Bain-Reguis, N.; Smith, A.; Martin, C.H.; Currie, J. (2022). Indoor CO_2 and Thermal Conditions in Twenty Scottish Primary School Classrooms with Different Ventilation Systems during the COVID-19 Pandemic. *Pollutants* 2022, *2*, 180-204. https://doi.org/10.3390/pollutants2020014

Berner, R. A. (1991). A model for atmospheric CO_2 over Phanerozoic time: American Journal of Science, 291, 339–376.

Berner, R.A. (2004). The Phanerozoic carbon cycle: CO_2 and O2: Oxford University Press, 158p. ISBN-13: 978-0195173338.

Bogdanovica, Snezana, Jurgis Zemitis, and Raimonds Bogdanovics. (2020). "The Effect of CO_2 Concentration on Children’s Well-Being during the Process of Learning" *Energies* 13, no. 22: 6099. https://doi.org/10.3390/en13226099

BRANZ (2019). Research Now: Indoor air quality #2: An overview of indoor air contaminants in New Zealand schools. 3 p. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://d39d3mj7qio96p.cloudfront.net/media/documents/BRANZ-RN-Indoor_Air_Quality_2.pdf

Brown, E.W. (1930). The physiological effects of high concentrations of carbon dioxide. U.S. Naval Med. Bull. 28:721-934 (as cited in NRC 1996).

Canha N, Mandin C, Ramalho O, Wyart G, Ribéron J, Dassonville C, Hänninen O, Almeida SM, Derbez M. (2016). Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2016 Jun;26(3):350-65. doi: 10.1111/ina.12222. Epub 2015 Jul 7. PMID: 25955661.

Cao X, Zevitas CD, Spengler JD, et al. (2019) The on-board carbon dioxide concentrations and ventilation performance in passenger cabins of US domestic flights. *Indoor and Built Environment*. 2019;28(6):761-771. doi:10.1177/1420326X18793997

CBC News (2023). CO_2 levels in more than 5,000 Quebec classrooms exceed province-set limit, data shows. https://www.cbc.ca/news/canada/montreal/CO_2-levels-quebec-classrooms-exceed-limit-1.6722410 Retrieved August 21, 2024

Chan, W. R. et al. (2020). Ventilation rates in California classrooms: Why many recent HVAC retrofits are not delivering sufficient ventilation. Building and Environment, 2020, v. 167, p. 106426. https://doi.org/10.1016/j.buildenv.2019.106426 Retrieved August 16, 2924

Chand, S.S., Walsh, K.J.E., Camargo, S.J., Kossin, J. P., Tory, K. J., Wehner, M. F., Chan, J. C. L., Klotzbach, P. J., Dowdy, S. J., Bell, S. S., Ramsay, H. A. and Murakami, H. (2022). Declining tropical cyclone frequency under global warming. Nature Climate Change. 12, 655–661.

Chandrasekharam, D. 2021. The NZE tamasha and the CoP 26. https://timesofindia.indiatimes.com/blogs/dornadula-c/the-nze-tamasha-and-the-cop-26/ Retrieved May 10, 2023.

Chen, R., Fang, L., Liu, J., Herbig, B., Norrefeldt, V., Mayer, F., Fox, R., & Wargocki, P. (2021). Cabin air quality on non-smoking commercial flights: A review of published data on airborne pollutants. Indoor air, 31(4), 926-957. https://doi.org/10.1111/ina.12831

Christy, John R., (2022). Data shows there's no climate catastrophe looming –climatologist Dr J Christy debunks the narrative. BizNewsTv. ttps://www.youtube.com/watch?v=qJv1IPNZQao Retrieved May 2, 2023.

CO_2meter (2024). ASHRAE Carbon Dioxide Levels in the Classroom https://www.CO_2meter.com/blogs/news/ashrae-CO_2-standards-classrooms?srsltid=AfmBOoqNSgQbfUveGPmqsbrc8kO4THtFU3fNhYqfZC2-MmiMtiMSFsO8 Retrieved August 16, 2024

COT (Committee on the Toxicity) (2022). Carbon monoxide and carbon dioxide in aircraft cabin air. OX/2022/65. Chrome extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cot.food.gov.uk/sites/default/files/2022-12/TOX-2022-65%20Aircraft%20cabin%20air%20CO_2%20and%20CO.pdfRetrieved September 5, 2024

COT Meeting (2023). Aircraft cabin air: Basis of the regulatory values for carbon dioxide. https://cot.food.gov.uk/Aircraft%20cabin%20air%3A%20Basis%20of%20the%20regulatory%20values%20for%20carbon%20dioxide Retrieved August 16, 2924

Cowlin, Shannon; Edwards, Rufus; Kaufmann,Rachel Beth; Smith,Kirk Robert. (2006). *Impact of improved stoves on indoor air quality in Ulaanbaatar, Mongolia (English)*. Energy Sector Management Assistance Program working paper series ; ESM 313/05 Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/179361468060899591/Impact-of-improved-stoves-on-indoor-air-quality-in-Ulaanbaatar-Mongolia

Curry, J. (2023). Climate Uncertainty and Risk: Rethinking Our Response. Anthem Press, ISBN-13 : . 978-1839989254. 340 p

Di Gilio A, Palmisani J, Pulimeno M, Cerino F, Cacace M, Miani A, de Gennaro G. (2021) CO_2 concentration monitoring inside educational buildings as a strategic tool to reduce the risk of Sars-CoV-2 airborne transmission. Environ Res. 2021 Nov;202:111560. doi: 10.1016/j.envres.2021.111560. Epub 2021 Jul 3. PMID: 34224708; PMCID: PMC8253691.

Durkin, Martin and Nelson, Tom (2024). The "Climate: The Movie (The Cold Truth)" . The Movie highlights a different perspective on the climate change debate and is supported by scientists who have signed the Clintel's World Climate Declaration. It features interviews by world-renowned scientists, such as William Happer, Richard Lindzen, Patric Moore, among others. https://www.google.com/search?q=climate%3A+the+movie+(the+cold+truth&oq=&gs_lcrp=EgZjaHJvbWUqCQgAEEUYOxjCAzIJCAAQRRg7GMIDMgkIARBFGDsYwgMyCQgCEEUYOxjCAzIJCAMQRRg7GMIDMgkIBBBFGDsYwgMyCQgFEEUYOxjCAzIJCAYQRRg7GMIDMgkIBxBFGDsYwgPSAQ0yMzE0NzAxNzdqMGo3qAIIsAIB&sourceid=chrome&ie=UTF-8#fpstate=ive&vld=cid:b3840434,vid:zmfRG8-RHEI,st:0

Dyson, Freeman (2007). Freeman Dyson on Global Warming 1of 2 Bogus Climate Models. https://www.youtube.com/watch?v=JTSxubKfTBU Retrieved June 19, 2023

Epstein, A. (2022). Fossil Future: Why Global Human Flourishing Requires More Oil, Coal, and Natural Gas—Not Less. Portfolio/Penguin,480 p.

Fankhauser, Sam; Smith, Stephen M.; Allen, Myles; Axelsson, Kaya; Hale, Thomas; Hepburn, Cameron; Kendall, J. Michael; Khosla, Radhika; Lezaun, Javier; Mitchell-Larson, Eli; Obersteiner, Michael; Rajamani, Lavanya; Rickaby, Rosalind; Seddon, Nathalie; Wetzer, Thom (2022). "The meaning of net zero and how to get it right". *Nature Climate Change*. **12** (1): 15–21. Bibcode:2022NatCC..12...15F. doi:10.1038/s41558-021-01245-w.

Ferreira AM, Cardoso SM. (2013) Estudo exploratório da qualidade do ar em escolas de educação básica, Coimbra, Portugal [Exploratory study of air quality in elementary schools, Coimbra, Portugal]. Rev Saude Publica. 2013 Dec;47(6):1059-68. doi: 10.1590/s0034-8910.2013047004810. PMID: 24626544; PMCID: PMC4206112.

Glatte, Jr., H.A., G.J. Motsay, and B.E. Welch. (1967). Carbon Dioxide Tolerance Studies. Rep. No. SAM-TR-67-77. Aerospace Medical Division, USAF School of Aerospace Medicine, Brooks Air Force Base, San Antonio, TX (as cited in NRC 1996).

Greene, Robert, Mahroo Eftekhari, Derek Clements–Croome, and Georgios Georgiou, (2012). Measurements of CO_2 levels in a classroom and its effect on the performance of the students. CIBSE ASHRAE Technical Symposium, Imperial College, London UK – 18th and 19thApril2012.https://www.researchgate.net/publication/344227240_Measurements_of_CO2_levels_in_a_Classroom_and_its_effect_on_the_performance Retrieved August 27, 2024

Guillerm, R., and E. Radziszewski. (1979). Effects on man of 30-day exposure to a PI CO_2 of 14 torr (2%): Application to exposure limits. Undersea Biomed. Res. (Submarine Suppl.): S91-S114.

Hagar, R. (2003). Submarine Atmosphere Control and Monitoring Brief for the COT Committee. Presentation at the First Meeting on Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants, January 23, 2003, Washington, DC.

Hama, S., P. Kumar, A. Tiwari, Y. Wang, P.F. Linden. (2023). The underpinning factors affecting the classroom air quality, thermal comfort and ventilation in 30 classrooms of primary schools in London Environ. Res., 236 (2023), Article 116863

Han, B., Hong, K., Shin, D., Kim, H.J., Kim, Y.J., Kim, S.B., Kim, S., Hwang, C.H, Noh, K.C. (2022). Field Tests of Indoor Air Cleaners for Removal of $PM_{2.5}$ and PM_{10} in Elementary School Classrooms in Seoul, Korea. Aerosol Air Qual. Res. 22, 210383. https://doi.org/10.4209/aaqr.210383

Happer, W. (2014). Princeton's William Happer rebuts myth of carbon pollution. John Locke Foundation, September 8, 2014. Raleigh, Nort Carolina. https://www.youtube.com/watch?v=M8iEEO2UIbA Retrieved June 25, 2023

Happer, W. (2020). CLINTEL lecture William Happer in Amsterdam. https://CO2coalition.org/media/clintel-lecture-william-happer-in-amsterdam/ Retrieved February 15, 2023.

