Transboundary Environmental Stressors on India-Pakistan Relations

An Analysis of Shared Air and Water Resources
Preface

This report addresses an important, yet sometimes overlooked, potential flashpoint between India and Pakistan: the ongoing discourse by governments, news media, and citizens over transboundary water resources and air quality between India and Pakistan. Each nation has continued to express concerns over the perceived impacts from water resources development plans and air pollution from agricultural burning. Yet the conversation about shared air and water resources between the two nations could benefit from tangible science and analysis on the actual causes and effects of water and agricultural management activities. This report is an initial step in that direction. It details the results of a preliminary pilot study intended to spur future in-depth research. We provide a first-order assessment of the potential capacity of 13 hydroelectric projects to effectively control downstream flows in Pakistan along the Chenab River—a major tributary of the Indus River that has its source in India and flows through both nations. We also examine the influence of agricultural burning from the Punjab State in India, as well as from an approximately equivalent area across the border in Pakistan, on air pollution in both countries. Finally, this report details the implications of our research on policy debate and decisions in South Asia and outlines follow-on research that could be instrumental to formulating policies related to the shared use of water and air between India and Pakistan.

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Summary

This report addresses an important, yet sometimes overlooked, potential flashpoint between India and Pakistan: the sharing and management of transboundary environmental resources. Across the India–Pakistan border, air and water resources are part of complex and interconnected natural and manmade systems that are essential to the health and well-being of both nations’ economies and populations. However, infrastructure development along shared water resources and declining air quality are heightening tensions between the two nations, with governments and news media increasingly highlighting water resources and air quality as critical national concerns. These transboundary issues between India and Pakistan would benefit from informed, objective analysis of the issues. This report makes an effort in that direction.

The first part of our analysis examines the potential impacts of Indian hydroelectric projects along the Chenab River (a principal tributary of the Indus River) on the downstream flow into Pakistan. We quantified these impacts using the concept of degree of regulation (DOR) and available documentation on India’s planned run-of-the-river hydroelectric projects. Our DOR analysis suggests a minimal capacity for control during normal and high flow years because these projects have relatively small storage volumes compared with total annual water availability. As all projects include some degree of storage, however, this analysis also indicates that, when considered together, all facilities could affect downstream flow in the Chenab River, but the full timing and magnitude of this control needs further modeling and investigation.

The second part of our analysis examines Indian and Pakistani contributions to transboundary pollution levels associated with crop residue burning. Remote sensing and atmospheric transport analyses suggest that pollution from India and Pakistan’s Punjab agricultural regions contributes to air pollution impacts within each country, as well as across the border, but the levels vary by season. In the premonsoon burning season (April to May), fire activity is observed in both India and Pakistan’s Punjab agricultural regions. The October–November postmonsoon burning mostly occurs in India’s Punjab State. However, atmospheric transport patterns show that pollution from postmonsoon agricultural fires flows primarily to the southeast, where it can impact air pollution in other regions in India but generally does not cross the border to Pakistan. However, Pakistan’s fire activity was consistently lower during the postmonsoon burning season. If burning were to increase in Pakistan during the postmonsoon season, it could have implications for transboundary pollution transport as well.

There is a larger issue at stake here: Transboundary environmental issues should be seen as an opportunity for enhanced cooperation to improve the health and well-being of this region’s population, rather than as a source of conflict. As climate change, population growth, and aging infrastructure continue to stress resource quantity and quality, India and Pakistan could better
coordinate management and share information to amplify the benefits of sustainable resource management strategies for both nations’ populations.
Acknowledgments

The authors gratefully acknowledge the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) for the provision of the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) transport and dispersion model and READY website (http://www.ready.noaa.gov) used in this publication. We would like to thank Rafiq Dossani and Robin Meili for their guidance and assistance and Jonah Blank, Debra Knopman, and Ritesh Guatam for their quality assurance review and comments.
Abbreviations

<table>
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<th>Abbreviation</th>
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<tr>
<td>DOR</td>
<td>degree of regulation</td>
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<tr>
<td>FRP</td>
<td>fire radiative power</td>
</tr>
<tr>
<td>HYSPLIT</td>
<td>Hybrid Single Particle Lagrangian Integrated Trajectory</td>
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<td>IBIS</td>
<td>Indus Basin Irrigation System</td>
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<td>IGP</td>
<td>Indo-Gangetic Plain</td>
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<td>IRB</td>
<td>Indus River Basin</td>
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<td>IWT</td>
<td>Indus Water Treaty</td>
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<tr>
<td>MAF</td>
<td>million acre-feet</td>
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<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>PCA</td>
<td>Permanent Court of Arbitration</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>fine particulate matter</td>
</tr>
<tr>
<td>UNMOGIP</td>
<td>United Nations Military Observers Group in India and Pakistan</td>
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As India and Pakistan, both declared nuclear-armed states, continue to struggle to normalize relations and to reduce tensions along their shared (official and nonofficial) border, it is increasingly important that both real and perceived irritants across this border be desensitized to the fullest extent possible. This report examines one such irritant: the ongoing tension over transboundary environmental resources, focusing specifically on water and air. Governments and news media in both nations continue to voice concerns over air and water issues. However, many of these discussions lack grounding in science and would benefit from informed, objective analysis of the environmental dynamics at play. This report makes an effort in that direction.

The initial research and analysis in this pilot project reveal that there may be more opportunity for collaboration than the ongoing rhetoric would suggest. Transboundary environmental issues could be a source of enhanced cooperation to improve the health and well-being of the region’s population, rather than a source of conflict. As climate change, population growth, and aging infrastructure continue to stress resource quantity and quality, India and Pakistan could better coordinate management and share information to amplify the benefits of sustainable resource management strategies for both nations’ populations. The current situation, however, is mostly one of uncoordinated management, stressed water and air resources, and disagreement over shared responsibilities for environmental management.

Water

The Indus River Basin (IRB) is the largest freshwater source shared between India and Pakistan (see Figure 1.1). Because of the substantial and interdependent demands on the IRB’s water resources, the need to formalize the surface water rights between India and Pakistan was recognized soon after the Partition of India. The Indus Water Treaty (IWT) was signed in 1960 and governs the rights to the waters of the shared portions of the IRB between India and Pakistan. The IWT is the formal mechanism under which the two countries mediate, allocate, and manage the Indus River’s resources and irrigation infrastructure.\footnote{Mary Miner, Gauri Patankar, Shama Gamkhar, and David J. Eaton, “Water Sharing Between India and Pakistan: A Critical Evaluation of the Indus Water Treaty,” \textit{Water International}, Vol. 34, May 2009.} Under the IWT, India has rights to the consumptive water use of the three eastern rivers of the IRB—the Ravi, the Beas and the Sutlej—and Pakistan has rights to the consumptive water use of the three western rivers—the Indus, the Jehlum, and the Chenab.\footnote{India and Pakistan, The Indus Waters Treaty, Karachi, September 19, 1960.} Over time, however, disagreements have emerged on the effects of India’s construction projects along those rivers that flow from India into Pakistan—rivers that are allocated to Pakistan under the IWT. In recent years, India has
increasingly sought to use IRB waters to satisfy the growing energy and water demands of its population.

Figure 1.1. Overview of Shared Water and Air Resources Across the Indian-Pakistani Border

NOTE: In our air pollution analysis, we focus on Punjab State in India (orange), as well as an approximately equivalent area across the border in Pakistan (red), composed of Faisalabad, Gujranwala, and Lahore Districts in Pakistan’s Punjab Province.

Pakistan is worried, however, that Indian projects might reduce the amount of water available for irrigation and populations in Pakistan\(^3\) and that India’s capacity to hold and release Pakistan’s water resources at will could potentially “destabilize its water supplies” during periods of drought or conflict.\(^4\) These concerns have become a major source of conflict between the two countries.\(^5\) In Pakistan, political leaders, the press, and militant groups “have made water sharing an emotive issue.”\(^6\) In 2011, the former chair of Pakistan’s Indus Rivers System Authority wrote,

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\(^3\) India’s planned run-of-the-river hydroelectric projects require a degree of storage, or pondage, to function (“India Hastens Hydropower Projects in Jammu and Kashmir,” *Financial Times*, July 26, 2017).


\(^5\) Miner et al., 2009.

\(^6\) Miner et al., 2009.
Over and above, India has built 3 dozens of dams in occupied Kashmir on Chenab, Jehlum and the Indus Rivers and on their tributaries to hold water, waging silent water war by violating the Indus Waters Treaty and using water as weapon of mass hunger, death and destruction.\(^7\)

Pakistan has real and vital concerns about the continued availability of water to meet growing demand, which contributes to its fears over loss of Indus water. The Pakistan Council of Research in Water Resources has been warning since 2016 that Pakistan could run out of water by 2025 if the government does not take immediate action. The International Monetary Fund points to Pakistan as one of the “most water-stressed countries in the world,” with its water management issues predominantly related to irrigation management.\(^8\) These warnings have highlighted Pakistan’s need to overhaul its national water management systems; however, Pakistan continues to attribute many of its water woes to India.

