COUNCIL ON STRATEGIC RISKS

BRIEFER

No. 6 | March 20, 2020

Climate Risks to India's Nuclear Program

Sarang Shidore

KEY TAKEAWAYS

India is among the countries most at risk due to climate change with a large part of the nation's area as well as population in a high-risk zone even at the threshold 1.5 C mean temperature rise. By 2050, climate change will present multiple threats such as heatwaves, increased rainfall and cyclone intensity, and sea level rise.

India has a large and growing nuclear program with 22 civilian reactors, multiple nuclear processing sites, uranium mines, and likely more than 100 nuclear warheads.

India has not suffered major loss of life due to a nuclear accident but has had several near-misses and frequent minor mishaps. Although the country's nuclear establishment vouches for the safety of all facilities, the lack of an independent regulator and relative paucity of information has raised concerns.

Climate and nuclear risks intersect in India most overtly in terms of safety of nuclear installations to extreme weather events. Risk enhancement is probably the greatest for facilities located on the country's west coast and in the southern state of Tamil Nadu.

Inland installations are also at enhanced risk of major flooding due to expected increase in extreme rainfall events in the future.

A growing nuclear program implies that climate risks will also become more prominent during routine nuclear materials transport, which in India is across large distances.

Climate change could also play an indirect role in impacting nuclear risks through its effects on the Indus River Basin and the India-Pakistan rivalry.

Nuclear safety in third countries could potentially involve India in the future, as New Delhi is positioning itself as a vendor in nuclear projects abroad in partnership with Russia.

Background

India has well-established nuclear energy and weapons programs, with their technological beginnings soon after the country achieved independence from British colonial rule in 1947. They currently consist of 22 civilian reactors for energy generation as well as several military, research, and processing sites and likely more than 100 nuclear warheads.

India is also one of the world's most vulnerable countries to climate change. Adverse climate impacts by 2050 or sooner will include sea level rise, coastal flooding, intense rainfall events, and water stress. Although the expansion of India's nuclear reactors has been slower than anticipated, there are numerous operational and planned nuclear sites located in climate-sensitive zones such as coastlines and riverbanks and in water-stressed zones of the country.

This paper aims to analyze the intersection of nuclear and climate risks and assess the risks presented by climate change to India's nuclear program. The focus is on India's civilian nuclear sector, though military aspects will also be covered.

India's Nuclear Facilities

In 2009, India was granted relief from international sanctions and access to global nuclear commerce with the signing of the civil nuclear agreement with the United States (U.S. Department of State, 2007) and the subsequent safeguards agreement with the International Atomic Energy Agency (IAEA, 2009).

However, India's nuclear program predates by many decades the imposition of two major rounds of sanctions in the wake of its 1974 and 1998 nuclear tests. The country embarked on the program under the leadership of its first prime minister, Jawaharlal Nehru, only a few years after independence from British colonial rule in 1947. This early initiative benefited from international cooperation, including the "Atoms for Peace" program under President Eisenhower in the 1950s, in an era when nuclear energy was heralded as a major source for future global energy abundance.

India's first research reactor, the modest 1 megawatt-capacity Apsara located in the neighborhood of Trombay in the country's financial capital of Mumbai, was commissioned in 1956 with assistance from the United Kingdom. The first commercial power plant began operations in Tarapur, located near Mumbai, in 1969 with major assistance from the U.S. Agency for International Development (USAID). This was followed by a second research reactor named CIRUS that was launched in 1960 in Trombay.

CIRUS was the inspiration for the first commercial-scale reactors, built in Rawatbhata in the state of Rajasthan. Built with the assistance of Canada, the RAPS-I and RAPS-2 reactors[1] were of the Pressurized Heavy Water Reactor (PHWR) type, similar to CIRUS. This Canadian design had the advantage of using unenriched uranium and became the mainstay of India's nuclear program in the following decades.

As of early 2020, India has 22 civilian commercial reactors for power generation in operation with a total capacity of 6.78 gigawatts (GW). (AERB, 2020). They are located in seven sites in the north, west and south of the country, namely Tarapur in the state of Maharashtra, Kakrapar in Gujarat, Rawatbhata in Rajasthan, Narora in Uttar Pradesh, Kalpakkam and Koodankulam in Tamil Nadu and Kaiga in Karnataka (figure 1). Two of the four reactors located in Tarapur are of the BWR (Boiling Water Reactor) design and the two reactors in Koodankulam are Russian VVER-1000 designs. The remaining 18 civilian reactors are of the PHWR variety. Additional research or military reactors include Purnima and Dhruva in Trombay and the Fast Breeder Test Reactor (FBTR) at Kalpakkam. All these reactors are located on the coast or next to major water bodies due to requirements of coolant water in their designs.