Happer, W. (2022). 138. Climate Physics w/Professor William Happer. October 29, 2022. https://www.google.com/search?q=harper+climate+physics+ y o u t u b e & o q = h a r p e r + c l i m a t e + p h y s i c s + y o u t u b e & a q s = c h r o m e . 69i57j33i160l2.19747j0j7&sourceid=chrome&ie =UTF 8 # f p s t a t e = ive&vld=cid:e59ba35f,vid:5Uf_AbyG6ho RetrievedNovember 23, 2022.

Happer, W. (2023). YouTube video. "CO_2 , The Gas of Life"-Dr. William Happer. Old Guard Summit. https://www.youtube.com/watch?v=tXJ7UZjFDHU **Retrieved November 5, 2024..**

Happer, W., Lindzen, R. (2022). Responses and Declaration on the "CFTC Climate-Related Financial Risk RFI" 87 Fed. Reg. 34856 (June 8,2022).HIDOE (Hawaii Department of Education) (2022). Report on CO_2 concentrations in classrooms by the Office of Facilities and Operations. Leter dated July 26, 2022 by Randall M. Tanaka, Assistant Superintendent. chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.hsta.org/wp-content/uploads/2022/07/HIDOE-response-ventilation-07.26.2022.pdf Retrieved September 9, 2024.

Hocking, & Hocking. (2005). Air Quality in Airplane Cabins and Similar Enclosed Spaces in The Handbook of Environmental Chemistry.

IES (2024). AMBER - CO_2 Dashboards for Ventilation Monitoring. https://www.iesve.com/services/projects/18325/CO2-dashboards-schools Retrieved September 1, 2024

IPCC. (2000). "Emissions Scenarios." Special Report of Intergovernmental Panel on Climate Change Working Group III, published for the IPCC. https://tinyurl.com/3sw65a3u

IPCC AR6 (2021). Figures. https://www.ipcc.ch/report/ar6/wg1/figures/technical-summary

Retrieved November 4, 2024.

Judd, E. J. et al., (2024). A 485-million-year history of Earth's surface temperature. Science 385, eadk3705 (2024). DOI: 10.1126/science.adk3705

Jurado SR, Bankoff AD, Sanchez A. (2014). Indoor air quality in Brazilian universities. Int J Environ Res Public Health. 2014 Jul 11;11(7):7081-93. doi: 10.3390/ijerph110707081. PMID: 25019268; PMCID: PMC4113862

Koonin, S. E. (2021). Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters. BenBella Books. 316 p.

Kotol, Martin, Carsten Rode, Geo Clausen, Toke Rammer Nielsen (2014). Indoor environment in bedrooms in 79 Greenlandic household. Building and Environment, Volume 81, November 2014, Pages 29-36 https://doi.org/10.1016/j.buildenv.2014.05.016Get rights and content

Kotol, Martin (2014). Survey of Indoor Air Quality-University of Alaska Fairbanks Sustainable Village. Cold Climate Housing Research Center, Report 33 p. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cchrc.org/media/SustainableVillage_Indoor AirQualitySurvey.pdf Retrieved September 10, 2024

Krawczyka, D.A. , A. Roderob, K. Gładyszewska-Fiedoruka, A. Gajewskia aBialystok (2016). CO_2 concentration in naturally ventilated classrooms located in different climates—Measurements and simulations. Energy & Buildings, Volume 129, pp. 491-498.

Lee SC, Chang M. (2000) Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere. 11, 109-113.

Let's Talk Science (2024). Carbon Dioxide on Earth and on the ISS (International Space Station) https://letstalkscience.ca/educational-resources/backgrounders/carbon-dioxide-on-earth-and-on-iss Retrieved August 16, 2924

Lindsey, R. (2022). Climate Change: Atmospheric Carbon Dioxide. Climate. Gov. https://www.climate.gov/news-features/understanding-climate/ climate-change-atmospheric-carbon-dioxide Rretrieved February 5, 2023.

Lindzen, R. (2023). Richard Lindzen's Climate Reality Check: Bridging the Gap Between Data and Climate Policy. 15th International Conference on Climate Change. February 23-25, 2023, Orlando, Florida (USA). The Hearland Institute. https://www.youtube.com/watch?v=h5D6hSYxlcM Retrieved June 15, 2023

Lipsett MJ, Shusterman DJ, Beard RR. 1994. Inorganic compounds of carbon, nitrogen, and oxygen. In: Patty's Industrial Hygiene and Toxicology (Clayton GD, Clayton FD, eds). New York:John Wiley & Sons, 4523–4554.

MedlinePlus (2024). Alkalosis. https://medlineplus.gov/ency/article/001183.htm Retrieved August 16, 2924

Lomborg, B. (2007). Cool It: The Skeptical Environmentalist's Guide to Global Warming. Knopf Publishing Group. 272 p.

Meehl, G.A., T.F. Stocker, et al., (2007). "Global climate projections." *AR4 Climate Change 2007: The Physical Science Basis* 4:758–856.

Menn, S.J., R.D. Sinclair, and B.E. Welch. 1970. Effect of inspired pCO_2 up to 30 mm Hg on response of normal man to exercise. J. Appl. Physiol. 28(5):663-671 (as cited in NRC 1996).

Messina Z, Patrick H. Partial Pressure of Carbon Dioxide. [Updated 2022 Sep 26]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551648/

Mills, B.J.W., Krause, A.J., Scotese, C.R., Hill, D.J., Shields, G.A., and Lenton, T.M., (2019). Modelling the long-term carbon cycle, atmospheric CO_2, and Earth surface temperature from late Neoproterozoic to present-day, Gondwana Research, v. 67, p. 172-186, doi: 10.1016/j.gr.2018.12.001 1342-937.

MNDOH 2024). Carbon Dioxide (CO_2). https://www.health.state.mn.us/communities/environment/air/toxins/CO2.htmlRetrieved August 16, 2024

Moore, P. (2021). Greenpeace's Ex-President - Is Climate Change Fake? - Patrick Moore | Modern Wisdom Podcast 373. https://www.youtube.com/ watch?v=E5K5i5Wv7jQ Retrieved June 18, 2023

Moser, Tom. (2023). NASA Engineer Tom Moser Reveals the Truth About Climate Science. 15th International Conference on Climate Change. February 23-25, 2023, Orlando, Florida (USA). The Hearland Institute. https://www.youtube.com/watch?v=1-gHWcrCK7w Retrieved June 15, 2023

Mulhern, O. (2020). A Graphical History of Atmospheric CO_2 Levels Over Time.https://earth.org/data_visualization/a-brief-history-of-CO2/ earth.org. Retrieved January 26, 2023

Muscatiello N, McCarthy A, Kielb C, Hsu WH, Hwang SA, Lin S. (2015). Classroom conditions and CO_2 concentrations and teacher health symptom reporting in 10 New York State Schools. Indoor Air. 2015 Apr;25(2):157-67. doi: 10.1111/ina.12136. Epub 2014 Jul 14. PMID: 24920413.

NASA. (2021). "Global Climate Change Carbon Dioxide." NASA. https://tinyurl.com/ntvyuzha

NASA (*National Aeronautics and Space Administration)*, (2023). Graphic:The relentless rise of carbon dioxide. https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/ Retrieved February 10, 2023

NOAA (2024). Global Monitoring Laboratory. Earth System Research Laboratories. Trends in Atmospheric Carbon Dioxide (CO_2). https://gml.noaa.gov/ccgg/trends/ Retrieved August 16, 2024

NRC (National Research Council). (1996). Carbon dioxide. Pp. 105-189 in Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, Vol. 2. Washington, DC: National Academy Press.

NRC (National Research Council) (2007). 3 Carbon Dioxide." National Research Council. 2007. Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants: Volume 1. Washington, DC: The National Academies Press. doi: 10.17226/11170.×

OSHA (Occupational Safety and Health Administration). 2012. Sampling and Analytical Methods: Carbon Dioxide in Workplace Atmospheres. Available: http://www.osha.gov/dts/sltc/methods/inorganic/id172/id172.html [accessed 7 May 2012]

Persily AK. {1997). Evaluating building IAQ and ventilation with carbon dioxide. ASHRAE Transactions 103(2):193–204.

Persily AK, Gorfain J. (2008). Analysis of Ventilation Data from the U.S. Environmental Protection Agency Building Assessment Survey and Evaluation (BASE) Study. NISTIR-7145-Revised. Gaithersburg, MD:National Institute for Standards and Technology.

Pingree, B.J.W. 1977. Acid base and respiratory changes after prolonged exposure to 1% carbon dioxide. Clin. Sci. Mol. Med. 52(1):67-74 (as cited in NRC 1996).

Plimer, Ian. (2023). Ian Plimer, a Geologist's View of Climate Change at Heartland Institute Climate Conference, 2023. 15th International Conference on Climate Change. February 23-25, 2023, Orlando, Flori (USA). The Hearland Institute. https://www.youtube.com/watch?v= tK4LNIvlcCY Retrieved June 15, 2023

Putin, V. (2024). YouTube Video. Interview with Tucker Carlson.https://www.youtube.com/watch?v=5joqUZTT4m0 Retrieved February 10, 2024. Video Length: 4:38.