**Air**

The Indo-Gangetic Plain (IGP) is one of the most highly polluted regions in the world,\(^9\) Pakistan and India each face negative health and economic consequences associated with exposure to severe air pollution. One increasingly important pollution source is smoke from agricultural residue burning in the border region between northwestern India and eastern Pakistan (see Figure 1)—the focus of our air quality analysis in this report. Pakistan considers India responsible for increased air pollution in Lahore and the Punjab; Pakistani media has reported that, “the smog [in Pakistan] is coming from the burning of agricultural waste in Indian Punjab, and satellite imagery actually shows the widespread prevalence of the farm fires,” and that “the noxious smog engulfing large parts of upper Punjab is yet another reminder that Pakistan and India have much to talk about beyond geopolitics.”\(^10\) Reports in Indian sources, on the other hand, point to Pakistani contributions to degraded air quality in India: “[I]f anything, stubble burning around Islamabad and Lahore is adding to the deadly smog in northern India.”\(^11\)

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\(^7\) Fateh Ullah Khan Gandapur, “Silent Water War by India Against Pakistan Violating IWT and Using Water as Weapon of War,” [*Fateh Gandapur’s Blog on Water Issues of Pakistan*], May 26, 2011.

\(^8\) “Despite an abundant endowment [of water], crops are predominantly irrigated, and agriculture consumes about 95 percent of annual available surface water. Yet agriculture is largely untaxed, even though it accounts for 20 percent of [gross domestic product] and employs 40 percent of the population. Irrigation fees are based on land area rather than actual water consumption, which has impeded the adoption of more efficient technology and less-water-intensive crops” (Kalpana Kochhar, Catherine Pattillo, and Yan Sun, “Is the Glass Half Empty or Half Full?” [*International Monetary Fund Finance and Development*], June 2015).


\(^11\) Shimona Kanwar, “Pakistan Smog Adds to India’s Woes, Thanks to Wind Direction,” [*Times of India*], November 8, 2016.
Objectives

The goals of this research are to

1. provide a preliminary overview of the status of shared water and air resources and transboundary environmental management practices that impact Indian and Pakistani populations
2. provide an initial analysis of the effect that planned hydropower facilities in India could have on water availability in Pakistan
3. examine whether the transboundary transport of smoke from agricultural waste burning contributes to degraded air quality in both nations
4. analyze which existing transboundary environmental practices are heightening tensions and which could mitigate water and air quality impacts and ease friction.

This report details our preliminary findings. Chapter Two outlines our first-order assessment of the potential capacity of 13 hydroelectric projects to effectively control downstream flows into Pakistan along the Chenab River, one of the principal tributaries of the Indus River. Chapter Three provides the results of research that examined the influence of agricultural burning in the Punjab regions of India and Pakistan on air pollution within each country and across borders. Chapter Four discusses the main conclusions and policy implications of our work and outlines potential follow-on research that could be instrumental formulating policies related to the shared use of air and water between India and Pakistan. Appendix A provides an overview of the geopolitical context that surrounds these environmental issues, detailing important historical conflict and agreements between the two nations. Appendix B provides an atmospheric back trajectory analysis.
The IRB is shared between India, Pakistan, China, and Afghanistan, with 86 percent of the basin area in India and Pakistan. Historically, annual surface water availability in the basin has averaged 146 million acre-feet (MAF) per year in Pakistan and 59 MAF per year in India and China combined.1 Approximate average annual agriculture, domestic, and industrial water use ranges from 28 to 33 MAF per year in India and from 56 to 80 MAF per year in Pakistan.2 Agricultural irrigation uses the most water, with an estimated 60.9 percent and 37.2 percent of the basin’s irrigated area in Pakistan and India, respectively.3

While the IWT, which governs the rights to these shared surface water sources between India and Pakistan, is simple in principle, a number of complications have led to tensions between the two nations. The IWT fixes water allocations in each of the rivers based on a volumetric basis, which was set in 1960, and does not provide guidance on what will happen during periods of water scarcity, when water availability dips below the amount available during the 1960 allocation.4 The IWT also does not consider groundwater extraction, which can impact water availability in the river system, nor does it mention environmental flows or ecosystem needs.5 In addition, the three western rivers designated to Pakistan originate in Indian-administered Kashmir. According to the terms of the IWT, India has the right to nonconsumptive use of water where it flows through Indian-administered Kashmir, along the Jehlum and Chenab Rivers. India has never fully utilized these terms.6

Indian plans for the development of hydroelectric projects that utilize their right to nonconsumptive use of water along the three western rivers have, however, developed over time. In response to these plans, Pakistan has questioned India’s right to construct such projects, maintaining that the projects did not constitute a nonconsumptive use of water, leading to growing tensions between the two nations. Such disagreements over hydroelectric projects in the upstream portions of the three western rivers have continued over the past several decades.7

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4 Ahmad, 2012.
5 Ahmad, 2012.
7 For example, in 1984, Pakistan raised concerns over India’s planned construction of the Wullar Barrage on the Jhelum River, calling it a violation of the IWT (Pakistan refers to this infrastructure project as the Wullar Barrage; India refers to it as the Tulbul Navigation Project). In response, India halted construction in 1987. Construction is
More recently, tensions have risen further over a few key projects, and these tensions have been aggravated by geopolitical events.

In 2007, Pakistan raised new concerns about India’s planned construction of the Kishanganga hydroelectric facility, a 330-megawatt project on the Jhelum River, close to the Line of Control (the de facto border between India and Pakistan in Jammu and Kashmir). Pakistan sought international arbitration from the Hague’s Permanent Court of Arbitration (PCA) in May 2010, stating that the Kishanganga plant violated the IWT by increasing storage capacity along the Jhelum River upstream of Pakistan, thus depriving Pakistan of its water rights. At the same time, thousands of Pakistani farmers driving tractors and carrying signs warning “Water Flows or Blood” protested Indian plans for hydroelectric development, including the Kishanganga project. Hafiz Saeed—whose organization, Lashkar-e-Taiba, is identified as a terrorist group by the United Nations and banned by Pakistan itself—led the protest, claiming that India was guilty of “water terrorism.” This might be the highest-profile instance of a call to arms in Pakistan focused not on border disputes or rights of Kashmiris but on access to water. Speaking at the time, John Briscoe, a Harvard professor and former World Bank water specialist focused on Pakistan and India, said that allegations of India's “water robbery” were unfounded and that “the last thing [Briscoe] would want to come into India-Pakistan relations is an issue as visceral as water.”

The official ruling on the Kishanganga project came in December 2013. The PCA unanimously decided on minimum and emergency downstream flow rates for the Kishanganga project and allowed for a request for reconsideration by either party seven years after water diversions for the power project began. While disagreements over water and other issues continued between India and Pakistan, the IWT held; for years, discussions about shared water remained peaceful, if sometimes difficult.

That changed in September 2016, following an attack by Pakistan-based terrorist group Jaish-e-Muhammad on an Indian Army base near Uri, in the state of Jammu and Kashmir. Indian domestic clamor for action against Pakistan in the wake of the attack, which killed 18 soldiers, resulted, 11 days later, in an announcement by the Indian Ministry of Defense that appropriate action had been taken: Indian
While India’s actions garnered media coverage, India also levied a more subtle threat in the weeks between the Uri attack and the Indian military response. On September 22, India’s Ministry of External Affairs Spokesman Vikas Swarup said about the IWT, “There are differences on the treaty. For any such treaty to work, it is important there must be mutual trust and cooperation. It can’t be a one-sided affair,” which was taken by many observers to mean that India might consider revoking the treaty.

On September 26, 2016, Indian Prime Minister Narendra Modi told a group of Indian officials who had met to review the IWT that “blood and water cannot flow together,” an ominous parallel to Hafiz Saeed’s and Pakistani protestor comments six years earlier. India decided not to abrogate the treaty but did suspend meetings between Indian and Pakistani Indus waters commissioners. Eventually, a regular meeting was held in March 2017, but regular meetings were suspended again in 2017 after a Pakistani Army court sentenced an alleged Indian spy, Kulbhushan Jadhav, to death.

During this geopolitical turmoil, India announced plans to “exploit to the maximum” its right to nonconsumptive use of the upstream flows of Pakistan’s IRB western rivers. Since then, India has begun construction of hydropower facilities along the western rivers and their tributaries—the Chenab, Jhelum, and Neelum—in Indian-administered Kashmir. Along the Chenab River, which serves as the focus of our analysis, Indian plans included eight hydroelectric projects in addition to the two that are already under construction. Of these planned projects along the Chenab River, Pakistan strongly opposes the Sawalkot, Ratle, Pakal Dul, and Lower Kalnai projects, claiming their potential to limit flow in the Chenab River, as well as the Kishanganga along the Jhelum River. Pakistan called upon the World Bank to hold negotiations over these planned hydroelectric facilities, and such negotiations began in the fall of 2017.

forces, according to the ministry, had conducted a “surgical strike” into the Pakistan-administered state of Azad Kashmir that targeted seven terrorist camps and killed multiple militants. Pakistan denied that the strike had even occurred but announced that two soldiers had been killed in clashes with Indian troops along the Line of Control.