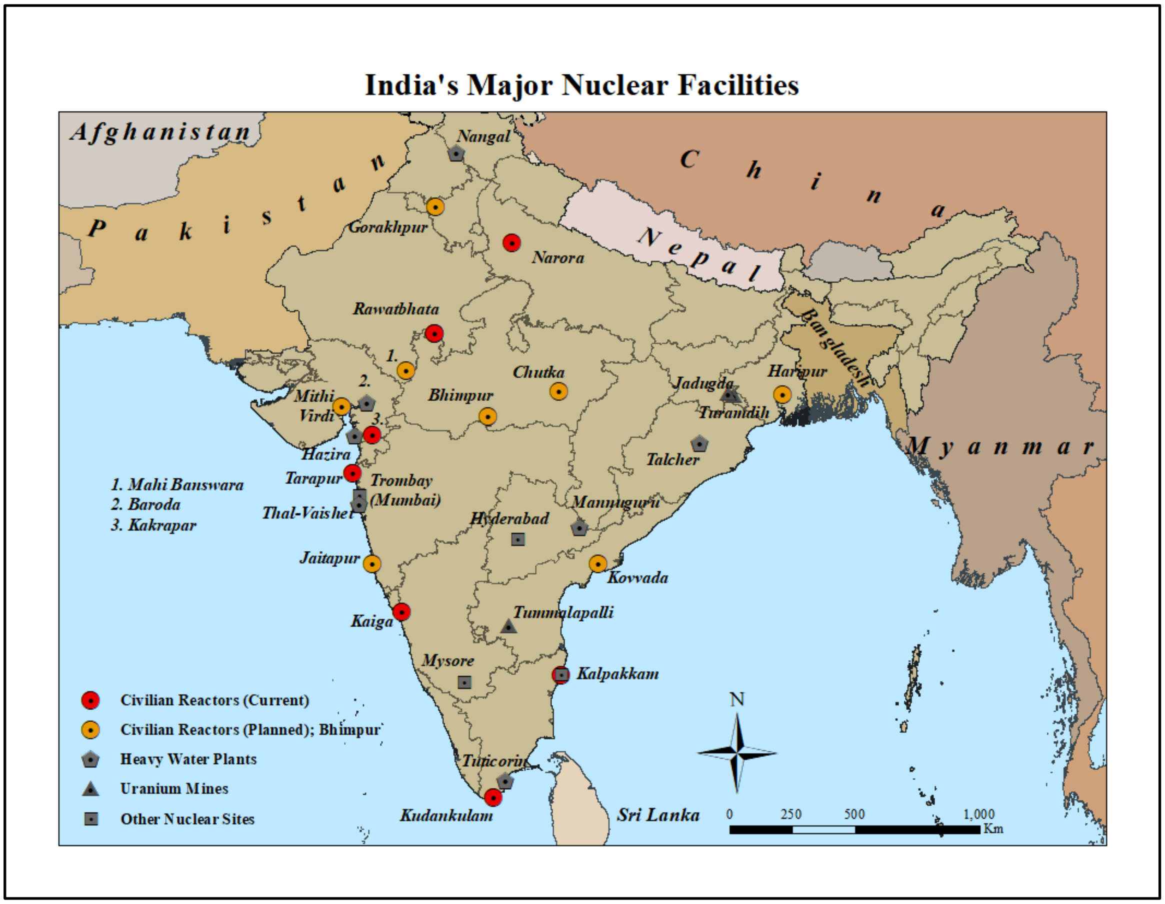

FIGURE 1: India's Major Nuclear Facilities. Source – (World Nuclear Association, 2019; DAE, 2018).

India lacks major uranium deposits. This motivated the construction of the FBTR, which is an attempt to demonstrate the viability of a three-stage nuclear cycle that will enable India to use its large thorium reserves as fuel in the future, in theory freeing it of foreign dependence. The FBTR is to be followed by the construction of a Prototype Fast Breeder Reactor (PFBR), which is aimed to be the template for scores of such reactors that will follow. However, the three-stage cycle has faced major delays with the FBTR's performance being poor. It seems unlikely that India will be able to realize its unique nuclear scale-up vision in the foreseeable future.

In addition to power and research reactors, India also has a variety of other sites such as heavy water production plants, fuel fabrication plants, reprocessing facilities, enrichment sites, and uranium mines, and reactors specifically developed for its sea-based deterrent program.

The India-IAEA agreement effectively divided Indian nuclear facilities into three streams from the standpoint of international safeguards – the civilian safeguarded, the civilian unsafeguarded, and the military unsafeguarded (Robertson & Carlson, 2016).[2] The civilian safeguarded stream includes 14 commercial power reactors, six fuel fabrication and conversion facilities for these reactors, and two spent fuel storage sites. The civilian unsafeguarded stream includes the remaining eight commercial power reactors, fast breeder reactors, uranium mines, three heavy water production sites, research reactors such as Purnima, and fuel reprocessing sites. Military sites include enrichment complexes, reprocessing sites, uranium mines, naval reactors, four heavy water production sites, and a few other facilities.

The military dimension of India's nuclear program has been steadily expanding since its 1998 tests that heralded the coming of a new overt nuclear weapons power. India keeps its data on nuclear material confidential, but an assessment put India's stockpile within a range of 77 and 123 warheads (with a median figure of 97) in 2014, a number that has likely grown further in the intervening six years (Albright & Kelleher-Vergantini, 2015). This is far smaller than the arsenals of the U.S. or Russia but very substantial for a developing country.

INDIA'S NUCLEAR EXPANSION PLANS

In the wake of the heady days of the Indo-U.S. nuclear agreement, the Indian government projected a net 63 GW of nuclear capacity by 2032. In 2018 however, this number was greatly downscaled to 22.48 GW, with 13.48 GW expected to be achieved by 2024 (Srivastava, 2018). Approval has been granted for the construction of 16 additional civilian reactors (figure 1). They will be located in Bhimpur, Chutka (both in the state of Madhya Pradesh), Kaiga (Karnataka), Mahi Banswara (Rajasthan), Gorakhpur (Haryana), and Kudankulam (Tamil Nadu). All except Kudankulam will be indigenous PHWR-type designs, but with a higher 700 MW capacity (DAE, 2018). The Kudankulam reactors will be from Russia.

In the wake of the India-U.S. nuclear agreement, there were high expectations of a major role for foreign (especially U.S. and French) vendors in adding future nuclear capacity. However, foreign investments in nuclear power have essentially failed to materialize even a decade after the legitimization of India's nuclear program.[3] Foreign vendors have been reluctant partly due to disputes over India's nuclear liability regime which differs from the international standard. Vendors in Europe and the U.S. have also suffered from their own financial problems, which has slowed their plans.

Currently, talks are ongoing for six 1.25 GW AP1000 reactors from Westinghouse in Kovvada (Andhra Pradesh), six 1.65 GW EPR reactors from the French vendor EDF at Jaitapur (Maharashtra) and additional Russian reactors in Haripur (West Bengal). The Westinghouse agreement was slated to be signed soon after President Trump's recent visit to India, but the signing did not take place, indicative of the barriers to realizing the promise of the nuclear agreement (Miglani & Dasgupta, 2020). India is reportedly waiting for the first-ever EPR reactor to begin functioning before finalizing the Jaitapur deal (PTI, 2019).

SAFETY AND SECURITY

India's large and growing nuclear program raises questions as to how safe its facilities are in terms of the risk of accidents and how secure they are from attacks by malevolent actors.

Safety

India has not suffered a major nuclear accident similar to Chernobyl, Fukushima, or Three Mile Island. The Indian nuclear establishment has consistently claimed that India's nuclear program is safe (Chidambaram, 1999), at one point even claiming "100%" safety (Bagla, 2011). In any organization, an extremely high self-belief in the level of safety achieved can, paradoxically, itself endanger safety (Reason, 2000). The record demonstrates a number of lapses and accidents thus far.

India's most serious nuclear accident took place at the Narora nuclear power plant on March 31, 1993. The accident was triggered by cracks in the locally manufactured steam turbine that led to the breakage of two blades. This in turn caused hydrogen and oil leakage, leading to a fire that gutted the turbine building and forced operators out of the central control room. The plant's fire detection systems failed – the fire was attended to only when operators noticed the smoke. The reactor was shut down manually, but waste heat continued to build up in its core and had to be contained using water intended for fire control. Meanwhile, neutrons continued to build up in the core threatening a runaway critical reaction that would have meant a catastrophic accident, but for a few heroic operators who manually injected liquid boron into the reactor core, thus averting a meltdown similar to the Fukushima accident (Ramana, 2012, 203; Chellaney, 1993).

The Narora accident was avoidable, as the state-owned turbine manufacturer Bharat Heavy Electricals Limited had notified Nuclear Power Corporation of India Limited (NPCIL), the state-owned organization that operates India’s nuclear power plants, about the design flaw in the turbines. However, no action was taken to replace the turbines or rectify the flaw (Ramana, 2012, 204). The Narora incident however did lead to the temporary closure of India’s nuclear power plants as safety reviews were conducted. In the wake of an investigation committee report, several corrective measures were taken including a periodic review mechanism for nuclear plants (Mishra, 2017, 125-126; AERB, 2018, 1-29).