Quora (2024). What is the percentage of nitrogen after breathing and before breathing?https://www.quora.com/What-is-the-percentage-of-nitrogen-after-breathing-and-before-breathing#:~:text=https%3A//www.mheducation.com/highered/product/anatomy%2Dphysiology%2Dunity%2Dform%2Dfunction%2Dsaladin/M1259277720.html%20 August 16, 2024

Radziszewski, E., L. Giacomoni, and R. Guillerm. (1988). Effets physiologiques chez l'homme du confinement du longue duree en atmosphere enrichie en dioxyde de carbone. Pp. 19-23 in Proceedings of the Colloquium on Space and Sea [in French]. European Space Agency, Brussels, Belgium (as cited in NRC 1996).

Randall, Scott (2010). Air Quality in the Classroom. 2009 Scandinavian student-based research campaign. NILU OR;6/2010. Norwegian Institute for Air Research. (**Norwegian**: NILU – Norsk Institutt for luftforskning) 120 p. chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.nilu.no/wp-content/uploads/dnn/06-2010-sr-FK2009.pdf

Rivera, Maria (20120). Indoor Environmental Quality in Chilean Classrooms. University of Oregon. Scholars' Bank URI: https://scholarsbank.uoregon.edu/xmlui/handle/1794/25257Retrieved August 30, 2024

Robson, John. (2024). YouTube video. All about EV. Climate Discussion NEXUS. https://www.youtube.com/watch?v=gYgAZRcVbmw Retrieved November 5, 2024

Satish, U, Mendell MJ, Shekhar K, Hotchi T, Sullivan D, Streufert S, Fisk WJ.(2012). Is CO_2 an indoor pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance. Environ Health Perspect. 2012 Dec;120(12):1671-7. doi: 10.1289/ehp.1104789. Epub 2012 Sep 20. PMID: 23008272; PMCID: PMC3548274.

Scheid P, Piiper J. (1980). Blood/gas equilibrium of carbon dioxide in lungs. A critical review. Respir Physiol. 1980 Jan;39(1):1-31. doi: 10.1016/0034-5687(80)90011-0. PMID: 6987719.

Schneider, E.C., and D. Truesdale. (1922). The effects on the circulation and respiration of a increase in carbon dioxide content of the blood in man. Am. J. Physiol. 63:155-175 (as cited in NRC 1996).

Scotese, C. R., H. Song, B. J. Mills, D. G. van der Meer, (2021). Phanerozoic paleotemperatures: The earth's changing climate during the last 540 million years. Earth Sci. Rev. 215, 103503 (2021). doi: 10.1016/j.earscirev.2021.103503

Scripps CO_2 Program (2023). CO_2 Concentration at Mauna Loa Observatory, Hawaii. Scripps Institution of Oceanography. UC San Diego, California. https:// scrippsCO₂.ucsd.edu/ Retrieved February 8, 2023.

Senseair (2024). Case Study: Tagoura Junior High School (Classroom). CO_2 Concentrations in Classrooms. https://www.akm.com/us/en/products/CO2-sensor/application/CO2-monitoring-school-top/3-classroom-demonstrations/ Retrieved September 8, 2024.

Shanmugam, G. (2006). The tsunamite problem. J. Sedimentary Research, 76, 718–730.

Shanmugam, G. (2008). The constructive functions of tropical cyclones and tsunamis on deepwater sand deposition during sea level highstand: implications for petroleum exploration. AAPG Bulletin, 92, 443-471.

Shanmugam, G. (2012). Process-sedimentological challenges in distinguishing paleo-tsunami deposits. In: Kumar, A., Nister, I. (Eds.), Paleo-tsunamis. Natural Hazards, 63, pp. 5–30.

Shanmugam, G. (2022). Sedimentary Basins: Processes, deposits, palaeogeography, and challenges. Keynote Lecture, 37th Convention of the Indian Association of Sedimentologists, University of Jammu, India, April 27, Wednesday, 10:00 AM (Jammu, India Time), 2022, Virtual Platform. In: IAS Abstract volume. P. 6-26.

Shanmugam, G. (2023). 200 Years of Fossil Fuels and Climate Change (1900-2100). The Journal of the Geological Society of India, v. 99, 1043-1062.

Shanmugam. G. (2024a). Reminiscing over six decades of global scientific journey (1962-2024): Sedimentary processes, environments, deposits, deformation, fossil fuels, Climate change, and groupthink. IAS Magazine, 3, I, 1 – 87. DOI: https://doi.org/10.51710/jias.v3i1.378

Shanmugam, G. (2024b). Fossil fuels, climate change, and the vital role of CO_2 Plays in Thriving people and plants on planet Earth. Bulletin of the Mineral Research and Exploration, v. 175, 167-208. https://dergi.mta.gov.tr/article/show/2800.html Retrieved October 17, 2023

Shanmugam, G. (2024c). A remarkable decade of learning and sharing knowledge through the Journal of Palaeogeography (JoP) (2014─2024): Reminiscences from an Associate Editor-in-Chief. Journal of Palaeogeography, 13, 1029-1040.

Shanmugam, G: (2024d). “Climate: The Movie (The Cold Truth)”: The categorical science film in discrediting the climate scare and a consequential documentary for a flourishing human civilization.” Review article. IAS Magazine (Submitted on April 9, 2024). 62 p.

Sinclair, R.D., J.M. Clark, and B.E. Welch. (1969). Carbon dioxide tolerance levels for space cabins. Proceedings of the Fifth Annual Conference on Atmospheric Contamination in Confined Spaces, September 16-18, Wright-Patterson Air Force Base, Dayton, OH.

Sinclair, R.D., J.M. Clark, and B.E. Welch. (1971). Comparison of physiological responses of normal man to exercise in air and in acute and chronic hypercapnia. Pp. 409-417 in Underwater Physiology, C.J. Lambertsen, ed. New York: Academic Press.

Singer, S. Fred, Idso, Craig Douglas; (2009). Climate Change Reconsidered: The Report of the 1368 Nongovernmental International Panel on Climate Change (NIPCC), 880 p. ISBN 978- 1369 1934791288

Soomro, Majid Ali; Sheeraz Ahmed Memon; Muhammad Mujtaba Shaikh; Azizullah Channa (2018). Indoor air CO_2 assessment of classrooms of educational institutes of hyderabad city and its comparison with other countries. 5TH INTERNATIONAL CONFERENCE ON ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT (EESD-2018) 14–16 November 2018, Jamshoro, Pakistan.

Soon, W, Connolly, R., Connolly, M. 2015. Reevaluating the role of solar variability on Northern Hemisphere temperature trends since the 19th century. Earth-Science Reviews, 150, 409-452.

Stumm, Robert. E. (2022). Revisiting the 1,000 ppm CO_2 Limit. ASHRAE Journal, 2022, v. 64, n. 6, p. 14-22.

Teleszewski, T., Gładyszewska-Fiedoruk, K. (2019). The concentration of carbon dioxide in conference rooms: a simplified model and experimental verification. *Int. J. Environ. Sci. Technol.* **16**, 8031–8040 (2019). https://doi.org/10.1007/s13762-019-02412-5

Trump-Musk Conversation on X (2024). Full Transcript. Musk claims on CO_2. [01:09:35].https://aliceapp.ai/recordings/u3eRUJ4Dc8AgSh56T7t1IwnmBFz_Hosk Retrieved August 16, 2024.

USDA (2024). Carbon dioxide. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.fsis.usda.gov/sites/default/files/media_file/2020-08/Carbon-Dioxide.pdf Retrieved September 17, 2024

Valdes, P.J., Lunt, D.L., and Scotese, C.R., (2018). Modelling the Climate History of the Phanerozoic, (abstract), American Geophysical Union, Monday, December 10, 2018, Convention Center, Hall A-C (Poster Hall), Fall Meeting 2018, #PP11F-1031, Washington, D.C.

Van der Walt, R.E. van der Walt, S.S. Grobbelaar, M.J. Booysen, (2024). Indoor temperature and CO_2 in South African primary school classrooms: Inspecting brick, container, and prefab structures. Journal of Cleaner Production 470 (2024) 143120

Van Wijngaarden, W. A. and Happer, W. (2020). Dependence of Earth’s Thermal Radiation on Five Most Abundant Greenhouse Gases (June 8, 2020), https://arxiv.org/pdf/2006.03098 Retrieved April 30, 2023

Wang, Lei, Yanling Wang, Fang Wang, and Haiyan Wang (2022). Quantitative Assessment of Indoor CO_2 Concentration of a Comprehensive Office Building.The 16th ROOMVENT Conference (ROOMVENT 2022), Xiâ€ ™an, China, Edited by Li, A.; Olofsson, T.; Kosonen, R.; E3S Web of Conferences, Volume 356, id.05043

Watts, Anthony (2009). Is the US surface temperature record reliable?. SurfaceStations.org, 28 p. ISBN 978-1934791295

White, C.S., J.H. Humm, E.D. Armstrong, and N.P.V. Lundgren. (1952). Human tolerance to acute exposure to carbon dioxide. 1. Six Per Cent Carbon Dioxide in Air and in Oxygen. J. Aviat. Med. 23:439-455 (as cited in NRC 1996).

Wilson, Diane (2022). Higher than normal levels of CO_2 detected in classrooms, Wake County parents want answers, abc11 troubleshooter. Thursday, November 10, 2022. https://abc11.com/wake-county-schools-nc-high-CO2-levels-indoor-air-quality-students-parents/12437952/ Retrieved August 27, 2024

Wing, S., and Huber, B., (2019). Earth's Temperature History Workshop, Smithsonian National Museum of Natural History, March 30-31, 2018, Washington, D.C.