14 “India Cannot Unilaterally Revoke or Alter Indus Treaty: Pakistan,” The Hindu, New Delhi, October 7, 2016.


19 Bagchi and Mohan, 2016.

20 Qureshi, 2017.

Following the suspension of meetings in 2017, India and Pakistan resumed normal Indus Water Treaty meetings of the Pakistan-India Permanent Indus Commission in March 2018. This 114th meeting of the Pakistan-India Permanent Indus Commission occurred during a period of ongoing tension surrounding a host of issues, including allegations of Indian harassment of Pakistani diplomats.\(^{22}\) In May 2018, Indian Prime Minister Narendra Modi inaugurated the Kishanganga hydroelectric project that started in 2009 and was opposed by Pakistan. Days later, and in spite of the 2013 ruling by the PCA that established minimum flow rates, Pakistan levied allegations, through the World Bank, that the Kishanganga project was a violation of the IWT.\(^{23}\)

After meeting with the Pakistani delegation, the World Bank announced,

> Several procedural options for resolving the disagreement over the interpretation of the Treaty’s provisions were discussed. While an agreement on the way forward was not reached at the conclusion of the meetings, the World Bank will continue to work with both countries to resolve the issues in an amicable manner and in line with the Treaty provisions. The Indus Waters Treaty is a profoundly important international agreement that provides an essential cooperative framework for India and Pakistan to address current and future challenges of effective water management to meet human needs and achieve development goals.\(^{24}\)

Several media outlets reported that the World Bank had denied Pakistan’s request for arbitration and suggested that the World Bank’s views on how Pakistan and India might proceed to settle their differences was “unclear,” but that the World Bank remained committed to helping assist in the process.\(^{25}\) India and Pakistan met in Lahore in late August 2018 to discuss various aspects of the IWT and the issues surrounding the disputed hydroelectric projects.\(^{26}\) An agreement was reached to allow Pakistani experts to inspect the Pakal Dul and Lower Kalnai sites, but no updates on the debate surrounding the Kishanganga project were released.\(^{27}\)

While much of the discourse on water management in the IRB has focused on the threats to water scarcity that Indian-operated hydropower facilities could pose to Pakistan, population growth, irrigation inefficiencies, and increasing water demand could further threaten the treaty.\(^{28}\) Because of Pakistan’s arid and semiarid climate and the continuous growth of agriculture,

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\(^{23}\) “Pakistan Raises India’s ‘Violation’ of Indus Water Treaty with World Bank,” Livemint, New Delhi, May 22, 2018.


\(^{26}\) “India, Pakistan to Resume Talks on Indus Water Treaty This Week,” Economic Times, August 27, 2018.

\(^{27}\) “India, Pak Agree to Tours on Both Sides of Indus Basin for Power Projects,” NDTV, September 1, 2018.

\(^{28}\) Ahmad, 2012.
Pakistan’s portion of the IRB is one of the most intensely irrigated regions of the world. Pakistan manages the world’s largest continuous irrigation system—the Indus Basin Irrigation System (IBIS) that supports the provision of food and water to millions of Pakistanis. As cropped area and population have increased, the demands on Pakistan’s limited water supplies have also increased (see Figure 2.1). Between 1971–1975 and 1991–1995, Pakistan saw an average 39-percent increase in cropped area for all crops, with the area for fruit crops increasing by an estimated 150 percent.

**Figure 2.1. Hectares Under Production for Principal Crops in Pakistan**

![Figure 2.1. Hectares Under Production for Principal Crops in Pakistan](image)

Despite the growing need for water, the IBIS experiences water losses at nearly 55 percent because of aging irrigation canals, evaporation, and insufficient lining of waterways. The IBIS and the surrounding agricultural regions also face significant and pervasive threats to agricultural production because of soil salinization, quality degradation of surface water and groundwater, and overexploitation of groundwater resources. Further, research has suggested that, more than

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30 Ahmad, 2012.
31 Ahmad, 2012.
32 Food and Agriculture Organization of the United Nations, 2011.
34 Ahmad and Majeed, 1982.
the Indian construction of dams, “it is inadequate water policies and loopholes in the regulations for management of water systems, that are acknowledged as the causes of water crisis in Pakistan.”\textsuperscript{35} In fact, the anthropogenic impacts on the IRB are so significant that for nearly ten months of the year, the Indus River runs dry before entering the sea.\textsuperscript{36}

Disputes over water in the IRB are also aggravated by climate. The impact of climate change on water availability is already evident in the high-mountain regions of Kashmir, as glaciers recede. The IRB receives half of its flow from glacial melt water, and as that resource dries up, India and Pakistan will need to work together to share research, communicate about water management, and more accurately and comprehensively map and model the region.\textsuperscript{37} These compounding political and environmental issues make quantifying the impacts of various infrastructure projects and determining adequate transboundary management strategies a challenge.

Methodology

Despite the growing risk that climate and water management pose to water availability in the IRB, dam operations and storage projects are often pointed to as the main contributor to flow regulation in river systems.\textsuperscript{38} The primary goal of these reservoir projects is to eliminate and store peak flows, either for flood control, water supply storage for irrigation, or for energy production, creating a more stable downstream flow system and providing a source of energy. The consequence of regulating river flows is often felt by downstream ecosystems and communities and can have impacts on water availability many hundreds of kilometers downstream.\textsuperscript{39} Thus, the magnitude of regulation of the downstream hydrologic system by a given project or set of reservoir projects is one important metric to consider in assessing their full impact.

Here we describe our methodological approach to quantifying the magnitude of regulation that Indian hydroelectric projects could have on downstream flows in Pakistan, focusing on the Chenab River. The Chenab River is one of the three western rivers that Pakistan has the primary rights to and is the river on which India has planned the majority of its hydroelectric projects. It is important to note that the analyses presented in this report constitute an initial assessment

intended to spur more rigorous and in-depth research on the full impact of India’s hydroelectric projects on downstream riverine systems. Suggested directions for a full treatment of this topic are included in Chapters 3 and 4.

Various approaches exist to quantify the impact of dams and other water infrastructure on downstream flows at a river basin scale. For example, Riedy Liermann uses the concept of a freshwater ecoregion, or the length of a river reach without impoundments, as the spatial framework to assess the extent to which a dam has obstructed riverine habitats and flows.40 Other researchers have developed species-specific distribution models that include variables—height, distance from the outlet, and percentage of river downstream of a dam—to characterize the relationship between dams, flow regimes, and biological impacts.41 Arheimer uses numerical catchment modeling to compare natural to regulated flow regimes and predict the amount of regulated flow in the study region.42 To quantify the larger-scale impacts of dams in the United States on downstream communities, Graf utilizes a variety of metrics, including dams per area, persons per dam, storage per area, and storage-to-runoff ratio.43 The storage-to-runoff ratio is particularly useful for conceptualizing amount of control a single dam could have on a downstream region. This ratio describes the amount of annual water available in a river basin that could be effectively stored in a reservoir.44 The concept of degree of regulation (DOR) is similar. DOR measures the ratio of mean annual inflow to reservoir storage capacity, also reflecting the capacity of a dam to capture the annual flow in a river.45 The DOR has been used in many studies to quantify the impacts on individual and series of dams on downstream flow regimes and is particularly useful when multisite and high-resolution gauge data are not available.46

Because of limited data availability and the pilot nature of this study, we used the concept of DOR in conjunction with available research and documentation on India’s planned run-of-the-river hydroelectric projects to analyze the potential capacity of hydroelectric projects to

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40 Catherine Reidy Liermann, Christer Nilsson, James Robertson, and Rebecca Y. Ng, “Implications of Dam Obstruction for Global Freshwater Fish Diversity,” *Bioscience*, June 2012.


effectively control downstream flows on the Chenab River. For larger hydroelectric projects, we also examined available documents and resolutions on points of difference between India and Pakistan on now-complete hydroelectric projects for comparison to planned facilities. India has already constructed several run-of-the-river hydroelectric projects along the Chenab River in Indian-administered Kashmir—the Salal I and II, Baglihar, and Dulhasti. The quantitative DOR analysis did not include an examination of the existing Baglihar or planned Bursar facilities, as these have larger storage volumes that can fluctuate more significantly on seasonal, rather than annual time scales. The Baglihar and Bursar facilities are discussed qualitatively following the DOR analysis.