The closure inadvertently prevented a second major accident in 1994 at the low-lying Kakrapar nuclear plant in Gujarat, when heavy rain caused major floods in the area. The power plant is located next to an artificial lake that is used as the source for coolant water for the plant. Due to lack of use, the outflow gates of this lake were clogged with weeds and other obstructions and could not be opened after lake levels began to rise to dangerous levels. Eventually, floodwaters entered the reactor building, submerging much equipment including coolant pumps. Floodwaters carried away several canisters of radioactive waste, which were never traced. Had the reactor been operational on that day, the consequences could have been severe (Ramana, 2012, 207).

Two other major nuclear accidents in India are noteworthy. During the construction phase of the Kaiga nuclear plant in 1994, the containment dome (the key structural component that encloses the core fissionable material in a nuclear plant) collapsed, injuring 13 workers (Chengappa, 1994). A faulty design and poor work practices were the likely cause (Ramana, 2012, 209). The massive Asian Tsunami of 2004 caused much death and destruction in the state of Tamil Nadu. The tsunami flooded parts of Kalpakkam, a major complex containing power reactors, the FBTR, reprocessing sites and other facilities, and necessitated activating backup systems and the emergency shutdown of one reactor (Jin et al., 2006).

Oil leaks, turbine vibrations, and leakage of coolants and heavy water have featured in many smaller accidents in Indian nuclear reactors (Ramana, 2012, 205). Most recently, a likely and potentially serious coolant leak was reported at the Kakrapar plant, but authorities released few details (Sundaram, 2016). Concerns have also been expressed about the design of the proposed PFBR, which is seen as vulnerable to failure of its liquid sodium-based cooling system (Ramana, 2012, 198).

In general, India’s nuclear establishment is perceived to have a culture of extreme secrecy (Ramana, 2009; Rethinaraj, 1999). For example, the 1994 Kakrapar flooding incident came to light only through a whistleblower, a worker at the plant, who was then terminated from employment and eventually lost his legal case against the Indian government. It has been argued that the opaqueness has its roots in the unique origins of the civilian nuclear program as compared to other government initiatives, and its later intimate connection with weaponization (Ramana, 2009).

India’s nuclear regulatory authority, the Atomic Energy Regulatory Board (AERB) is not independent of the Atomic Energy Commission (AEC) and the Department of Atomic Energy (DAE), which govern the nuclear program. The lack of autonomy of the regulator has often come under major criticism (including from an ex-head of the AERB itself and the official government auditor), and does not conform to international best practices (Ramana, 2009; Jayaraman, 2012; Gopalakrishnan, 1999). The DAE however strongly defends its safety record and points to two recent extensive safety reviews conducted in 1995 and in the wake of the Fukushima disaster in 2011 (AERB, 2011).

In an effort to create a truly autonomous regulator, the Indian government introduced the Nuclear Safety Regulatory Authority (NSRA) bill in parliament in 2011, which envisaged replacing the AERB with a new regulator that reported directly to the prime minister’s office. However, the bill never passed and ultimately lapsed. The NSRA bill has also been criticized for not going far enough (Pandey, 2015).

Security

India lives in a tough neighborhood and has been a victim of terrorist attacks from multiple violent actors over the decades. Its rivalry with Pakistan has been a key cause for violence in the disputed territory of Kashmir, currently de facto partitioned between the two rivals and China. Terrorist groups based in Pakistan such as the Lashkar-e-Tayyaba and Jaish-e-Muhammad have been responsible for attacks in and outside Kashmir, Maoist militants have conducted strikes in central and eastern India, and various smaller ethnic nationalist militants have historically been active in the country's remote northeast (figure 2).[4]

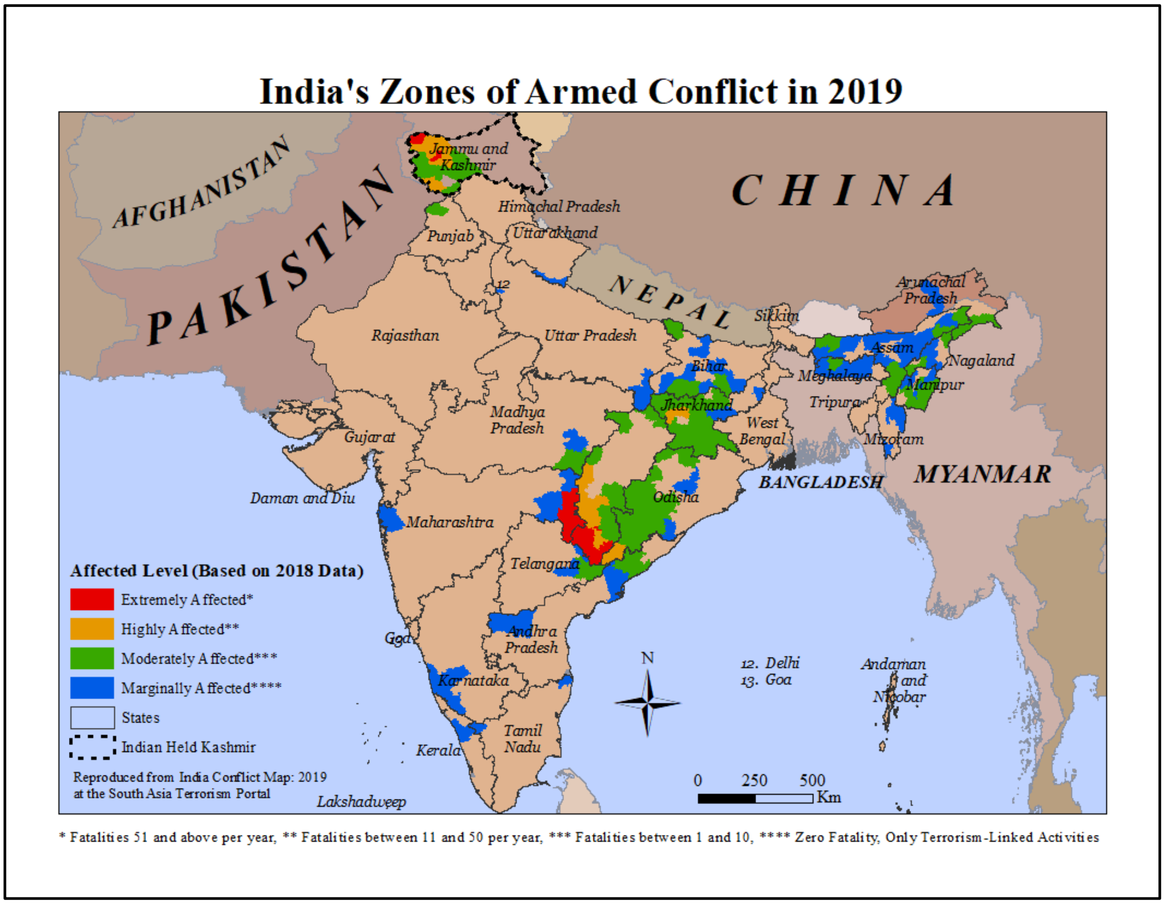

FIGURE 2: Zones of armed conflict in India. Source: Reconstructed from South Asian Terrorism Portal, 2019.