Wikipedia (2024a). Military expenditure by country. . https://commons.wikimedia.org/wiki/File:Military_Expenditures_by_Country_2019.svgRetrieved August16, 2024

Wikipedia (2024b). List of countries with highest military expenditure. https://en.wikipedia.org/wiki/List_of_countries_with_highest_military_expenditures Retrieved August16, 2024

Wikipedia (2024c). Developed Country. https://en.wikipedia.org/wiki/Developed_country Retrieved August16, 2024

Wikipedia (2024d). Elon Musk. https://en.wikipedia.org/wiki/Elon_MuskRetrieved August16, 2024

Zemitis, Jurgis, Raimonds Bogdanovics and Snezana Bogdanovica (2021). The Study of CO_2 Concentration in A Classroom During The Covid-19 Safety Measures. E3S Web Conf. Volume 246, 2021, Cold Climate HVAC & Energy 2021.

Zhu YD, Li X, Fan L, Li L, Wang J, Yang WJ, Wang L, Yao XY, Wang XL. (2021) Indoor air quality in the primary school of China-results from CIEHS 2018 study. Environ Pollut. 2021 Dec 15;291:118094. doi: 10.1016/j.envpol.2021.118094. Epub 2021 Sep 1. PMID: 34517175

IAS MAGAZINE
Vol. 3, Issue II, 2024, pp. 35 – 44
DOI: https://doi.org/10.51710/jias.v41iII.385

ISSN NO 2582 – 2020

Rich or Poor Nation: Water Scarcity is a Global Crisis

Naresh Kumar
Growth Oil and Gas
Austin, Texas, USA
E-mail Address: naresh@growth-energy.com

ABSTRACT

Almost four billion people face severe water scarcity worldwide. This is not a problem of either rich or poor countries. Simply using more fresh water than is available for agriculture, industry, or domestic use has made the crisis critical. Climate change has degraded the patterns of fresh-water availability worldwide while population growth and rising standards of living have caused increasing demand on the supplies. This paper discusses only the supply and demand side of fresh water. The problems related to the distribution or quality of that water is beyond the scope of this study. Although citing examples of water-related crises in USA, Brazil, and North and North-Central Africa (hereafter referred to as NNCA), the main part of the paper deals with the causes and possible solutions for hydrological "emergency" in India. India provides a type example for the causes of water crisis and its possible solutions. Logical steps taken at one time to raise the standards of living and provide plentiful food for the population appear to have worsened the crisis many years later. Population growth, increased living standards, growing urbanization (considered public good) have all contributed to the water crisis not just in India, but worldwide. Perhaps the Indian example can serve as a "model" for what to do and perhaps more importantly, what not to do for other parts of the world.

In 1951 the Indian population stood at 361million; by 2023 it has exceeded China's at 1.461 billion. During this period, the per-capita water availability has decreased almost fourfold! The urban population has more than doubled (from less than 20% to 40%) causing metropolitan areas to grow outwards and upwards and reducing the recharge areas to provide for the water needs of the cities. To feed the growing population, during the "Green Revolution" in the 1960s, the government provided incentives to farmers to use mechanical pumps (subsidies for electricity and fuel), for water from canals, and for fertilizers. All of this made India not only self-sufficient in food, but the world's top producer of rice and the second largest producer of wheat. However, it has also made India *number one* out of 170 countries in total freshwater withdrawal (2.5 trillion m^3). As a result, the water table is dangerously low in many of the aquifers. In addition, pollution of surface and ground water, lack of storage capacity for the available water, and weakening of monsoons have added to the water crisis.

Steps to manage the surface waters by interlinking river systems, harvesting rain water, improving irrigation methods, changing crop patterns to reduce the use of groundwater and improving wastewater treatment may be parts of the solution not just in India, but worldwide. However, the key factors are political will and economic realities if the problem is to be tackled in a timely manner.

INTRODUCTION

The Hydrologic or "Water" Cycle is one of the basic natural cycles that describes the path of essentially each water molecule through the atmosphere, on the surface and in the subsurface of land areas, and through the oceans. The total available water supply is finite, and the freshwater which we consume for agricultural, industrial, and domestic use constitutes only 2.5% of Earth's water. Because most of the fresh water is trapped in ice sheets, the total water available for human use as surface or ground water at a given time is only 0.8% of the total water volume (Water Science School, 2019). In the pre-industrial era (mid-18th Century, as defined by Encyclopedia Britannica, 2024) when populations worldwide were small and the water usage for agriculture and industry was limited, the total available water supply was generally not a problem. However, today in the early 21st century, with the world's population having surpassed 8 billion (Worldometer, 2023), elevated living standards requiring increased water use for

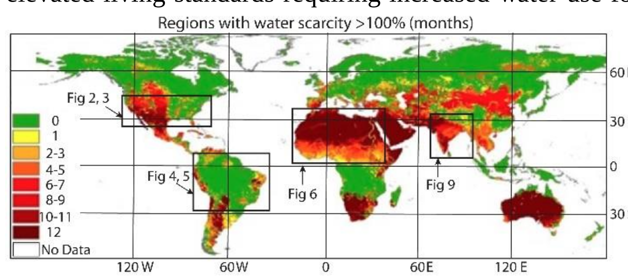


Figure 1: Map showing in colors ranging from green to red, areas where water scarcity lasts from 0 to 12 months/year. Red-colored areas are countries where water scarcity lasts at least six months or more. Darkest red areas have year-round scarcity >100% (Carrington, 2016). Locations of Fig 2,3,4,5,6, and 9 are also shown.

agriculture and industry, and large population concentrations in "mega cities" (populations generally >10 million), more than four billion people (50% of world's population) face *severe water scarcity* (Carrington, 2016) (Figure 1).

As shown in the Figure 1, the problem spans the globe and afflicts countries as disparate as the USA, Brazil, and India. In addition, multiple countries in North and Central Africa (hereafter referred to as NNCA and consisting of Egypt, Libya, Algeria, Morocco, Sudan, Chad, Niger, Mali and Mauritania) face year around water scarcity. The income level, industrial development and the population size in each of these areas is very different, yet

Use of Fresh water Withdrawal by Sector (2019)

Table 1: Comparison of use of fresh-water withdrawal in agriculture, industry, and domestic consumption for the USA, Brazil, North and North-Central Africa* (NNCA includes Egypt, Libya, Algeria, Tunisia, Morocco, Sudan, Chad, Niger, Mali, and Mauritania), and India (data from Ritchie and Roser, 2024). Agriculture, by far, uses an overwhelming share of the available water except in the richest countries.

Sector%	USA	Brazil	NNCA*	India
Agriculture	40	61	84	90
Industry	47	15	3	2
Domestic	13	24	13	8

each is facing water scarcity issues as discussed in this paper. However, the main discussion in this paper is centered on India as a "case study".

With the exception of air, water is the most important commodity for human survival. Hence, understanding and managing the risks imposed by water scarcity worldwide is critical for the global future. Table 1 shows the use of fresh-water withdrawal in each of the areas mentioned. Of the three primary sectors where freshwater is consumed worldwide, agriculture is the dominant sector (Ritchie and Roser, 2024). In developed countries, the industrial sector (including power generation) consumes as much as the agriculture, or more, whereas the domestic use is a relatively minor component. Thus, although water scarcity in mega cities makes the headline news, any efforts to conserve and streamline the use of freshwater in agriculture will produce the largest impact.

This paper describes in brief various factors affecting water availability in the USA, Brazil and NNCA first. It then describes the water crisis in India as a "type example". Some of the factors that have caused the crisis in India are more or less the same as those affecting many other countries worldwide. However, India's population and the size of its GDP (Gross Domestic Product; 2019 ranking: 5th in the world in nominal dollars, and 3rd in Purchasing Power Parity, Wikipedia 2024) makes the problem not only critical for India, but for the whole world. Also, perhaps some of the approaches to tackle this crisis, if successful in India, may be applied to other smaller populations and economies as well.

WATER CRISIS IN THE UNITED STATES

With one of the highest standards of living in the world, we normally do not associate the United States with

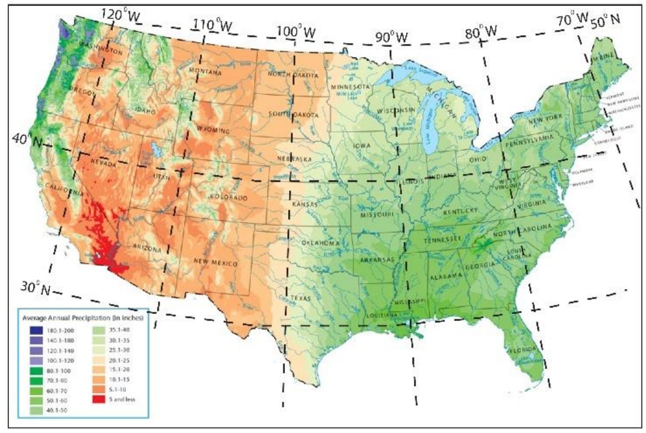


Figure 2. Map showing the US annual rainfall in inches (1 inch = 25.4 mm). Almost the entire Western half of the United States (areas in earth colors) has rainfall less than 500mm/year (20 inches) and is classified as semi-arid or arid (GIS Geography, 2015).

having a water scarcity or water crisis. However, in reality, the pattern of usage which allows higher withdrawal rates than natural replenishment, especially in the western parts of the country has created conditions of severe to extreme drought (Wyler, 2013).