Using publicly available information, we collected storage capacity and energy production data for each Indian hydroelectric project planned, under construction, and in operation along the Chenab. Table 2.1 details each of these projects, and Figure 2.2 displays them on a map of the region.
Table 2.1. Energy Protection Potential and Storage Capacities of Hydroelectric Projects Along the Chenab River in India

<table>
<thead>
<tr>
<th>Hydroelectric Projects</th>
<th>Stage of Completion</th>
<th>Energy Production (MW)</th>
<th>Storage (MAF)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawalkote(^b)</td>
<td>Planning Stage</td>
<td>1,856</td>
<td>0.019</td>
</tr>
<tr>
<td>Kirthai-I(^c)</td>
<td>Planning Stage</td>
<td>390</td>
<td>0.085</td>
</tr>
<tr>
<td>Kirthai-II(^d)</td>
<td>Planning Stage</td>
<td>930</td>
<td>0.0415</td>
</tr>
<tr>
<td>Shamnot</td>
<td>Planning Stage</td>
<td>370</td>
<td>0.0178(^e)</td>
</tr>
<tr>
<td>Bursar(^f)</td>
<td>Planning Stage</td>
<td>1,020</td>
<td>0.58</td>
</tr>
<tr>
<td>Kiru(^g)</td>
<td>Planning Stage</td>
<td>624</td>
<td>0.03</td>
</tr>
<tr>
<td>Kwar(^h)</td>
<td>Planning Stage</td>
<td>540</td>
<td>0.022</td>
</tr>
<tr>
<td>Pakal Dul(^i)</td>
<td>Planning Stage</td>
<td>1,000</td>
<td>0.0864</td>
</tr>
<tr>
<td>Ralte(^j)</td>
<td>Under Construction</td>
<td>850</td>
<td>0.0195</td>
</tr>
<tr>
<td>Lower Kalnai(^d)</td>
<td>Under Construction</td>
<td>48</td>
<td>0.0015</td>
</tr>
<tr>
<td>Salal I&amp;II(^i)</td>
<td>In Operation</td>
<td>690</td>
<td>0.0204</td>
</tr>
<tr>
<td>Baglihar I&amp;II(^k)</td>
<td>In Operation</td>
<td>900</td>
<td>0.29</td>
</tr>
<tr>
<td>Dulhasti(^l)</td>
<td>In Operation</td>
<td>390</td>
<td>0.0104</td>
</tr>
</tbody>
</table>

NOTE: Baglihar I and II and Bursar HEPs are excluded from the DOR analysis; MW = megawatts.
\(^a\) Storage values represent the total storage capacity of planned reservoirs, including dead storage; the operational storage may be much less.
\(^e\) This value is based on an extrapolation of the relationship between energy production and storage from other planned hydroelectric projects. At the time of writing, no storage capacity estimate for the Shamnot hydroelectric project was available.
In Figure 2.2, we see that the majority of these facilities are planned further upstream from existing hydroelectric projects and are fairly small in capacity compared with the reservoirs included in the Global Reservoir and Dam Database, which only records reservoirs with storage greater than 0.08 MAF.47

Using the storage capacity information in Table 1, we developed three storage scenarios:

1. hydroelectric projects in operation (those shown in red in Figure 2.2, with the exception of Baglihar I and II)
2. hydroelectric projects in operation and under construction (those shown in red and black in Figure 2.3, with the exception of Baglihar I and II)
3. all planned, under construction, and in operation hydroelectric projects (all facilities shown in Figure 2.3, with the exception of Bursar and Baglihar I and II).

These storage scenarios are shown in Figure 2.3.

47 Lehner et al., 2011.
Next, we calculated three river flow scenarios, reflecting realistic hydrologic regimes, based on historical flow data for the Chenab River. Figure 2.4 shows the low, normal, and high average annual flow data. Significant variability in Chenab River flow is caused by the high amount of precipitation received in strong monsoon years, coupled with the drought-prone nature of the basin, exemplified in low flow years.
The cumulative DOR is calculated for each flow and storage scenario as

\[
DOR = \frac{\sum \text{Storage Capacity}}{\text{Mean Annual Inflow}},
\]

where storage capacity is either 0.03 MAF, 0.05 MAF or 0.35 MAF for the three cumulative storage scenarios, and mean annual inflow is either 18 MAF, 25 MAF or 37 MAF for the low, normal, and high flow scenarios, respectively.

The DOR analysis includes a number of limitations. The storage capacity values used represent the total storage capacity of planned reservoirs, including dead storage. These were the consistently available values for all facilities. This may lead to overstating the DOR values, as the operational storage may be much less. The DOR indicator is used as a first-order metric to quantify dams’ impacts on flow regulation in the downstream hydrologic system. However, an additional consequence of dam and storage construction on river systems is fragmentation, which is the disruption of the natural connectivity in river systems critical to ecosystem health, groundwater replenishment, and biodiversity. Further, the DOR metric is calculated on an annual basis using average streamflow values. Hydroelectric projects are operated daily, with changes in operations occurring at the very least on seasonal time scales. Thus, the DOR cannot capture intra-annual variability in streamflow and operations, which could have significantly different dynamics and impacts to average annual values.

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48 Grantham, Viers, and Moyle, 2014.
Because of these limitations and the increasing complexity of larger systems, we elected to examine the larger hydroelectric projects along the Chenab River using existing research. We reviewed available documentation on the Bursar hydroelectric project, which is currently in its planning stage, and the Baglihar I and II hydroelectric projects, which are complete. For this portion of the analysis, we used Baglihar as a case study to understand the potential impacts of the Bursar hydroelectric project. Full modeling or quantitative studies from nonpartisan sources of the hydrologic impacts of Baglihar I and II were not found in our literature review. Instead, a broad literature includes discussions on the geopolitical and legal implications of the IWT on the dispute over the Baglihar dam. A number of Pakistani sources do cite decreases in flow following the construction of Baglihar I and II, but these could not be confirmed with third-party data.

The most comprehensive and neutral source of information on the quantitative impacts of the Baglihar hydroelectric project is the executive summary of the neutral expert determination conducted by the World Bank. This document details the concerns Pakistan raised over the Baglihar hydroelectric project, stating that Baglihar had the potential to regulate downstream flow, the position India took, and the determination by the neutral expert. The final ruling allowed India to continue construction of the Baglihar dam and hydroelectric project with a few design changes, as the final dimensions of the project were agreed upon by the neutral expert, Pakistan, and India to fall within the terms of the IWT. The Bursar has a much larger planned total storage capacity of 0.58 MAF compared with Baglihar’s capacity of 0.29 MAF. The estimated energy production of both facilities is much closer (1,020 MW for Bursar and 900 MW for Baglihar). The other engineering specifications of the facilities, such as freeboard height and elevation of power intake, are site specific and not comparable.

Results

The results of the DOR scenario analysis are shown in Figure 2.5. Because of the small difference in storage between the first two storage scenarios (left and middle columns), the results for each of these two scenarios are quite similar. Within these two storage scenarios, the DOR value is nearly double during a low flow year (shown in light blue) compared with a high flow year (shown in dark blue) during the peak flow period. The DOR value decreases significantly during the period of low flow, indicating a significant decrease in water availability for downstream users. The data suggest that the Bursar project has a higher DOR value during low flow periods compared to Baglihar, highlighting the importance of understanding the potential impacts of such projects on water resources management.
flow year (shown in dark blue), suggesting that the impact of hydroelectric projects is more significant when water availability is limited, such as during a drought.

Figure 2.5. Degree of Regulation Under Different Storage and Flow Scenarios, Chenab River

When the planned, under construction, and in-operation hydroelectric projects are considered (right column), the DOR values are significantly higher. Higher DOR values indicate that a larger percentage of the annual flow can be stored and released at a later date, demonstrating a higher capacity to control a given river. In the context of other regions, these DOR values are fairly low. In a study of hydrologic alteration from 181 dams in California, the DOR threshold used to represent “altered” river systems was 1, or 100 percent, based on research on streamflow alteration in Spain and across the United States. Other notable work with DOR has used a much smaller threshold of 2 percent to classify river systems as “affected.” The 2-percent threshold is described as reservoirs that have the capacity to store one week of the river’s average annual flow. In the low flow, high–storage capacity scenario (light blue bar of right column),

53 Grantham et al., 2014.
56 Lehner et al., 2011.
57 Lehner et al., 2011.
all hydroelectric projects planned, under construction, and in operation could store just under one week of the annual flow of the Chenab River. This nearly meets the “affected” classification, suggesting the need for further, more rigorous research to quantify the true impact that these projects could have during periods of low flow.

The review of available documentation on the Bursar and Baglihar hydroelectric projects also suggests a thorough hydrologic impact analysis is needed for both facilities, complete with hydrologic modeling to determine the impact on downstream flows at a seasonal time scale. This analysis is particularly critical for these two larger facilities. Notably, the planned storage volume in the Bursar hydroelectric project is over one-and-a-half times larger than all facilities considered in the DOR analysis. In addition, while the World Bank expert determination on the Baglihar I and II indicated that the adjusted dimensions would not violate the terms of the IWT, there is no accompanying analysis or examination on the impact on downstream flows in the Chenab River.