India secures its nuclear facilities through a 95,000-strong paramilitary organization called the Central Industrial Security Force (CISF), which is also tasked with guarding major state-owned industries, airports, key railway stations and other infrastructural sites. However, it is reportedly underfunded and under-armed. Nuclear installations observed by U.S. diplomats during a visit in 2008 lacked adequate security, according to a leaked State Department cable (Levy & Smith, 2015).

India also moves its nuclear material over large distances in unmarked vehicles without obvious security (Levy & Smith, 2015). Though this practice camouflages such sensitive cargo by lending it anonymity, it also allows for the possibility of a breach of security due to an insider attack, or limits accompanying resources to contain any radioactive spillage due to an accident or a natural disaster on India's often poorly maintained road system.

India is however most concerned with an insider attack. It has worked to an extent with the U.S. and other countries on upgrading its nuclear security (Guenther et al., 2013). It implements the Personnel Reliability Program, a global best practice, which involves rigorous background verification and continued monitoring of employees (Rajagopalan, 2015). However, this did not prevent an attack in 2014 by a mentally stressed constable at Kalpakkam---one of India's most complex and sensitive nuclear facilities---who killed and injured several personnel. Warning signs were reportedly ignored in the days leading up to the attack (Levy & Smith, 2015). Media also reported incidents of nuclear theft in October 1994, June and July 1998, August 2001, and February and September 2008 (Haegelund, 2016).

External attacks also present a major risk, including from the cyber domain. The planners of the 2008 terrorist attack in Mumbai, conducted by militants from Pakistan, initially included nuclear sites present in the city as a part of their plan. The Russian-built Kudankaulam nuclear power plant, India's largest in terms of generation capacity, came under cyber-attack in 2019 from as-yet unidentified attackers. The attack fortunately only affected the plant's business network and not its operational network, which plays a part in the actual running of the plant. The incident exposed the lack of preparedness of the country's nuclear program, though India is hardly the only nation in this category (Campbell & Singh, 2019; Chatham House, 2015).

CONVERGING CLIMATE AND NUCLEAR RISKS

India is one of the countries most seriously threatened by climate change. In 2018, it was the fifth worst country affected according to the Bonn-based think-tank Germanwatch, up nine notches from the previous year. The damage was estimated to be $37.8bn and 2038 lives during that year (Germanwatch, 2019). India also has the largest number of people facing extreme climate-exposure in the world (Busby, et al., 2018). Climate change is impacting temperatures, rainfall, causing sea level rise and helping strengthen extreme weather events such as cyclones.

As far as risks to nuclear installations are concerned, cyclones, extreme rainfall events, and floods are the most relevant. Cyclones (known as hurricanes in the Americas) are most relevant to coastal plants. Acute water stress and drought in inland areas can also be a factor in threatening the viability of nuclear plants situated away from the coasts. Water shortages are highly unlikely to trigger a major nuclear accident but are relevant from an energy security perspective.

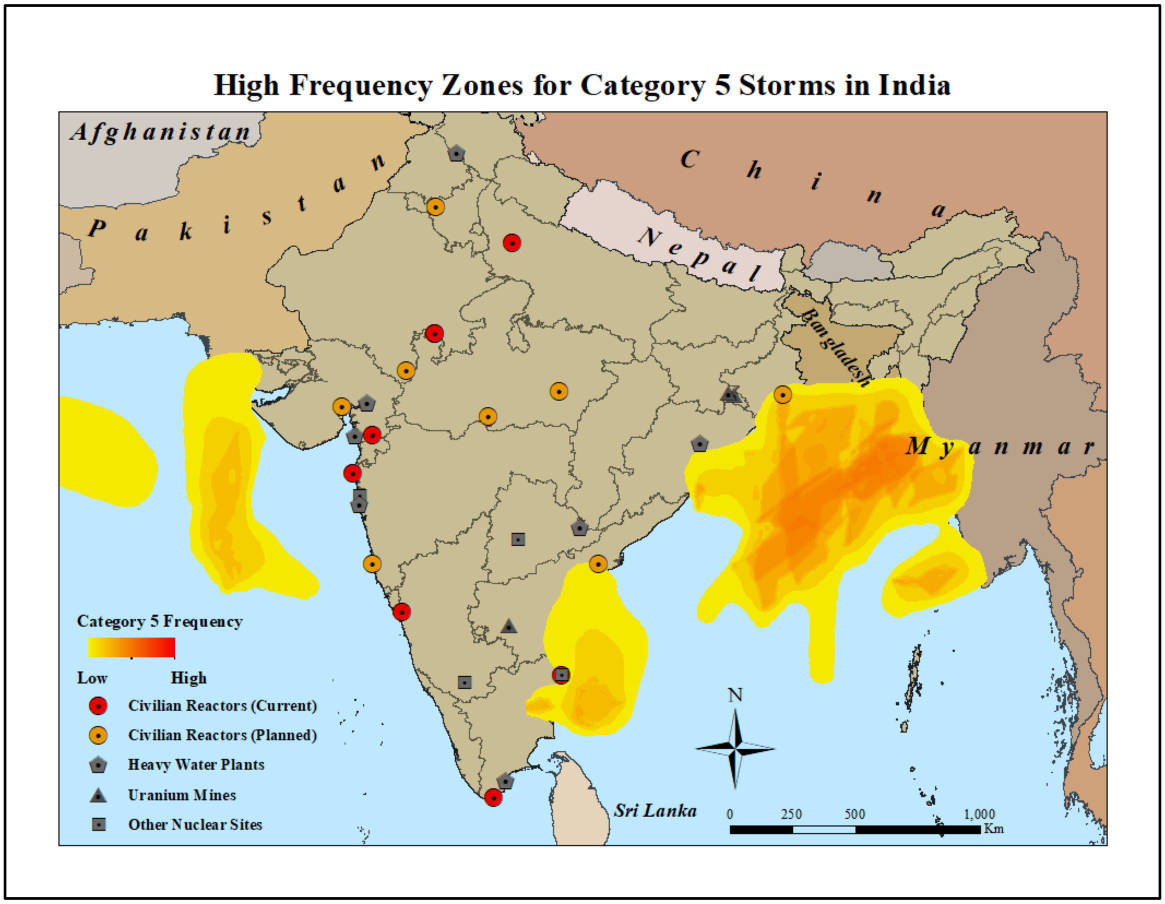

FIGURE 3: Zones of frequent Category 5 intensity cyclones in India. Source (Global Risk Data Platform, 2014)

Climate change will likely induce greater cyclone intensity with greater rainfall (Mann et al., 2017).[5] The most severe (Category 5) cyclones have historically been the most frequent in India along its east coast (figure 3). Historically the west coast has seen far fewer major cyclones. However, modeling tells us that cyclone intensity is projected to especially increase on India's west coast due to climate change (Yadav, 2019). This encompasses several nuclear sites such as Trombay (Mumbai), Tarapur, Kakrapar, and the planned site of Chaya Mithi Virdi. This is due to particularly high increases in sea temperatures in the northern part of the Arabian Sea. Cyclone threats, already significant, will likely further increase on India's east coast which includes the complex facility at Kalpakkam, reactors in Kudankulam, and planned sites in Kovvada and Haripur.