As shown in Figure 2, almost the entire western one-half of the US is either arid or semi-arid (rainfall <250 mm or <500mm). Yet, these western states have grown in population and have become some of the primary agricultural states in the country. "Overcoming the nature" has been considered almost an American tradition and thus, through dams, canals, pipelines, and groundwater withdrawals, this half of the country has been able to essentially "ignore" the lack of water. However, during the last thirty years, whereas the eastern half of the country has become wetter, the western half has become drier. The

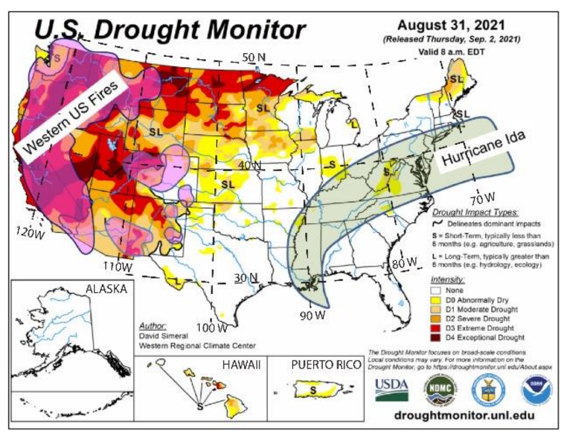


Figure 3. Map for the week of August 31, 2021 showing moderate to exceptional drought throughout most of the western US (US Drought Monitor, 2021). Map also shows the locations of forest fires during the same week as well as the path of Hurricane Ida, which created extreme flooding conditions in parts of the eastern US (taken from various news sources for that week).

average precipitation in the western US has decreased by up to 100mm (20% to 40% less than the average during the twentieth century) (Bhatia and Popovich, 2021). This has led to declarations of "drought" or "extreme drought" in much of the western half of the country (Figure 3). In fact, 2021 being an exceptionally dry year, the 22-year-long drought in the western US has been the worst in 1,200 years (Harvey and E.E. News 2022). In addition to stress on agriculture and domestic use, these drought conditions have led to extreme fire conditions along the same western states.

In fact, in order to support the population growth and support the agriculture for the western US, giant dams and hydroelectric projects have been built along the Colorado River in the states of Arizona and Nevada. Water supplied from these projects support farming, especially in California, which does not have enough of its own ground water to support the level of its agriculture industry. While this has worked reasonably well for more than 80 years (with many years of shortage in between), because of long-term drought a first-ever water "shortage" was declared for the Colorado River (Munch, 2021). The water levels in the reservoirs behind some of the largest dams ever built in the US have dropped by almost 50 meters in 2021 from their highest levels in 1983. This type of declaration may result in cutback in water supply and power generation and may affect more than 40 million people who live in the areas supplied by the Colorado River (Munch, 2021, Harvey and E&E News, 2022).

One of the side effects of water scarcity in the western US is also the severe forest fires that have occurred for many years. During the years 2020 and 2021, more than seven million hectares have been destroyed by fires (Insurance Information Institute, 2022) and the economic damage from 2021 fires alone is estimated at US $70 to 90 billion out of which $45 to $55 billion is in the state of California alone (Puelo, 2021).

Regardless of where a country fits on the economic scale, the basic reason for water shortage is simple: *demand outstripping supply*. Whereas a discussion of climate change is beyond the scope of this paper, long-term droughts have occurred in all the countries that are discussed in this paper. It is not the *average* shortage of water in a given year that should be of most concern, but the *"cumulative deficit*" caused by long-term reduction in replenishment over draw-down that should be most worrisome (Shi et al., 2013). Using this parameter, almost half of the United States, including the central part that produces a large amount of national agricultural products, is facing critical water shortage (Shi et al., 2013). In fact, "overdrawing" on the ground water has caused the declining of wells in almost half the sites throughout the country, especially in the agricultural land in the center (Rojanasakul et al., 2023). For example, in the state of Kansas, almost a million hectares (2.6m acres) of aquifer can no longer support industrial-scale agriculture. Every year since 1940, more wells have had falling water levels than rising levels, and this makes it almost impossible to replenish the aquifers (Rojanasakul et al., 2023).

SCARCITY AMONG PLENTY IN BRAZIL

It is ironic that with one of the highest per-capita renewable freshwater resource among large-population countries in the world (26,553 m^3 in 2020, Ritchie and Roser, 2024), Brazil should even be listed among the countries with water "scarcity". In fact, the water resource for Brazil is three times that of United States, and 25 times that of India on a per-capita basis (Ritchie and Roser, 2024). Using the parameter of freshwater per capita, Brazil would be considered "low stress", whereas the United States falls in the "low-to-medium stress" and India and NNCA fall into "high-stress" category. However, a prolonged drought in the south and southeast of the country, coupled with an increase in population and domestic and industrial use, has created severe shortages especially in the São Paulo region (Figure 4, Getirana et al., 2021).

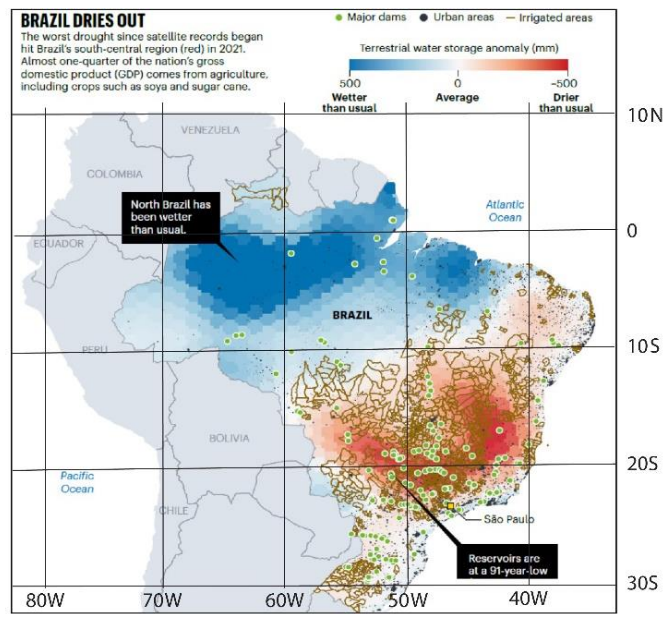


Figure 4. Map showing the terrestrial water storage anomaly. Southeast Brazil has an anomaly of as much as 500mm (drier than normal). Map also shows major dams (green dots) and areas under irrigation (brown outlines) (Getirana et al., 2021).

Because most of the Amazon Basin is located in Brazil, the surface and groundwater flow within the boundaries of Brazil counts as part of Brazil's resource. However, the largest cities of Brazil and a great majority of the population is located thousands of kilometers away. Indirectly, climate change and deforestation in Amazon region affects the hydroclimate in the south-central region where 70% of Brazil's gross domestic product (GDP) is generated. Brazil depends on hydroelectricity for as much as 70% of its electric needs. As the reservoir levels have gone down, generation and consequently, industrial and agricultural production may be in jeopardy (Brandimarte and Freitas Jr., 2021).

According to Slater (2019), Brazil has experienced one of the worst droughts in its history since 2015. This has been caused by a combination of natural and man-made causes including climate change, environmental degradation, poor urban planning, a lack of maintenance of existing infrastructure and the mismanagement of water resources. The effects of climate change in agricultural production in Brazil can be severe. A 1^0 C change in temperature could decrease the Brazilian coffee production by as much as 24%, and soybean production by 14% (Getirana et al., 2021). These crops represent some of the most valuable crops in Brazil. Of course, the urban areas, such as the city of São Paulo, have suffered severe consequences of this drought as well. During this period, one of the main water reservoirs of this city was functioning at only 5.4% of its capacity (Getirana et al., 2021).

In addition, the Amazon Basin itself has also been facing a long-term drought despite the 2021 “wetter than normal” season as shown in Figure 4. In 2023, the entire Amazon Basin was facing “severe to exceptional” drought (Poynting, 2024) (Figure 5).

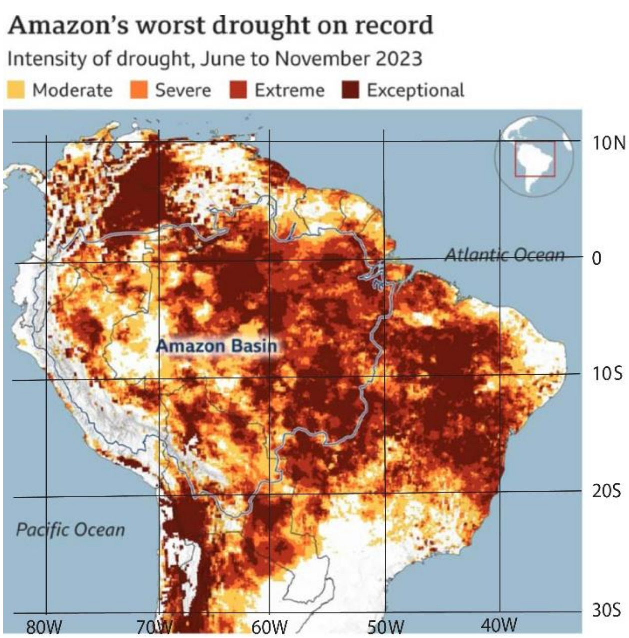


Figure 5. Intensity of drought as measured by SPEI (Standard Precipitation Evapotranspiration Index) for Brazil and surrounding countries (Poynting, 2024) from June to November 2023. The boundaries of the Amazon Basin, which covers a majority of the territory of Brazil, is shown in dark outline.

In April and May 2024, southern Brazil state of Rio Grande do Sul had historic floods, the worst in at least 70 years (Ledur, 2024). The state received roughly eight months’ worth of average rainfall in just the first half of May. More than 450 municipalities were flooded causing death and destruction and thousands of people were displaced (Ledur, 2024). However, such sudden events do not change the trajectory of regional droughts because the excess water is not captured and flows back to the ocean rapidly. The regions to the north of Rio Grande do Sul in south-east and central Brazil continued to be hot and dry in mid-May and early June, 2024 (Climate Impact Company, 2024).