Conclusions

Our pilot study analysis examined the potential impacts that planned hydroelectric projects along the Chenab River in India may have on the downstream flow regime in Pakistan. We employed DOR as an indicator for control over flows in the river under three storage scenarios. We also compared the impact that low, normal, and high flows may have on this indicator. For two larger facilities (Bursar and Baglihar I and II), we examined available documentation and studies to better understand their potential impacts.

As all projects include some degree of storage, this analysis indicates that, when considered together, all facilities have a capacity for control of flow in the Chenab River, but the full timing and magnitude of this control needs further modeling and investigation. The DOR analysis suggests a minimal capacity for control during normal and high flow years because of relatively small storage volumes compared with the total annual water availability. During low flow periods, however, these facilities could induce more changes in the downstream hydrologic regime. For the two larger facilities examined using available documentation, no further conclusion can be drawn in the absence of additional study and information.

However, merely examining the total storage capacities for each hydroelectric project does not present the full picture. Operationally, hydroelectric projects require the persistence of flow in addition to a degree of storage to generate electricity. This degree of storage is likely less than the volumes considered in this study and could fluctuate considerably within a given year. In addition, if all facilities blocked downstream flows completely to fill their full storage capacity, they would stop their production of energy. As India’s main use of these facilities is the production of energy via hydropower, this is not a likely case. At a minimum, further analysis must include the consideration of expected and actual operational rules for all facilities.
Future work could provide additional insight into the more localized impacts of planned hydroelectric projects. As a direct extension of this pilot study, tributary- and stream-specific analysis using the river regulation index, for example, could consider individual dam contributions to the DOR by the volume of flow each year in the impacted river reach, rather than in the river as a whole. Additional analyses could also be performed to better characterize the impacts of planned hydroelectric projects on river fragmentation in addition to river regulation.\textsuperscript{58} A more rigorous approach to quantifying the impacts of hydroelectric projects would be based on a hydrologic analysis of each facility and include higher-resolution data sets and consider both daily and seasonal time scales. Hydrologic analyses in the Himalayan region would also require the inclusion of data on soil moisture, snowpack depth and coverage, temperature, elevation, and albedo to calculate the timing and magnitude of snowmelt contributions to streamflow. Finally, future work should extend this analysis to include a consideration for the impacts of climate change on the DOR of the region’s river systems. Because a high percentage of baseflow in the Chenab River and in the IRB as a whole is derived from snowmelt, as glaciers recede and baseflow declines, the impact of hydroelectric projects could be more significant. This is particularly critical in low-flow years when baseflow constitutes the majority of the flow in the IRB.\textsuperscript{59}

\textsuperscript{58} Research by Grill et al., 2015, would provide the framework for this analysis.

\textsuperscript{59} In monsoon years with high streamflows, runoff from precipitation events increases the total flow in the IRB. Baseflow is derived principally from snowmelt, glacial melt, and groundwater inflows into surface water.
3. Clearing the Air

India and Pakistan have some of the most severe outdoor air pollution in the world,\(^1\) and this pollution is increasingly recognized as a transboundary environmental and public health hazard. Saif Anjum, a retired Pakistani army captain and secretary of Punjab’s Environment Protection Department, described the situation: “We have a common enemy. We have already requested the federal government for approaching the Indian side. Both sides need to work on it jointly, there’s no other way.”\(^2\) However, without reliable information on how pollution originating in each country impacts the other, developing cooperative, sustainable solutions is a challenge.

Each year, more than 645,000 and 111,000 estimated premature deaths in India and Pakistan, respectively, are attributed to exposure to outdoor air pollution.\(^3\) People on both sides of the border are experiencing difficulty breathing, upper respiratory illness, choking, and other health issues. Pollution in this region has recently hit record levels—fine particulate matter concentrations (particles less than 2.5 µm in diameter; PM\(_{2.5}\)) were recorded at over 1,000 µg/m\(^3\) and nearly 700 µg/m\(^3\) in Lahore and New Delhi, respectively.\(^4\) This greatly exceeds the daily PM\(_{2.5}\) guideline of 25 µg/m\(^3\) established by the World Health Organization (WHO) to protect public health.\(^5\) In addition to adverse health impacts, outdoor air pollution also has negative economic impacts, equivalent to 3.1 percent of gross domestic product across South Asia.\(^6\)

Air pollution in India and Pakistan is driven by a wide variety of sources. These include broad categories, such as residential energy, power generation, industry, natural factors, transportation, agriculture, and biomass burning.\(^7\) Tracking pollution sources is further complicated because regional sources, such as biomass burning, can mix with local urban sources of pollution to exacerbate dangerous levels. New scientific methods are being applied to

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\(^1\) World Health Organization, *Ambient Air Pollution Database*, April 2018.
\(^4\) PM\(_{2.5}\) is an important contributor to urban and rural air pollution and causes negative cardiovascular and respiratory outcomes. Mehrseen Zahra-Malik, “In Lahore, Pakistan, Smog Has Become a ‘Fifth Season,’” *New York Times*, November 10, 2017; Geeta Anand, “Farmers’ Unchecked Crop Burning Fuels India’s Air Pollution,” *New York Times*, November 2, 2016.
\(^6\) World Bank and Institute for Health Metrics and Evaluation, “The Cost of Air Pollution: Strengthening the Economic Case for Action,” Washington, D.C., 2016; this calculation monetizes the increased fatality risk of such pollution based on individuals’ willingness to pay.
\(^7\) Lelieveld et al., 2015.
better understand the relationship between sources of pollution and exposure of populations. However, most scientific research in this region that traces the source or path of pollution tends to focus its analysis on factors within a specific country, rather than on those with transboundary origins. Lack of accurate and timely data on these source-receptor relationships could make attribution and arbitration difficult.

In this chapter, we focus on one of these sources: the air quality impacts of agricultural burning of crop residue. Burning crop residue can have important seasonal impacts on air pollution. Farmers ignite fires in between harvest cycles to quickly and cheaply prepare their fields for planting the next crop.8 Crop residue burning is widely used across the Punjab region, which is considered the “breadbasket” of India and Pakistan. Burning has been commonplace since the introduction of mechanized harvesting in the mid-late 1980s that leaves root-bound stalks post-harvest in fields that farmers then remove by burning their fields.9 A study in Punjab, Pakistan found that burning agricultural residue was 34 percent cheaper for farmers than removing the residue for other uses, such as livestock feed.10 In northern India, fire activity peaks twice per year, from April to May and again from October to November, corresponding to the wheat and rice residue burning periods.11 Pollution is particularly intense during the October to November burning season, which coincides with meteorological conditions that transport pollution from fires across the IGP.12 Recent studies have estimated that crop residue burning is responsible for 6 percent of PM2.5-attributable mortality in India,13 although this estimate is likely conservative, given the coarse spatial resolution of data sets used for these estimates.

Methodology

Our analysis consisted of two primary steps. First, we used satellite observations of fire activity in the primary agricultural regions in India and Pakistan to measure seasonal contributions from each country. We then explored atmospheric transport pathways from these source regions. Taken together, the combined remote sensing and atmospheric modeling

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9 Singh and Kaskaoutis, 2014.
13 GBD MAPS Working Group, Burden of Disease Attributable to Major Air Pollution Sources in India, Boston: Health Effects Institute, Special Report 21, January 2018.
approach was used to evaluate potential transboundary contributions of air pollution caused by agricultural burning.

We focused on the Punjab State in India, as well as an approximately equivalent area across the border in Pakistan, composed of Faisalabad, Gujranwala, and Lahore Districts in Punjab Province (hereafter referred to as Pakistan’s Punjab region). In 2015, 25.6 million people lived in India’s Punjab State, and 43.5 million lived in Pakistan’s Punjab region. These two areas are predominantly agricultural regions and are important contributors to overall fire activity for each country, particularly when considering the shared border region. The northern part of India’s Punjab State is classified as a double cropping agriculture system, mostly rice and wheat in the northern section, along with rice only in the southern section. The northern part of Pakistan’s Punjab region is mostly irrigated rice farms on a double cropping system; the central and southern part includes rainfed mixed crops and plantations on a single cropping schedule, and irrigated rice and wheat on a double cropping schedule.

The first step in our analysis used satellite observations of active fires to map the spatial and temporal patterns in fire activity in the Punjab across the India-Pakistan border. We used fire radiative power (FRP) observations from the MODerate Resolution Imaging Spectroradiometer (MODIS) sensor onboard the Aqua and Terra satellites, which measure daily fire activity at a 1-km² spatial resolution during a morning (10:30 A.M.) and afternoon (1:30 P.M.) overpass, respectively. FRP quantifies the total energy released from a fire in MW, which is a more suitable proxy for fire emissions than active fire counts alone. We examined fire activity over a five-year period from January 2010 to December 2014 to explore variations over several seasons and to help ensure that our results were not skewed by an outlier burning season.