Significant parts of India are already subject to considerable flood risk (figure 4). Even if a nuclear plant is located inland, as a number of them are, it always lies next to a major water body due to the necessity of drawing large quantities of water for cooling. In India, such plants tend to be close to major rivers and dams – for example Kakrapar is located next to an artificial lake connected to the Tapi river, and Rawatbhata is sited next to the Chambal river. Extreme rainfall events, whose intensity will very likely increase with climate change, present enhanced risk of floods, which is heightened in cases of proximity to dams.

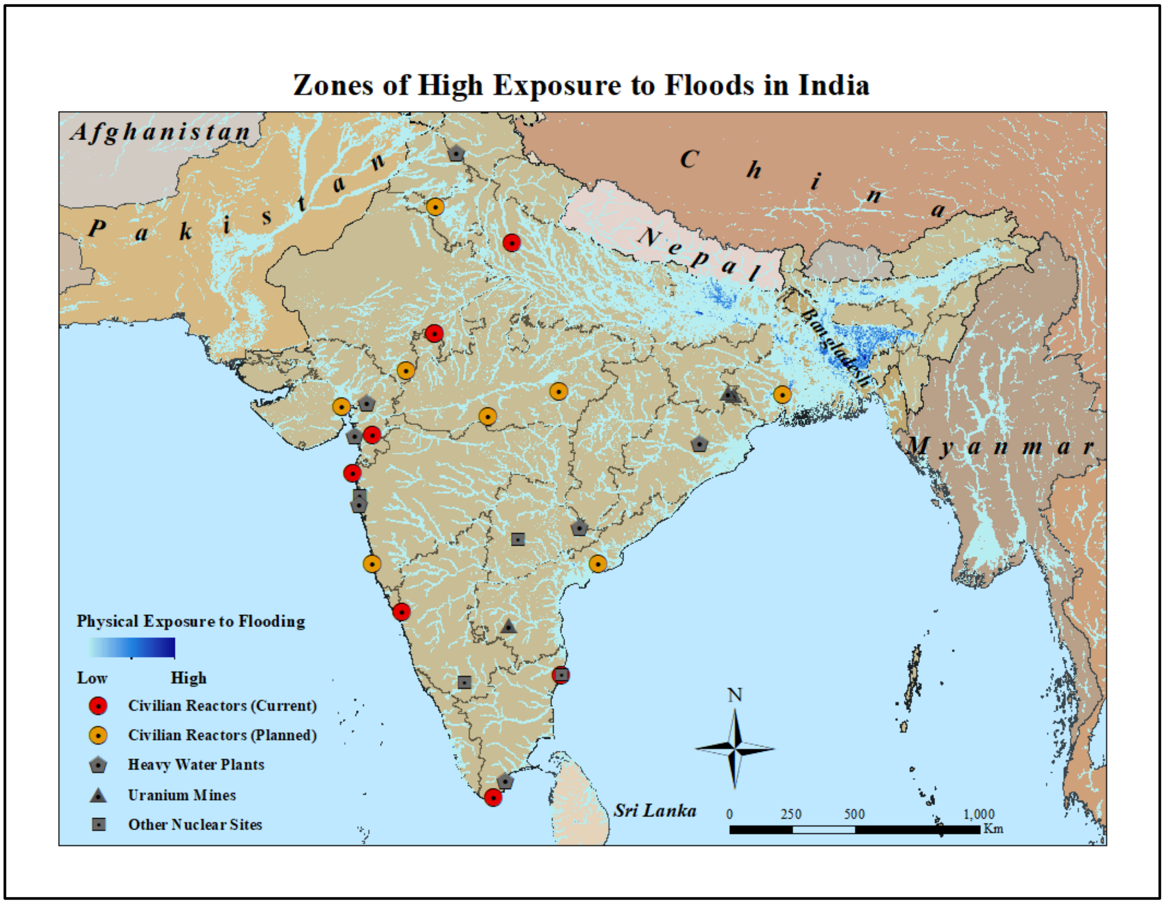

FIGURE 4: Zones of historically high exposure to floods in India. Source (Global Risk Data Platform, 2011)

According to the EM-DAT International Disasters database, India experienced 285 reported flooding events in the period 1950 to 2017. The death toll is estimated to be 71,000, and financial damage totaling $60 Billion (EM-DAT International Disasters Database). The Dartmouth Flood Observatory data indicates no clear pattern of increasing number of flooding events in India and a decreasing death toll from 23065 in the 1990s to 8514 in the current decade (Dartmouth Flood Observatory, 2019). However, climate change acts to increase intensities of adverse events rather than necessarily increase their frequency. As far as nuclear installations are concerned, it is the severity of a natural event that is of most concern.

Extreme rainfall events have been increasing in a wide swath across the middle of India and the western coast and this trend is likely to accelerate with climate change (figure 5). Thus, the massive cloudburst that triggered the 1994 Kakrapar accident therefore would no longer be a rare event. An official in the state government of Madhya Pradesh admitted recently that the 2019 extreme rainfall event in the state threatened the Rawatbhata nuclear site in the neighboring state of Rajasthan with a "Chernobyl-like" nuclear accident (DBPost, 2019). Flooding also enhances risks from India's expanding uranium mining. In 2008, flash floods caused uranium deposits to be swept onto farms in the state of Andhra Pradesh (Chauhan, 2008).