As we have seen from the discussion on the USA and on Brazil, meteorological droughts (dry-weather patterns due to periods of little rainfall or high temperatures) can cause hydrological droughts (water shortages on land surfaces such as rivers and lakes) which can dry out shallow aquifers and lower the regional water table. Consequent decline in soil-moisture levels jeopardizes food production (Getirana et al., 2021) and may cause other socio-economic disruptions.

WATER CRISIS IN NORTH AND NORTH-CENTRAL AFRICA (NNCA)

The countries included in this discussion (Egypt, Libya, Algeria, Tunisia, Morocco, Sudan, Chad, Niger, Mali, and Mauritania) with a total population of 337 million (Worldometer, 2023), are some of the most arid places in the world. However, because all of them are also very sparsely populated (with the exception of Egypt, 35% of the total), the aquifers in some of these countries have not been overdrawn but the withdrawal in these areas is considered “uneconomic”. Thus, the challenge in parts of Africa is of drawing the water from aquifers in appropriate amounts to meet the domestic, industrial, and agricultural needs of the population. Therefore, the water scarcity has been classified as “physical” or “economic” (Lai,2022) (Figure 6).

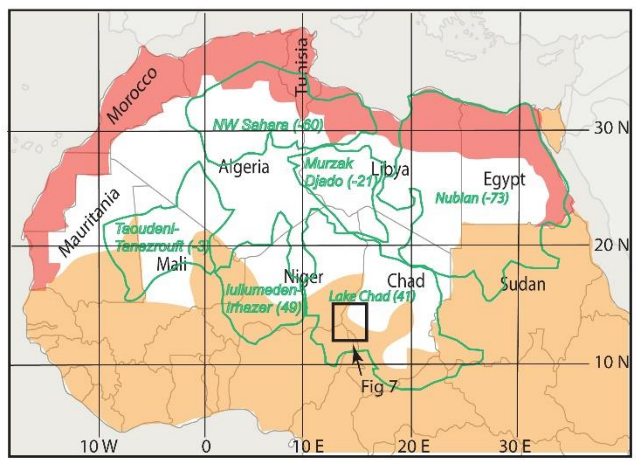


Figure 6. Map of NNCA countries showing physical (red) or economic (orange) water scarcity at basin level on the African continent (Lai, 2022). Blank areas have little data on water availability. Green outlines show major aquifers in the region and the numbers within show the change in TWS (Total Water Storage) in these aquifers as derived from satellite data between 2002 and 2020 (TWS = surface water+ soil moisture + shallow and deep ground water, storage units in cubic kilometers) (Scanlon et al., 2022). Location of Figure 7 is shown by a black rectangle.

Out of the countries mentioned above, only Egypt, Tunisia, Algeria and Morocco represent countries with “modest” relative water security and Libya and Mali have “slight” water security. On the other hand, Sudan, Chad and Niger are some of the least water-secure countries on the

African Continent (Oluwasanya et al., 2022). However, as shown in Fig. 6, the three northern aquifers, Nubian, Murzak-Djado, and NW Sahara have lost 73, 21, and 60 cubic kilometers of water storage (TWS), respectively during the eighteen years between 2002 and 2020 (Scanlon et al., 2022). As a reference, the maximum capacity of Lake Mead in United States, one of the largest man-made lakes in the world is 35 cubic kilometers (Britannica, 2024). Egypt is facing an annual water deficit of about 7 billion cubic meters and with rising population it could face severe water shortage as early as 2025 (Unicef, 2022). As everywhere in the world, the cause of water scarcity is primarily overexploitation driven by rise in population and the rate of urbanization along with drought conditions exacerbated by climate change (Scanlon et al., 2022).

Figure 7. Lake Chad, spanning parts of Niger, Chad, Nigeria, and Cameroon has shrunk in surface area by almost 90% between 1972 and 2007 (Lai, 2007). Regional location shown on Figure 6.

Lake Chad (Fig. 7), deemed Africa's largest freshwater body, has shrunk during last several decades. The water body of the lake has diminished by 90% since the 1960s, with the surface area of the lake decreasing from 26,000 km^2 in 1963 to less than 1,500 km^2 in 2018 (Lai, 2022, Oluwasanya et al., 2022). However, as shown in Fig 6, the three southern aquifers have either actually increased their water storage or have remained relatively stable during the years 2002 to 2020. Specifically, the Lake Chad aquifer has grown its TWS by 41 cubic kilometers (Fig. 6, Scanlon et. al., 2022), a counterintuitive observation given the shrinkage of the surface water in Lake Chad. This increase is explained by Scanlon et. al. (2022) to increased recharge from land-use change and cropland expansion. As the cropland expands, only the surface water and shallow ground water is used while the deep ground water may actually expand. In fact, Pham-Duc et. al. (2020) monitored the hydrology of Lake Chad using satellite data and found that "in tandem with groundwater and tropical origin of water supply, over the last two decades, Lake Chad is not shrinking" and that it seasonally recovers its surface water extent and volume, at least since the 2010s.

Thus, in countries with "physical" scarcity of water in North Africa, the emphasis needs to be on conservation of irrigation water and recycling of domestic and industrial water, and desalination if feasible. On the other hand, countries with "economic" scarcity of water, the emphasis needs to be on accessing the available natural water storage and efficient management of surface and ground waters.

BACKGROUND AND MAGNITUDE OF THE CRISIS IN INDIA

India's per capita water availability is one of the lowest in the world (Pulakkat, 2017). With 2.4% share of global land area, 4% share of world's water resources, but 17% of the world's population, India ranks 132nd in water availability (this paper is concerned primarily with water availability; but water quality is another issue and India ranks 122nd in the world in that parameter). Whereas in 1951 the water availability per capita stood at almost 5,000 meters^3, by 2001 it was already below 2,000 meters^3. Water availability at 1,800 meters^3 per capita is considered "Water Stress" and below 1,000 meters^3 is considered "Water Scarcity" (Josue, 2008). By 2025, almost the entire Indian population will approach the water scarcity level (Josue, 2008) (Figure 8).

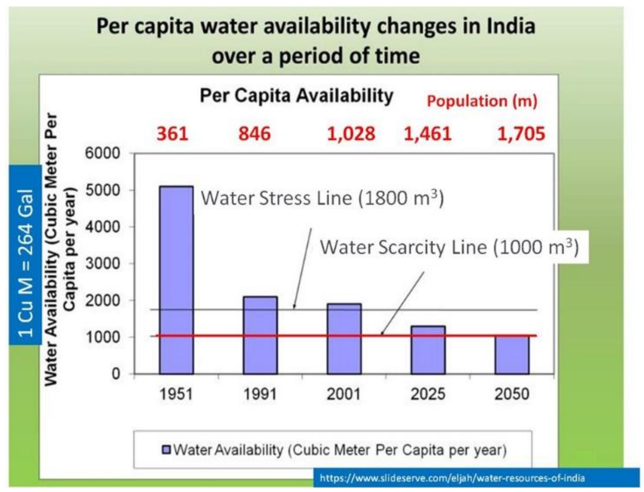


Figure 8. As the population of India has almost quadrupled in last 75 years, the water availability per capita has been cut by more than two-thirds. This has caused High to Extremely High-water stress in more than half of the country (Josue, 2008)

Additionally, whereas the domestic and industrial use of water accounts for approximately 15% of consumption, irrigation consumes more than 85% of the total water used (Josue, 2008). These percentages are slightly different from those shown in Table 1 for which the data is from Ritchie and Roser (2024). Demographic pressures and policy incentives introduced to increase the food production for an increasing population and rising living standards are responsible for this profligate use of water. The excessive withdrawal of water compared to available supply has resulted in 54% of the Indian landmass facing high (40-80% of available supply) to extremely high (>80% of available supply) water stress. These areas also happen to be some of the most populous and agriculturally most productive parts of the country (Shiao et al., 2015) (Figure 9).

Although still a poor country on a per-capita basis, Indian GDP has increased almost one hundred-fold since the 1950s (World Bank, 2023). In the 1950s, the industrial basis was small, and agriculture was almost entirely based on rainfall, surface water from canals and rivers, and well water. And water was pumped mostly by human- and animal-power. However, facing food shortages in India during 1960s, the government promoted a "green revolution" through improved seeds, providing subsidies for farmers for fertilizers, and essentially free water from canals, and free electricity for pumps. Thus, whereas in 1951 there were perhaps only 2,500 tube wells in all of India, currently at least 20 million (or more) tube wells exist in the country (Mukherji, 2012). As mentioned earlier, this has boosted the food production tremendously, but as the farmers have "overdrawn" on cheap (or free) water and

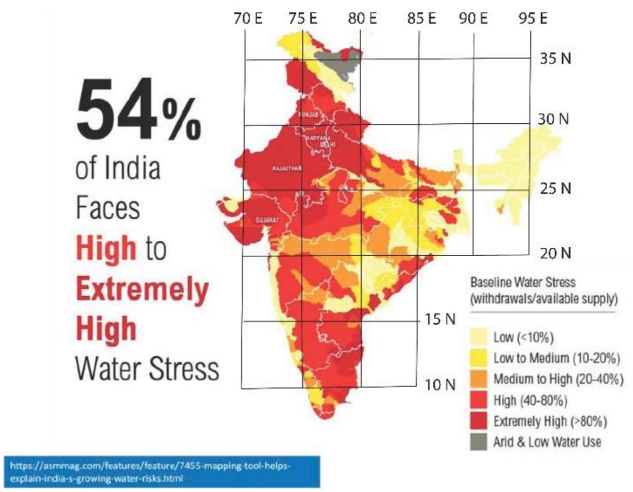


Figure 9. Areas in India facing "High" to "Extremely High" Water stress. In the darkest red areas (Extremely High) the withdrawal to available supply is >80% (Shiao et al., 2015).

electricity, the water table in most agricultural areas has not been able to keep up with natural recharge and has continued to drop over last several decades. Deficit recharge causes farmers to dig deeper and further draw down the water table in a vicious cycle (Figure 9).