We then used the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) atmospheric trajectory model to explore pathways of atmospheric transport from pollution source regions (the crop residue burning regions identified by our satellite fire analysis) to within-country and transboundary

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pollution. We initiated each trajectory at 11:00 A.M. coordinated universal time, which corresponds to the late afternoon in India and Pakistan, when fire activity peaks in this region.

The HYSPLIT model has been used around the world for air pollution research to model the dispersion of pollutants and to examine source-receptor relationships, including estimating the impact of smoke from fires on air quality in India. For example, Badarinath et al. used HYSPLIT to study long-range transport of aerosols from crop residue burning in the IGP. Similarly, Mishra and Shibata combined satellite observations of different air pollutants and fire detections with atmospheric back trajectory analysis to show the transport of pollution from fires, largely near the surface, from the northwest to the southeast IGP. Elevated pollution levels across northern India have also been found by other remote sensing-based analyses. However, many of these previous studies have generally focused on the transport of pollutants within India, without explicitly considering transboundary pollutant transport. We leveraged the complementary capabilities of the HYSPLIT system to perform both forward trajectories (track the transport of pollution from source regions) and back trajectories (track where a given city’s pollution comes from) to explore cross-border pollution.
Results

Satellite Fire Detections

From January 2010 to December 2014, total FRP was 3.9x10⁶ MW across India’s Punjab State. Cumulative FRP observations in Pakistan’s Punjab region were an order of magnitude lower at 7.4x10⁵ MW (see Figure 3.1). In addition to differences in the absolute magnitude of fire activity, there were also differences in the timing of burning over the course of the year (see Figure 3.2). Similar to results from prior research in India, we found that the postmonsoon (October to November) burning season was a more important contributor to fire activity in India’s Punjab State. However, in Pakistan’s Punjab region, we found the burning predominantly occurred during the April to May peak (the secondary peak for India’s Punjab State). April to May fire activity was more comparable between India and Pakistan’s Punjab regions. This difference is likely caused by multiple factors, such as the type of crop and method of harvesting, although other factors could also play a role. The dominant crop types (by area) in Pakistan’s Punjab Province are wheat, cotton, and rice, while wheat and rice cover the most agricultural land area in India’s Punjab State. Another source of variation could be difference in the prevalence of mechanized harvesting methods, which are linked with higher rates of burning because more crop residue is left in the fields that must be cleared before planting the next crop. The spatial distribution and accompanying totals of satellite FRP observations for individual years and seasons were similar.

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25 Liu et al., 2018.

26 Agriculture Department, Government of Punjab, “Area Yield & Production of Main Crops 2012 to 2017,” undated a. Note that these statistics are for the full Punjab Province of Pakistan, not for the subset included in our analysis.

27 Agriculture Department, Government of Punjab, undated a.


29 Data not shown but available upon request.
Atmospheric Trajectory Analysis

Based on our temporal analysis of fire activity (Figure 3.2), we examined atmospheric forward trajectories for each year in our 2010–2014 period. This analysis included the premonsoon season (April to May) in both Pakistan and India and postmonsoon season (October
to November) in India, as there was negligible burning detected by MODIS in Pakistan in this season. (The spring meteorology was unavailable for 2010, and this season was not included in our results.)

For the spring season, we determined the date of peak fire activity from the MODIS FRP analysis. We then selected three separate locations in Pakistan and India that corresponded to the highest levels of fire activity for each region at this time of peak burning and examined the forward transport of fire emissions from these source regions (Figure 3.3). This analysis shows that the 48-hour atmospheric trajectories from source regions follow variable pathways that include transboundary transport of fire emissions. For all years combined, an approximately equal percentage of the atmospheric pathways that originate from the Pakistani Punjab maximum burning region affect both India and Pakistan, whereas only 20 percent of pathways that originate from the Indian Punjab State maximum burning region cross into Pakistan; nearly 80 percent stay within India.

![Figure 3.3. Atmospheric Trajectories of Air Parcels from Pakistan (left) and India (right) in Peak Spring Burning Seasons, 2010–2014](image)

**Figure 3.3. Atmospheric Trajectories of Air Parcels from Pakistan (left) and India (right) in Peak Spring Burning Seasons, 2010–2014**

NOTE: Orange shading indicates portions of trajectories that cross into Pakistan; blue shading indicates portions of trajectories that cross into India. Red stars denote source regions.

For the analysis of the postmonsoon season, we focused on India only, as there was negligible fire activity in Pakistan during this period. We set a suite of starting locations as the source regions for the HYSPLIT model trajectory analysis since fire activity was widespread. Using the peak burning date from each year in our 2010–2014 study period, we then ran 48-hour forward trajectories from the source region. Multiple trajectories show that this pollution was transported to the southeast of the source region but did not cross the border with Pakistan.
Across all years, only a small portion of the atmospheric trajectories (less than 10 percent) crossed the border into Pakistan (Figure 3.4).

**Figure 3.4. Atmospheric Trajectories of Air Parcels from India’s Punjab Region in Peak Fall Burning Seasons, 2010–2014**

NOTE: Orange shading indicates portions of trajectories that cross into Pakistan; blue shading indicates portions of trajectories that cross into India. Red star denotes source region.

**Transboundary Pollution Contributions**

In contrast to the forward trajectory analysis explored in the previous section, which shows the transport pathways from source regions, backward trajectories are useful for examining the sources of pollution arriving at a given point location. For this part of the analysis, we focused on the cities of Lahore, Pakistan, and Amritsar, India, which are both close to the border. We found that for both seasons, atmospheric pathways that arrive in each city are a mix of within country and transboundary locations (see Appendix B).

**Conclusions**

This analysis reveals several key features of crop residue burning contributions to transboundary pollution in the India-Pakistan border region. In the premonsoon burning season (April to May), fire activity is observed at more comparable levels in both India and Pakistan’s Punjab regions. Atmospheric transport analysis suggests that pollution from each source region contributes to air pollution both within countries and across the border. In the postmonsoon burning season (October to November) when pollution levels are highest, agricultural burning is almost entirely focused in India’s Punjab State, according to the MODIS FRP record. Transport pathways indicate that this pollution flows primarily to the southeast, where it affects air pollution in other regions of India, but it generally does not cross the border to Pakistan.
However, if burning were to increase in Pakistan during this season, this could have implications for transboundary pollution transport, given the predominant atmospheric transport pathways toward the southeast.

Future analysis could contribute to our understanding of the transboundary impacts of air pollution in several ways. First, the satellite FRP detections from MODIS offer observations for an extended time period, but at a 1-km spatial resolution. Higher-resolution observations from new satellites, such as the Visible Infrared Imaging Radiometer Suite (VIIRS) available at 375-m spatial resolution, could be useful in detecting additional small fires that may be missed by MODIS.30 Second, the HYSPLIT atmospheric trajectory analysis is a useful tool for understanding the potential transport of emissions from source to receptor regions. Future work could couple the fire emissions analysis presented here with high-resolution atmospheric transport models, such as the GEOS-Chem chemical transport model, to quantify the relative contribution to pollution across the India-Pakistan border of fire emissions, compared with other sources of emissions. Finally, changing trends in land use or climate were outside the scope of this study. Changes in agricultural practices, along with the implications of changing climate on agricultural production and atmospheric transport pathways, could impact some of the relationships described in this work.

4. Policy Implications and Future Work

Environmental resources do not know national boundaries, and nations often must learn to work together to share these resources. For some nations, this could be an underlying and persistent irritant—for others, the source of successful and long-term cooperation. While water and air management across the India-Pakistan border could remain stressors on the relationship between the two nations, transboundary management could also evolve to offer opportunities for collaboration at both national and subnational levels. In this chapter, we offer insights from this study on our findings, possibilities for future work that could inform coordinated management, implications for the role of the international community, and other models of transboundary cooperation on water and air resources.

**Water**

Our research underscores the importance of the IWT as a framework to guide management and infrastructure development decisions and as a key path for mediation between India and Pakistan. The IWT has enabled ongoing communication between the two nations since its signing in 1960. These communications have not always been easy, particularly when geopolitical tensions between the two countries have aggravated water issues. Mediation of disagreements over water management via neutral experts and third-party international organizations, such as the World Bank, has been shown to move discussions and decisions along to the benefit of both nations.

Ongoing polarized disputes over the development of hydroelectric projects also demonstrate that impartial science and analysis could support technically sound decisionmaking between India and Pakistan and would shed important light on the true impact of Indian hydroelectric projects on downstream flows into Pakistan. Our analysis is a first step in that direction. We examined the potential impacts that planned hydroelectric projects along the Chenab River in India may have on the downstream flow regime in Pakistan. Our results showed that during low flow years, hydroelectric projects may have a higher potential for controlling downstream flow.