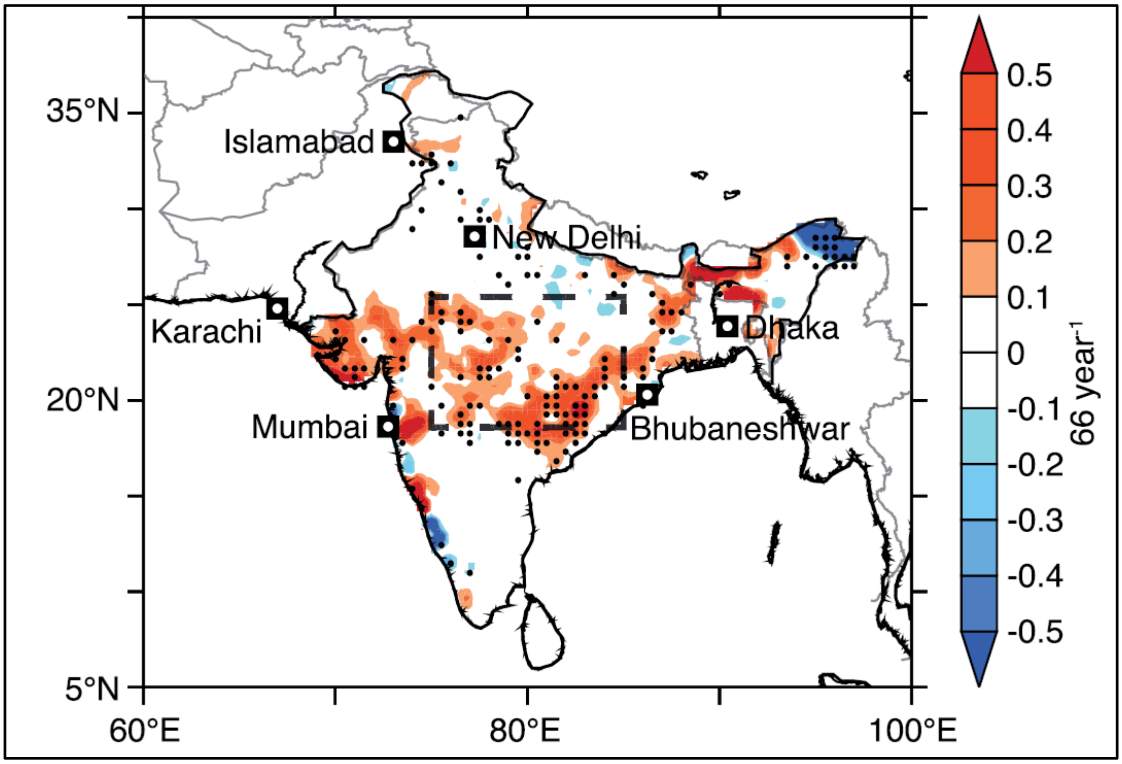

FIGURE 5: Extreme precipitation events in India are increasing across a wide band in the middle of the country, the west coast, and the northeast. Source (Roxy and Chaithra, 2018).

The presence of major nuclear sites next to megacities also ratchets up risk in the unfortunate event of a major accident. Tarapur and Kalpakkam nuclear facilities are located within 60 miles (100 km) of two of India's largest cities, Mumbai and Chennai. The dual civilian-military purposed Trombay site is located well within the city limits of Mumbai. An important nuclear complex is located adjacent to the southern city of Mysore, and unconfirmed reports indicate it is emerging as a major enrichment site (Albright & Kelleher-Vergantini, 2015).

Climate change will also cause global sea level rise due to melting ice in the Arctic, Antarctic and the "third pole" in the Himalaya-Hindukush-Karakoram-Tibet region of Asia. Even under optimistic mitigation scenarios, sea level rise could be up to 0.5 m or more by the end of the 21st century. Recent findings have tripled the globally vulnerable population exposed to sea level rise (Kulp & Strauss, 2019; Climate Central, 2019). Major coastal cities such as Mumbai (India's financial capital) and Kolkata (the largest city in the country's east) show major fractions of their land areas subject to sea level rise and annual flooding (figure 6). This too has major implications for nuclear plants situated on the coastline - Kalpakkam, Trombay, Tarapur, Kudankulam, and planned ones such as in Kovvada and Haripur (figure 6). India's nuclear establishment insists that all these reactors are completely safe pointing to a number of safety features and enhancements since the Fukushima disaster (Parthasarathy, 2011a, 2011b).

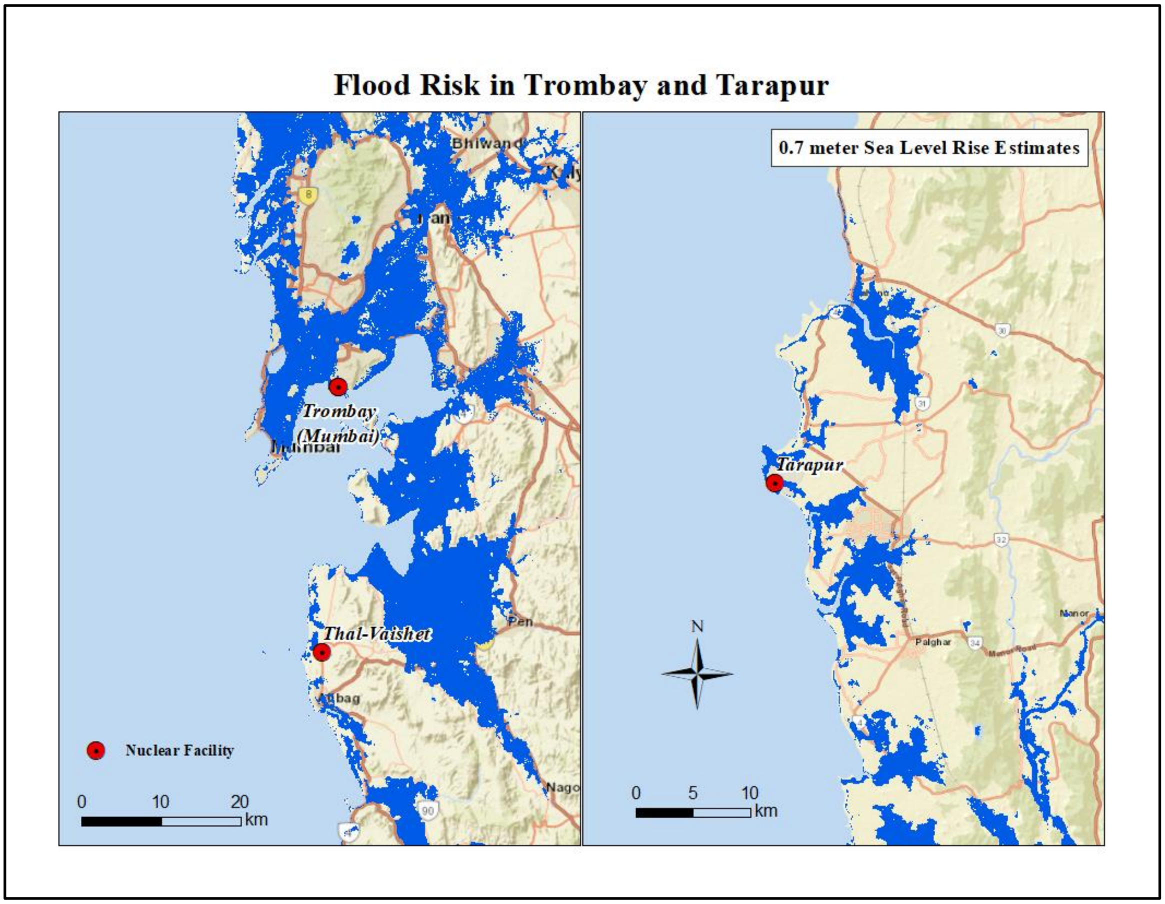

FIGURE 6: Risk of combined annual flooding and sea level rise at the Trombay (Mumbai) and Tarapur nuclear facilities on India's west coast with a 0.7 m sea level rise. Source (Climate Central, 2019).