Although the domestic and industrial use of water is a much smaller percentage than the agricultural use, it is also facing a crisis. According to Torkington (2016) there are five "mega cities" in India (New Delhi, Mumbai, Kolkata, Bengaluru, and Chennai), with two more expected by 2030. Three of these cities (Delhi, Bengaluru, and Chennai) have had major water crises during the last several years with water taps going dry and water distribution relying on tankers for months on end. For example, in 2019 the city of Chennai supplied water to its residents through 8,000 water trucks and brought water by railroad cars from more than a hundred miles away (Subramanian, 2019). Similar crisis management has been carried out in Delhi and in Bengaluru (Joshi et al, 2018, Jal Tarangg, 2016). This has happened through decades of unplanned growth, paving of natural recharge areas in watersheds near these cities, weak monsoon rains, and very little water treatment or recycling.

POSSIBLE APPROACHES TO SOLVING THE CRISIS

Water management is a multi-dimensional challenge that requires a comprehensive, multidisciplinary approach. In the past, in a large country like India, various local-, state- and federal-level authorities have managed surface- and subsurface-water usage and consumption in an ad-hoc manner. However, in May 2019, the Government of India formed a Ministry of Jal Shakti (Water Power) with an overall responsibility to implement a "National Water Mission" for an integrated water resource management to conserve water, minimize wastage and ensure more equitable distribution across and within the states (National Water Mission, 2019; NITI, 2019). Fortunately, over the years through various educational and government agencies' efforts, India does have good data on water budgets at the level of various catchment basins. These data bases can help guide the national policy.

Although the average annual rainfall in India is 300-650 millimeters (11.8-25.6in), almost 70% takes place during the summer monsoon (June-Sept) with a minor amount falling during the winter monsoon (Nov-Feb) (The Economist, 2019). Thus, if the monsoon is "less than average" for a year or two, and the surface-water irrigation is not sufficient, the surface reservoirs and aquifers are overdrawn and can be filled only if a "better than average" monsoon compensates for the deficit. At the Columbia Water Center of the Earth Institute of Columbia University, researchers have looked at water balance (rainfall vs ground water withdrawal) at multiyear scale and have mapped areas that, in order to avoid water scarcity, either need to have (a) excess surface storage capacity, or (b) should receive water through "inter-basin transfer" or (c) should carry out shift in crop patterns (Polycarpou, 2010; Devineni et al., 2013). All of these approaches have been tried in different parts of India at local or regional scales.

Unlined water storage structures have been built in the state of Rajasthan to store excess surface runoff and help replenish the local water table. According to Saini (2018), almost 100,000 water structures were built which reportedly, besides storing the water, also helped raise the ground water by 138 cm (almost 4 feet 8 inches) within a couple of years in certain districts.

An ambitious interbasin-transfer project in progress is the creation of nationwide "water-transfer links" comprising almost 15,000 km of canals and reservoirs, which would link rivers carrying excess of surface water during the rainy season to areas of water deficit where the surface water can be used and stored for agricultural and industrial uses. However, besides the cost ($168 billion), such a project requires careful attention to minimize the environmental impact of such an undertaking (Langar, 2017). Almost half of the proposed links have been completed.

Polycarpou (2010) has described the Columbia Water Center's pilot programs in India to encourage efficient use of water in agriculture as well as the proposed changes in crop patterns at a regional scale that would utilize available water optimally. In one case, rice farmers cut their water use by 30% using fairly low-cost methods (Polycarpou, 2010). Devineni et al. (2013), utilizing district-level data from all over India, describe a model which shows that crops like rice, sugarcane, lentils, and oil seeds should be grown where soil, climate, and water availability were best suited for those particular crops (Figure 10). Currently farmers grow crops wherever the subsidies for electricity, canal water, and fertilizers encourage them even at the cost of wasting precious water resources. Figure 10 illustrates how certain degree of regional shifting from current patterns of crops could optimize water usage while maintaining food security (Devineni et al., 2013).

As mentioned earlier, although the domestic and industrial use of water is a much smaller component of the total water usage, its scarcity has caused major disruptions in Indian megacities in the last few years. In order to mitigate the crisis, cities need to protect the recharge areas from development, maintain and build additional reservoirs and of course, enhance their water-treatment capacity.

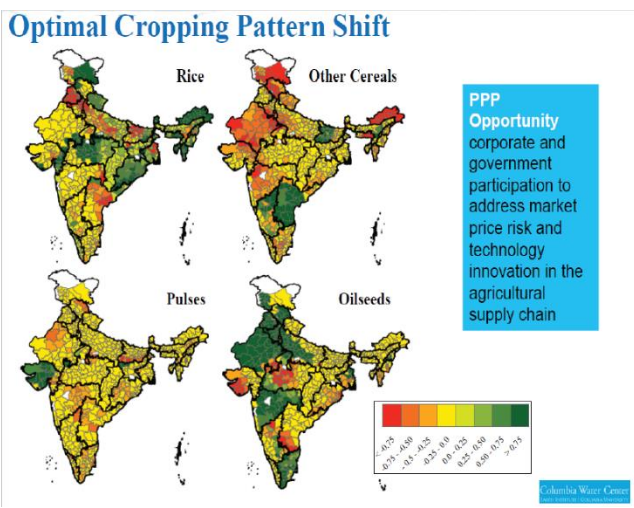


Figure 10. Maps showing district-level cropping patterns that would optimize water usage and would not jeopardize food security. However, this would require change in incentives to farmers to convince them to shift the crops planted without risking their economic gains (Devineni et al., 2013)

Whereas there are almost 16,000 treatment plants in the US serving more than 75% of the population, India has only 269 plants, of which only 231 are operational (Kamyotra and Bhardwaj, 2011) and which barely cover 21% of the generated sewage. Obviously, this would require a huge commitment of resources but it has the potential of generating tremendous rewards. For example, in a city like Bengaluru, treating waste-water could not only satisfy all the local needs and reduce water pollution, but also could generate up to 283 million m^3 (10 billion cubic feet) surplus treated water per year (Aravind, 2018).

SUMMARY

Mitigation of the water crisis needs to be carried out as one of the highest priorities for the population and economy not only for India but for the rest of the world. Of course, with the largest population in the world and the fifth-largest economy, whatever happens in India has global implications. But as described in this paper, the situation is quite dire in regions as diverse as NNCA, Brazil and the USA. Water scarcity is a global issue indeed.

Many problems can be tackled with invention of a new technology or an alternative approach. However, the problems related to water are multifaceted and have economic, legal and political dimensions. Hence solutions have to be also multidimensional and holistic. Water availability is obviously a very emotional issue and hence the "buy in" of general public is critical, if any of the proposed solutions are to be successful.

The solution lies in *conservation, storage, redistribution, and recycling* of available resources. Technology, and more than likely resources, are available to carry out all of these approaches at a national scale. However, governments at all levels, private industry, and the average citizen need to work together for mitigation of the crisis. Unfortunately, in most countries, policy makers are generally not inclined to work for long-term solutions. Tress (2010), based on a global survey, has listed 19 ways to solve the freshwater crisis. These solutions include educating the population to reduce consumption, recycling wastewater, improving water catchment, improving infrastructure, pricing water appropriately and developing public policy and legal framework to achieve these objectives. Each item on the list has a political, economic, legal and social component. And all of these require participation starting from a single household to the highest levels of national governments. Until all the stakeholders in this crisis work together, world will continue to face a risk of major disruptions emanating from the water scarcity.

CONCLUSIONS

1) Water scarcity is a worldwide concern demanding immediate attention from the people and leaders of all the nations in the world.

2) The crisis has been exacerbated by the growth in worldwide population, rising living standards, migration to large cities, and the change in weather patterns as a result of the climate change.

3) Water scarcity affects rich nations, such as the USA and the poor nations, such as those in the North and North Central Africa, as well as those in the middle, like Brazil and India.

4) India is a "poster child" of this crisis because many of the policies adopted to dramatically increase the food

production for its growing population have contributed to the crisis itself.

5) As agriculture is the largest consumer of fresh water in all economies, reducing the use of water in agriculture would produce the most relief. This could include crop rotation, crop redistribution, use of seed varieties using less water, and avoiding "over watering".

6) In large megacities, ground-water recharge areas must be protected and water treatment, storage, and conservation must be accelerated. These measures would help conserve the domestic and industrial use of fresh water.

7) Measures to alleviate water scarcity mostly require "common sense" solutions. However, they need consensus from individual citizens as well as from decision makers at all levels of the government. As vested interests would always resist change, public pressure and sound policy decisions are needed to avert a worldwide disaster.

ACKNOWLEDGMENTS

Discussions with Drs. Jed Damuth, G. Shanmugam, Luiz Gambôa, Maria Augusta Martins da Silva and Cleverson Silva have been very important in improving the content and quality of this paper. I thank them for their ideas and suggestions.