However, the full timing and magnitude of this control needs further investigation and requires higher-resolution streamflow data, information on reservoir operations, and project-specific hydrologic analysis. Such research would require support from the international community and both India’s and Pakistan’s participation. It would also necessitate ongoing and transparent data collection and data sharing efforts that could inform further research and support more collaborative transboundary water management between India and Pakistan. A more rigorous research approach would include tributary and stream specific analyses and consider the contributions of individual hydroelectric projects to the more directly impacted portion of a river,
rather than the river as a whole. These approaches require information on the operational rules of individual facilities and would depend upon the availability of high-resolution information. Daily streamflow data would be critical to any study that examines the flood control characteristics of hydroelectric facilities, and monthly (or at a minimum) seasonal streamflow data would be needed to understand how these facilities could impact water availability for downstream irrigation demands. Future work should also directly consider the combined impacts of both climate change and hydroelectric facilities on the DOR of the region’s river systems. Because a high percentage of baseflow in the Chenab River, and the IRB as a whole, is derived from snowmelt, the impact of hydroelectric projects could be more significant as glaciers recede and baseflow declines.

Climate change also emphasizes the growing need for more coordinated management, possibly beyond the bounds of the IWT. The IWT was signed nearly six decades ago under a different climate. Under the IWT, water allocations and storage apportionments are based upon an average historical year, but drought and glacial recession might eventually lower water availability below the water quantities allocated under the IWT. In such futures, India and Pakistan would need to work together to ensure that transboundary water management is coordinated to the maximum long-term benefit of the people and environment of both nations. Steps toward more collaborative management in the short term could prepare India and Pakistan to adapt to climate change before water shortages occur.

Despite these challenges, a final key policy implication of this work is that both parties should continue to uphold the IWT. The IWT remains a cornerstone in India-Pakistan relations and the foundational document governing infrastructure development along and use of water in the IRB, but Indian policymakers have hinted at possibly revoking the treaty. Michael Kugelman outlined in 2016 why India should refrain from revocation of the treaty. First, revoking the IWT would be met with “intense international opposition,” as it is widely regarded as “an international success story of transboundary water management.” Second, interrupting water flow to Pakistan could set a dangerous precedent for Pakistan’s ally, China, to consider suspension of waters of the Brahmaputra, upon which India depends. In 2016, China blocked a tributary of the Brahmaputra that flows from Tibet into India; while China maintains it was to build a dam, Indian media opined that China might be attempting to send a message to New Delhi about allowing free flow of water to Pakistan. Finally, an Indian decision to stifle water flow to Pakistan could inspire or provoke Lashkar-e-Taiba, the group responsible for the 2008 Mumbai attacks, to conduct additional attacks.¹

The signing of the IWT in 1960 was, as President Dwight D. Eisenhower said at the time, “one bright spot . . . in a very depressing world picture.”² Now 115 meetings of its council later,

in spite of ongoing tensions between New Delhi and Islamabad and multiple perturbations and complaints about water, the IWT remains a “bright spot” in bilateral relations specifically because India and Pakistan continue to talk about water, rather than fight over it. The United States and the international community should continue to encourage India and Pakistan to discuss rather than fight over their differences but should seek to provide as much data as possible to undergird informed, objective analysis of the issues. This report seeks to provide some of that analysis.

Air

Based on an examination of satellite FRP detections of crop residue burning and atmospheric transport patterns, our results suggest that neither country is entirely responsible for transboundary pollution. In certain seasons, such as the postmonsoon crop residue burning period when air pollution levels are typically highest, most of the smoke is caused by crop residue burning in India’s, rather than Pakistan’s, Punjab region. However, it mostly sweeps away from Pakistan and into the IGP, where it affects Indian cities. We note that there are some variations from year to year, depending on the timing of peak burning and prevailing wind patterns. Further, increased levels of burning in Pakistan during this season could contribute to transboundary pollution transport. In contrast, in the premonsoon burning season, air pollution levels are typically lower, and the magnitude of burning between each country is more comparable; the transboundary transport of smoke at the border is mixed within each country and across the border.

Future scientific analyses are needed to further explore the complex dynamics associated with transboundary impacts of air pollution. We focused on satellite FRP detections from MODIS, which offer a relatively long time period of observations (since 2000), but at a somewhat coarse 1-km spatial resolution. We used this data set in this preliminary analysis because FRP is a better proxy for emissions than fire counts or burned area. However, this analysis could be supported by additional observations available from more recently launched satellites that can monitor fire activity at a finer spatial resolution. Although available for a shorter time period, these data sets might be better suited to capturing the contributions of crop residue burning on smaller farms, which may indicate different patterns on either side of the border. Second, the atmospheric trajectory analysis used in this report focused on periods of peak agricultural residue burning only. Future analysis with chemical transport models could expand the analysis to include a wider temporal range and better quantify the contributions of other emissions sources to transboundary air pollution. Finally, future work could consider the impact of changes in land use, agricultural practices, and atmospheric transport pathways on the dynamics explored in this work.
While the drivers and effects of crop residue burning on air pollution are similar in the Punjab regions of both countries, there is not yet a coordinated response to reduce burning. As explained by Singh and Kaskaoutis,

> Both India and Pakistan rely on farms in Punjab—farms quickly harvested by combines—to feed their burgeoning populations, and manual harvesting may not offer the same yields. Further, for any change in practice to manifest into a change in pollution levels, both countries would need work to solve the problem because air cannot be confined within national borders.³

Furthermore, there is no air quality treaty between India and Pakistan under which arbitration could be sought.⁴ “Environmental standards and climate change issues are new nontraditional security threats,” said Hina Lotia, the director of programs at Leadership for Environment and Development Pakistan, an Islamabad-based think tank. “These issues are not any less important than the traditional disputes and differences that bedevil our relationship.”⁵ In response to Pakistan’s suggestion that the atmospheric pollution could be addressed by India and Pakistan under the South Asian Association for Regional Cooperation framework, India’s Ministry of External Affairs spokesman said that the meeting could happen only if “one country” stops providing an enabling environment to terrorism and suggested that India would continue to withhold discussions on air quality until Pakistan created a “conducive environment” which is “free of terrorism and free of terrorists getting support from Pakistan.”⁶

In response to recent severe air pollution episodes that coincided with agricultural burning seasons, both countries are exploring policy options to reduce the incidence of fires and improve air quality. India’s Ministry of Agriculture released a National Policy for Management of Crop Residues in November 2014.⁷ The National Policy for Management of Crop Residues includes objectives to control crop residue by promoting alternative management strategies (such as use by livestock or incorporating into soil), energy production, education campaigns on the harmful impacts of crop residue burning, and developing and implementing legal policies to reduce burning. However, the policy notes that agricultural policy is delegated to state governments, which will need to develop their own strategies and enforcement mechanisms to ban crop residue burning.

The National Green Tribunal, India’s environmental court, advised the government to stop farmers from burning crop residue, but without funding to subsidize new technologies, farmers

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⁵ Kay and Marlow, 2017.


often cannot afford alternatives to burning. For example, the Happy Seeder machine simultaneously disposes of crop residue and plants new crops, but the cost (approximately $2,000) is an unrealistic purchase for most farmers, who make an equivalent amount from their entire harvest. Government subsidies are not widespread, and the cost of implementation across the Punjab State is an estimated $1.5 billion. Other alternatives, such as using crop residue to generate power, would need to be scaled up to become feasible for many farmers.

Pakistan also has crop burning and antipollution policies in place but little air quality monitoring data to monitor compliance. Community members have tried to release data on air quality concentrations to make the public more aware of the problem and to motivate policy changes.

In October 2017, Punjab’s provincial government in Pakistan released a policy on controlling smog. The policy notes that, while studies have linked the pollution to crop residue burning in northwestern India, local sources have also contributed to the pollution. The policy directive points to near-term actions, such as satellite monitoring of crop residue burning in the Punjab and enforcement of a ban on open burning, in addition to public health advisories to limit harmful impacts of pollution exposure on local populations. Longer-term solutions included reducing emissions from open burning through education programs and alternative technologies, reducing emissions from other sources (such as transportation, dust, and urban development), and improving the capacity to monitor and forecast high air pollution events. Critically, the policy directive also highlights the regional nature of the air pollution as an environmental health issue and particularly emphasizes the need for a regional approach to solutions:

Smog being a regional problem cannot be effectively controlled by eliminating local sources of pollution alone. Comprehensive solution to this and other environmental problems such as contamination of water bodies flowing into the Punjab from across eastern borders requires a cooperative approach at the regional level. For this purpose, Federal Government will be approached to put environmental concerns on agenda of bilateral and multilateral dialogues between India and Pakistan. Although this may prove to be slow and difficult process, there is no way to save environment in the Punjab without such a collaborative agreement. A good example on regional environmental cooperation

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11 “Pakistan Air Quality Initiative,” Facebook group, undated.
12 Government of the Punjab, Environment Protection Department, 2017.
is the “Agreement on Transboundary Haze Pollution” concluded between ten ASEAN countries in 2002.13

This passage points to transboundary pollution in other parts of the world, noting the regional approaches by the Association of Southeast Asian Nations to reduce the impact of fires associated with land clearance and agricultural maintenance activities in Indonesia on regional haze across Indonesia, Malaysia, and Singapore. It also highlights the similarities with finding effective solutions to environmental issues that are transboundary in nature, noting the need for cooperation on both air and water resource management.