Climate change can also intersect with nuclear safety and security in more subtle and indirect ways. For instance, climate change is one factor in exacerbating tensions between India and its nuclear rival Pakistan over sharing waters in the Indus River Basin (IRB).[6] Any escalation of tensions between the neighbors over water security has the potential to turn nuclear and additionally involve cyberattacks on each other's civilian nuclear facilities.

Nuclear safety in third countries could potentially involve India in the future, as New Delhi is increasingly a stakeholder in third-country nuclear projects as a vendor in partnership with Russia. Construction has already begun on a major project in Rooppur in Bangladesh, and African countries such as Ethiopia are next targets of this cooperative venture (World Nuclear News, 2020). Bangladesh faces major climate risks due to sea-level rise and cyclonic activity. Although global liability standards indemnify nuclear vendors in the event of any accident, political realities could embroil Indo-Russian projects in any future nuclear incident in Bangladesh or elsewhere.

CONCLUSION

In contrast to its stall or reversal in North America and Europe, India has a large and growing nuclear program with 22 civilian reactors, multiple nuclear processing sites, uranium mines, and likely more than 100 nuclear warheads, even as climate change is expected to have substantially damaging impacts on the country within a decade or two. Thus, it is highly likely that convergences of nuclear and climate risks will only increase going forward.

Climate and nuclear risks intersect in India most overtly in terms of safety of nuclear installations to extreme weather events. India has not suffered major loss of life due to a nuclear accident but has had several near-misses and frequent minor mishaps. Although the country's nuclear establishment vouches for the safety of all facilities, the lack of an independent regulator has raised concerns. These concerns have reportedly been addressed through extensive safety reviews and remedial actions, but the paucity of verifiable information leads to lower confidence that installations are adequately safe in terms of future climate threats.

Risk enhancement is probably the greatest for a cluster of facilities concentrated on or near the country's west coast and in the state of Tamil Nadu due to cyclones, flooding and sea level rise. Inland installations are also at enhanced risk of major flooding due to expected increase in extreme rainfall events. A growing nuclear program implies that climate risks will also become more prominent during nuclear materials transport.

Climate change could also play an indirect role in impacting nuclear risks through its effects on the Indus River Basin and the India-Pakistan rivalry. Joint Indo-Russian nuclear projects in third countries such as Bangladesh imply that climate risks in these geographies will also have to be accounted for by Indian nuclear planners in the future.

Sarang Shidore is Senior Fellow at the Council on Strategic Risks and Senior Research Analyst at the Lyndon B. Johnson School of Public Affairs at the University of Texas at Austin, with expertise and multiple publications in geopolitical risk and the energy-climate nexus.

The assistance of Matthew Preisser in generating the figures and maps is gratefully acknowledged.

1 RAPS is the acronym for for Rajasthan Atomic Power Station.

2 Note that the term "safeguards" is related to monitoring sites to prevent nuclear proliferation and has little relationship with nuclear safety.

3 The Kudankulam reactors have been planned since 1988, and not a direct result of the India-U.S. and India-IAEA nuclear agreements.

4 Further details on India's security challenges are available in the first two briefers in this series from the Council on Strategic Risks. See (Shidore, 2020) and (Shidore with Busby, 2020).

5 The Clausius-Clapeyron equation in climate science yields a roughly 7% increase in water vapor per 1 C of warming.

6 An in-depth analysis of how climate change could impact the India-Pakistan rivalry is available in the first briefer of this series. See Shidore (2020).

REFERENCES

Abraham, Itty (2009), *South Asian Cultures of the Bomb: Atomic Publics and the State in India and Pakistan* (Bloomington and Indianapolis: Indiana University Press).

AERB (2011), "Report of AERB Committee to Review Safety of Indian Nuclear Power Plants against External Events of Natural Origin," https://www.aerb.gov.in/storage/images/PDF/09-November-2011.pdf

AERB (2018), "Annual Report 2018," https://www.aerb.gov.in/images/PDF/Annual_report/ar2018/AERB-Annual-Report-2018-1.pdf

AERB (2020), "Nuclear Power Plants," https://www.aerb.gov.in/english/regulatory-facilities/nuclear-power-plants

Albright David & Kelleher-Vergantini (2015), "India's Stocks of Civil and Military Plutonium and Highly Enriched Uranium, End 2014," Institute for Science and International Security, https://isis-online.org/isis-reports/detail/indias-stocks-of-civil-and-military-plutonium-and-highly-enriched-uranium-e

Bagla, Pallava (2011), "Why Nuclear Reactors are '100 per cent Safe'," NDTV, https://www.ndtv.com/india-news/why-nuclear-reactors-are-100-per-cent-safe-450513

Busby, Joshua et al. (2018), "The Double Burden of Climate Exposure and State Fragility," New Security Beat, https://www.newsecuritybeat.org/2018/10/double-burden-climate-exposure-state-fragility/

Campbell, Alexander & Singh, Vickram (2019), "Lessons from the Cyberattack on India's Largest Nuclear Power Plant," Bulletin of the Atomic Scientists, https://thebulletin.org/2019/11/lessons-from-the-cyberattack-on-indias-largest-nuclear-power-plant/

Chatham House (2015), "Cyber Security at Civil Nuclear Facilities: Understanding the Risks," https://www.chathamhouse.org/sites/default/files/field/field_document/20151005CyberSecurityNuclearBaylonBruntLivingstoneUpdate.pdf

Chauhan, Chetan (2008), "Floods Put Brakes on Uranium Mining," Hindustan Times, https://www.hindustantimes.com/india/floods-put-brakes-on-uranium-mining/story-q4tdKpOlXz9naZQpjrM8HI.html

Chellaney, Brahma (1993), "A Major Fire at a Nuclear Power Plant," UPI, https://www.upi.com/Archives/1993/04/23/A-major-fire-at-a-nuclear-power-plant-southeast/4832735537600/

Chengappa, Raj (1994), "Mishap at Kaiga Atomic Power Plant Raises Doubts Over Safety of N-Power Plants in India," India Today, https://www.indiatoday.in/magazine/science-and-technology/story/19940630-mishap-at-kaiga-atomic-power-plant-raises-doubts-over-safety-of-n-power-plants-in-india-809331-1994-06-30

Chidamabaram, R. (1999), "Address by Dr. R. Chidambaram, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy," Bhabha Atomic Research Center, http://www.barc.gov.in/publications/nl/1999/199911-02.pdf

Climate Central (2019), "Flooded Future," https://climatecentral.org/pdfs/2019CoastalDEMReport.pdf

DAE (2018), "Proposal for Nuclear Power Plants in States," https://pib.gov.in/newsite/PrintRelease.aspx?relid=177519

Dartmouth Flood Observatory (2019), https://floodobservatory.colorado.edu/Archives/index.html

DBPost (2019), "Gandhi Sagar Dam Could Have Burst, Accident Like Russia's Chernobyl Nuclear Plant Could Have Occurred," https://dbpost.com/madhya-pradesh-gandhi-sagar-dam-could-have-burst-accident-like-russias-chernobyl-nuclear-plant-could-have-occurred/

EM-DAT – "The International Disasters Database," https://www.emdat.be/

Guenther, Rita et al. (2013), *India-United States Cooperation on Global Security: Summary of A Workshop on Technical Aspects of Civilian Nuclear Materials Security*, National Academy of Sciences in Cooperation with the National Institute for Advanced Studies (Washington, D.C: National Academies Press, 2013).