REFERENCES

Aravind, I. (2018). How these companies are using tech to solve Bengaluru's deep-water crisis? Available online at: https://m.economictimes.com/industry/miscellaneous/how-these-companies-are-using-tech-to-solve-bengalurus-deep-water-crisis/articleshow/63660145.cms

Bhatia, A. and Popovich, N. (2021). These maps tell the story of two Americas: One parched, one soaked: New York Times (August 24, 2021), available online at: https://www.nytimes.com/interactive/2021/08/24/climate/warmer-wetter-world.html

Brandimarte, W. and Freitas Jr., G. (2021). Brazil's worst water crisis in 91 years threatens power supplies: Bloomberg News, available online at: https://www.bloomberg.com/news/articles/2021-05-28/brazil-s-worst-water-crisis-in-91-years-threatens-power-supplies

Britannica. (2024). Lake Mead, United States, available on line at: https://www.britannica.com/place/Lake-Mead

Carrington, D. (2016). Four billion people face severe water scarcity, new research finds: The Guardian: available on line at: https://www.theguardian.com/environment/2016/feb/12/four-billion-people-face-severe-water-scarcity-newresearch-finds

Climate Impact Company. (2024). The Brazil drought is worsening, May-June 2024: available online at: https://climateimpactcompany.com/south-america-week-2-4-outlook-brazil-drought-worsening-2/

Devineni, N., Perveen, S., Sen, R., Vatta, K., Lall, U. (2013). A water risk model to inform India's development: available online at: https://ficci.in/public/storage/events/22061/ISP/Upmanu-Lall.pdf

Encyclopedia Britannica. (2024). Industrial Revolution: The Encyclopedia Britannica: available online at: https://www.britannica.com/event/Industrial-Revolution

Getirana, A., Libonati, R., Cataldi, M. (2021). Brazil is in water crisis- it needs a drought plan: Nature, v. 600, December 9, 2021: available online at: https://media.nature.com/original/magazine-assets/d41586-021-03625-w/d41586-021-03625-w.pdf

GIS Geography. (2015). 13 open-source remote sensing software packages: available online at: https://gisgeography.com/open-source-remote-sensing-software-packages/

Insurance Information Institute. (2022). Facts + Statistics: Wildfires, available online at: https://www.iii.org/fact-statistic/facts-statistics-wildfires

Harvey, C. and E&E News. (2022). Western "Megadrought" is the worst in 1,200 years: Scientific American, Feb 15: available online at: https://www.scientificamerican.com/article/western-megadrought-is-the-worst-in-1-200-years/

Jal Tarangg. (2016). Tag: Bangalore water crisis: Water water nowhere-nor a drop to drown: Wordpress: available online at: https://jaltarangg.wordpress.com/tag/bangalore-water-crisis/

Joshi, M., Nair, H., Baruah, S. (2018). Hardlook-Water scarcity in Delhi is playing out in many ways this year: The Indian Express: available online at: https://indianexpress.com/article/cities/delhi/hardlook-dry-days-summer-delhi-haryana-legal-dispute-water-crisis-scarcity-drying-river-5202688/

Josue, E. (2008). Water Resources of India: Online presentation available at: https://www.slideserve.com/eljah/water-resources-of-india

Kamyotra, J.S. and Bhardwaj, R.M. (2011). Municipal Wastewater Management in India: Chapter 20, India Infrastructure Report 2011, 12p: available online at: https://oldiwp.indiawaterportal.org/sites/default/files/iwp2/India_Infrastructure_Report_IDFC_2011.pdf#page=340

Lai, C. (2022). Water scarcity in Africa: Causes, effects, and solutions: Earth.org: available online at: https://earth.org/water-scarcity-in-africa/

Langar, S. (2017). Behind India's ambitious plan to create the world's longest river: Arch Daily: available on line at:https://www.archdaily.com/877423/behind-indias-ambitious-plan-to-create-the-worlds-longest-river

Ledur, J. (2024). Visualizing the scale of the floods that left south Brazil submerged: The Washington Post, May 23, 2024: available online at:

https://www.washingtonpost.com/world/interactive/2024/visualizing-scale-floods-that-left-south-brazil-submerged/

Mukherji, A. (2012). How many wells and tubewells in India: No one really knows!: Waterscapes: available online at: https://aditimukherji.wordpress.com/2012/07/13/how-many-wells-and-tubewells-in-india-no-one-really-knows/

Munch, D. (2021). First-ever Colorado River water shortage declaration spurs water cuts in the southwest: Market Intel: available online at: https://www.fb.org/market-intel/first-ever-colorado-river-water-shortage-declaration-spurs-water-cuts-in-th

National Water Mission. (2019). Objectives: available online at: http://nwm.gov.in

NITI. (2019). Composite water management index (in association with Min. of Jal Shakti and Min. of Rural Develop.) Aug. 2019, 239p: available online at: https://social.niti.gov.in/uploads/sample/water_index_report2.pdf

Oluwasanya, G., Perera, D., Qadir, M., Smakhtin, V. (2022). Water security in Africa: A preliminary assessment: UN Univ.-Inst of Water, Env. and Health, Technical Report: available on line at: https://www.researchgate.net/publication/359472596_Water_Security_in_Africa_A_Preliminary_Assessment_13

Pham-Duc, B., Sylvestre, F., Papa, F., Frappart, F., Buchez, C., Crétaux, J-F. (2020). The Lake Chad hydrology under current climate change: Nature Sci. Repts.: available online at: https://www.nature.com/articles/s41598-020-62417-w

Polycarpou, L. (2010). 'Small is Also Beautiful"- Appropriate Technology Cuts Rice Farmers' Water Use by 30 percent in Punjab, India: available online at: https://blogs.ei.columbia.edu/2010/11/17/%e2%80%9csmall-is-also-beautiful%e2%80%9d-%e2%80%93-appropriate-technology-cuts-rice-famers%e2%80%99-water-use-by-30-percent-in-punjab-india/

Poynting, M. (2024). Amazon's record drought driven by climate change: BBC: available online at: https://www.bbc.com/news/science-environment8032361

Puelo, M. (2021). Wildfire season: AccuWeather estimates $70 billion to $90 billion in damages: Accuweather: available online at: https://www.accuweather.com/en/severe-weather/2021-wildfire-season-economic-damages-estimate70billion-to-90-billion/1024414

Pulakkat, H. (2017). The precarious situation of India's water problem: The Economic Times: available online at: https://economictimes.indiatimes.com/news/politics-and-nation/the-precarious-situation-of-indias waterproblem/articleshow/57965416.cms

Rojanasakul, M., Flavelle, C., Migliozzi, B., Murray, E. (2023). America is draining its groundwater like there is no tomorrow, New York Times, Aug. 28, Sept. 3: available online at: https://www.nytimes.com/interactive/2023/08/28/climate/groundwater-drying-climate-change.html

Ritchie, H. and Roser, M. (2024). Water use and stress: Our World in Data: available online at: https://ourworldindata.org/water-use-stress

Saini, S. (2018). Groundwater level goes up in 21 districts of Rajasthan under CM scheme: Hindustan Times: available online at: https://www.hindustantimes.com/jaipur/groundwater-level-goes-up-in-21-districts-of-rajasthan-under-cm-scheme/story-dAzwT3UVHOrrfInup70reJ.html

Scanlon, B.R., Rateb, A., Anyamba, A., Kebede, S. MacDonald, A.M., Shamsudduha, M., Small, J., Sun, A., Taylor, R.G., Xie, H. (2022). Linkages between GRACE water storage, hydrologic extremes, and climate teleconnections in major African aquifers: Environ. Res. Lett. v. 17, 014046: available online at: https://doi.org/10.1088/1748-9326/ac3bfc

Shi, D., Devneni, N., Lall, U., Piñero, E. (2013). America's water risk: Water stress and climate variability: Columbia Water Center White Paper: available online at: https://aquadoc.typepad.com/files/gb_cwc_whitepaper_climate-water-stress_final.pdf

Shiao, T., Maddocks, A., Carson, C., Loizeaux, E. (2015). 3 maps explain India's growing water risks: World Resources Institute: available online at: https://www.wri.org/insights/3-maps-explain-indias-growing-water-risks

Slater, D. (2019). Water scarcity in Brazil: A case study: Expeditions with Marine Corps Univ. Press, 42p: available online at: https://muse.jhu.edu/article/795825/pdf

Subramanian, M. (2019). India's Terrifying Water Crisis: The New York Times: available online at: https://www.nytimes.com/2019/07/15/opinion/india-water-crisis.html

The Economist. (2019). The South Asian monsoon, past, present and future: available online at: https://www.economist.com/essay/2019/06/27/the-south-asian-monsoon-past-present-and-future

Torkington, S. (2016). India will have 7 megacities by 2030, says UN, World Economic Forum: available online at: https://www.weforum.org/agenda/2016/10/india-megacities-by-2030-united-nations/

Tress, S. (2010). 19 ways to solve the freshwater crisis: State of the Planet, Columbia Climate School: available online at: https://news.climate.columbia.edu/2010/06/10/19-ways-to-solve-the-freshwater-crisis/

Unicef. (2022). Water scarcity in Egypt: Growing concerns, and partnerships: Unicef Document: available online at: https://www.unicef.org/egypt/documents/water-scarcity-egypt

US Drought Monitor. (2021). Map dated August 31, 2021, released Thursday, Sep. 2, 2021: available online at: https://droughtmonitor.unl.edu/Maps/MapArchive.aspx

Water Science School. (2019). The natural water cycle (JPG): U.S. Geological Survey: available online at: https://www.usgs.gov/media/images/natural-water-cycle-jpg

Wikipedia. (2024). Economy of India: Wikipedia: available online at: https://en.wikipedia.org/wiki/Economy_of_India

World Bank. (2023). GDP (current US$) - India: World Bank: available online at: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=IN

Worldometer. (2023). Countries in the world by population (2024): available online at: https://www.worldometers.info/world-population/population-by-country/

Wyler, G. (2013). All around the US, risks of a water crisis are much bigger than people realize: Insider: available online at: https://www.businessinsider.com/us-drought-water-scarcity-2013-5