Germanwatch (2019), "Global Climate Risk Index," https://germanwatch.org/en/cri

Global Risk Data Platform (2011), "Floods – Physical Exposure," https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=3&lang=eng

Global Risk Data Platform (2014), "Cyclones – Frequency," https://preview.grid.unep.ch/index.php?preview=data&events=cyclones&evcat=2&lang=eng

Gopalakrishnan, A. (1999), "Issues of Nuclear Safety," Frontline, https://frontline.thehindu.com/other/article30256875.ece

Haegeland, Hannah (2016), "India's Nuclear Dangers," Foreign Policy, https://foreignpolicy.com/2016/03/31/indias-nuclear-dangers/

IAEA (2009), *Agreement Between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities*, https://www.iaea.org/publications/documents/infcircs/agreement-between-government-india-and-international-atomic-energy-agency-application-safeguards-civilian-nuclear-facilities

Jayaraman, K. S. (2012), "India's Nuclear Watchdog Criticized," Nature, https://www.nature.com/news/india-s-nuclear-watchdog-criticized-1.11290

Jin, Soebom et al., (2006), 2004 Indian Ocean Tsunami on the Madras Nuclear Power Plant, India," Transactions of the Korean Nuclear Society Spring Meeting, https://www.kns.org/files/pre_paper/16/127%EC%A7%84%EC%86%8C%EB%B2%94.pdf

Kulp, Scott and Strauss, Benjamin (2019), "New Elevation Data Triple Estimates of Global Vulnerability to Sea-level Rise and Coastal Flooding," Nature Communications 10, 4844.

Mann, Michael et al. (2017), "What We Know about the Climate Change–Hurricane Connection," Scientific American, https://blogs.scientificamerican.com/observations/what-we-know-about-the-climate-change-hurricane-connection/

Miglani, Sanjeev & Dasgupta, Neha (2020), "Exclusive: Westinghouse set to sign pact with Indian firm for nuclear reactors during Trump visit," Reuters, https://www.reuters.com/article/us-india-usa-trump-westinghouse-exclusiv/exclusive-westinghouse-set-to-sign-pact-with-indian-firm-for-nuclear-reactors-during-trump-visit-idUSKBN20E1PM

Mishra, Sitakanta (2017), *Defense Beyond Design: Contours of India's Nuclear Safety & Security* (London and New York: Routledge).

Pandey, Kundan (2015), "New Bill, Old Problems," Down to Earth, https://www.downtoearth.org.in/coverage/energy/new-bill-old-problems-48038

Parthasarathy, K. S. (2011a), "Are the units 1 & 2 of Tarapur safe?" Economic Times, https://economictimes.indiatimes.com/policy/are-the-units-1-2-of-tarapur-safe/articleshow/8613962.cms

Parthasarathy, K. S. (2011b), “How Safe Kudankulam Nuclear Power Reactors Are,” The Hindu, https://www.thehindu.com/sci-tech/science/how-safe-kudankulam-nuclear-power-reactors-are/article2612339.ece

PTI (2019), “India Must Provide Sovereign Guarantee for Financial Assistance to Jaitapur Nuclear Power Plant, says EDF,” https://www.financialexpress.com/industry/india-must-provide-sovereign-guarantee-for-financial-assistance-to-jaitapur-nuclear-power-plant-says-edf/1554773/

Rajagopalan, Rajeswari (2017), “India’s Nuclear Security: Strengths and Gaps,” Observer Research Foundation, https://www.orfonline.org/research/india-nuclear-security-strengths-gaps/

Ramana, M. V. (2009), “India’s Nuclear Enclave and the Practice of Secrecy” in ed. Itty Abraham, *South Asian Cultures of the Bomb: Atomic Publics and the State in India and Pakistan* (Bloomington and Indianapolis: Indiana University Press).

Ramana, M. V. (2012), *The Power of Promise: Examining Nuclear Energy in India* (New Delhi: Penguin-Viking).

Reason, James (2000), “Safety Paradoxes and Safety Culture,” Injury Control & Safety Promotion 7(1), 3-14.

Rethinaraj, T. S. G. (1999), “In the Comfort of Secrecy,” Bulletin of the Atomic Scientists, https://journals.sagepub.com/doi/full/10.2968/055006015

Roberston, Kalman & Carlson, John (2016), The Three Overlapping Streams of India’s Nuclear Programs, Harvard University, Belfer Center for Science and International Affairs, https://www.belfercenter.org/publication/three-overlapping-streams-indias-nuclear-power-programs

Roxy M. K. & S. T. Chaithra (2018), Impacts of Climate Change on the Indian Summer Monsoon. In *Climate Change and Water Resources in India*, Vimal Mishra, and J. R. Bhatt, Eds. (New Delhi: Ministry of Environment Forest and Climate Change), 21-37.

Shidore, Sarang (2020), “Climate Change and the India-Pakistan Rivalry,” Council on Strategic Risks, https://councilonstrategicrisks.org/2020/02/11/briefer-climate-change-and-the-india-pakistan-rivalry/

Shidore, Sarang with Busby, Joshua (2020), “Climate Risks to India’s Internal Security,” Council on Strategic Risks, *forthcoming*.

South Asia Terrorism Portal (2019), “India: Conflict Map 2019,” https://www.satp.org/latest-on-satp/india-conflict-map-2019

Srivastava, Pragya (2018), “Modi Government Cuts Nuclear Power Capacity Addition Target to One-Third,” Financial Express, https://www.financialexpress.com/economy/modi-government-cuts-nuclear-power-capacity-addition-target-to-one-third/1122715/

Sundaram, Kumar (2016), “Nuclear Leak in Kakrapar May Be More Serious Than the Government is Telling Us,” Scroll, https://scroll.in/article/805119/nuclear-leak-in-kakrapar-may-be-more-serious-than-the-government-is-telling-us

U.S. Department of State (2007), “U.S. and India Release Text of 123 Agreement,” https://2001-2009.state.gov/r/pa/prs/ps/2007/aug/90050.htm

World Nuclear Association (2019), “Nuclear Power in India,” https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/india.aspx

World Nuclear News (2020), “India, Russia Discuss Cooperation in Third Countries,” https://world-nuclear-news.org/Articles/India-Russia-discuss-cooperation-in-third-countrie