Coordinated Transboundary Management

While this research describes the heightened tension between India and Pakistan over its shared air and water resources, the results of the analysis also underscore just how interconnected and interdependent the two countries are. The management of air, land, and water resources should be looked to as an opportunity for collaborative rather than siloed management. Certainly, the success and long-lasting nature of the IWT suggests that coordinated environmental management is possible. Further transboundary coordination on water management and agricultural water use, cropping and burning practices, and the use and location of hydroelectric projects could amplify the benefits of management interventions. On the water side, coordinated management during high flow events could limit the magnitude of downstream flooding on Pakistan and provide more stable water and energy sources for India because of enhanced storage capacity in flood control reservoirs. To mitigate the negative impacts of agricultural residue burning on air quality, India and Pakistan could coordinate with an early warning system that alerts citizens to high levels of fire activity and pollution. This could also incorporate recommendations to for governments or individuals to reduce pollution exposure, such as the use of air filtration devices or the creation of additional provisions for vulnerable segments of the population. Furthermore, agreements or collaboration on agricultural management practices could alleviate stress on both air quality and water resources.

The problems faced by India and Pakistan are not unique, and solutions attempted in other parts of the world could be used as a model to improve air quality and water availability in India and Pakistan. Box 4.1 provides an overview of transboundary cooperative arrangements and agreements that could serve as models for India and Pakistan. While these examples detail collaborations at the national scale, transboundary coordination could focus instead on coordinated solutions by regional governments in India and Pakistan.14 More research on relevant subnational transboundary cooperation could provide alternative models for the two nations.

Box 4.1. Other Models of Transboundary Cooperation

India and Pakistan are not the only nations that face challenges of transboundary environmental management of shared water resources and air pollution from fires. In response to growing demands on water resources and energy supply from India and the potential for using water resources to spur economic development in Bhutan, India and Bhutan embarked on a collaborative approach to hydropower development and water management in the 1980s. India helped finance hydropower projects in upstream Bhutan in return for the right to purchase excess electricity generated at an agreed-upon rate. Since then, ongoing shared hydropower and water management of the tributaries and rivers that run from Bhutan into India to become the Brahmaputra River have generated economic growth for Bhutan—hydropower constitutes 12 percent of Bhutan’s gross domestic product, with India as its main trading partner—and ongoing energy and water supply for downstream India.

There are also several examples of collaborative efforts to address regional air pollution from fires. The United States and Canada have faced transboundary air pollution issues from fires, with smoke from wildfires in British Columbia recently causing hazardous air quality across the border in Seattle and other cities. The United States and Canada already have an established framework to address air pollution issues—in 1991, both countries committed to the U.S.–Canada Air Quality Agreement. This agreement, originally developed to address acid rain, promotes emissions reductions strategies, scientific and technical collaboration between the two countries, information exchange, mitigation measures to control transboundary pollution, and regular progress assessments. The scope has been expanded and now includes PM$_{2.5}$ pollution, recognizes wildfires as a growing source of transboundary pollution, and supports joint air pollution modeling activities to better monitor the impacts of transboundary air pollution in a regional context. Examples such as these can serve as models for how India and Pakistan could develop a formal framework for reducing air pollution in order to reduce the negative impacts of future fires.

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*b* Biswas, 2011.


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Coordinated management also suggests the need for more readily available data and information sharing between the two neighbors. Memoranda of understanding or agreement are frequently used to facilitate and encourage regular information sharing between agencies, levels of government, or international partners. This could be a first step for India and Pakistan toward information sharing on air and water resources. An alternative option would be the sharing of
information through a neutral party. Armed with accurate data, U.S. or international diplomats would also be able to share with Indian and Pakistani policymakers and media and report on, for example, the actual extent of air pollution because of burning practices or flows downstream of Indian hydroelectric projects.

The transboundary water and air issues considered in this report are only two of a host of complex and interconnected environmental challenges that India and Pakistan jointly face. Research is needed to understand and quantify the impacts on climate change, including shifting monsoon patterns, receding glaciers, and increased temperatures, on these regional partners. Groundwater resources are also shared between India and Pakistan. Satellite-based analysis could be used to quantify the degree of exploitation of shared groundwater systems, and modeling and hydrologic studies could be performed to better characterize the interconnectivity of the two nations’ regional aquifers. Finally, the two transboundary environmental issues examined in this report are perhaps most strongly connected through their relationship with agricultural production and the food security of each country. When considered from this perspective, policy options can consider how agricultural practices can better influence both air and water resources. For example, shifting to new crop varieties that reduce water demand, while also supporting the clearing of agricultural fields between harvests without burning, could have co-benefits for the provision of water and air across borders and ease the tension between the two countries. Improved management of these resources would benefit the health and economic well-being of the citizens of India and Pakistan and provide an opportunity for these countries to work on a common problem, toward a common goal.
Appendix A. Geopolitical Context

These environmental complexities should be viewed in the context of current and historical relations between the two countries. The modern nation-states of India and Pakistan have fought three full-scale wars (1947–1948, 1965, and 1971) in their brief postindependence history and engaged in several contests (like the Kargil Conflict of 1999) that might be described as limited wars or large-scale military encounters. Their national geopolitical rivalry represents each nation’s most urgent security challenge for the immediate term, and likely for several decades to come.

The principal point of contention since 1947 has been control of the divided preindependence princely state of Jammu and Kashmir. India claims the entire state but currently controls Jammu, the Kashmir Valley, and Ladakh. Pakistan refutes India’s claim and controls Azad Kashmir and Gilgit-Baltistan.¹

Both nations have historically supported insurgencies inside the others’ territories, both openly accuse the other of covertly sponsoring subversive elements, and both continue to accuse each other of supporting terrorism in general—India denouncing specific terrorist attacks in its territory and Pakistan accusing India of using oppressive “state terrorism” to break the will of the Kashmiri people.²

The United Nations Military Observers Group in India and Pakistan (UNMOGIP), the organization that, since 1949, has observed developments pertaining to the strict observance of the ceasefire, observes and reports on exchanges of fire to the Secretary General. The armies and paramilitaries of Pakistan and India have routinely exchanged artillery, mortar, missile, and machine gun fire at intensity levels that outside observers might perceive, and have sometimes perceived, could lead to a full-blown war. The effects of this violence are not limited to the two militaries. Media on both sides of the border routinely report civilian casualties in border villages, schools, and neighboring fields caused by indirect shelling and direct fire from the other side. In addition, 11 UNMOGIP observers have died observing the ceasefire since 1949.³

Finally, Indian and Pakistani media routinely report on stories and accusations of kidnappings, abductions and murders of each other’s active and retired service members by the

¹ A small portion of Kashmir is controlled by China, given by Pakistan in what India considers an illegal transfer. It includes extensive uninhabited areas in the Aksai Chin region and the Shaksgam Valley.
other’s army, intelligence services, or proxies. Pakistan and India also accuse each other of sending spies into their countries to conduct espionage, resulting in an ongoing cycle of accusations and tit-for-tat expulsions of diplomats that reduce the two nations’ ability to negotiate and further stress the already strained relationship.⁴

Attempts at Negotiating

This narrative is not to suggest that Pakistan and India have never tried to find peace. On the contrary, their relationship is dotted by both minor and major attempts and successes at building trust and confidence, albeit sometimes with the help of outside assistance or mediation. National leaders, military representatives and diplomats have met frequently throughout their shared history, and while many talks or “summits” resulted in no formal agreement or improvement in relations, many resulted in actual treaties signed by both nations (see Table A.1), although lasting impacts have varied.

Table A.1. Treaties Signed Between India and Pakistan Since 1947

<table>
<thead>
<tr>
<th>Year</th>
<th>Agreement</th>
<th>Purpose</th>
<th>Signatories</th>
<th>Mediator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949</td>
<td>Karachi Agreement</td>
<td>Served as the cease-fire agreement for the 1947–1948 war; delineated the cease-fire line.</td>
<td>Military representatives of India and Pakistan</td>
<td>United Nations Commission for India and Pakistan</td>
</tr>
<tr>
<td>1950</td>
<td>Liaquat-Nehru Pact</td>
<td>Treaty to guarantee the safe return of properties of refugees and the rights of minorities; meant to avert another war</td>
<td>Prime Ministers Liaquat Ali Khan (Pakistan) and Jawaharlal Nehru (India)</td>
<td>Bilateral agreement</td>
</tr>
<tr>
<td>1960</td>
<td>Indus Water Treaty</td>
<td>Water distribution treaty that governs the rights to the waters of the shared portions of the Indus River basin</td>
<td>President Ayub Khan (Pakistan) and Prime Minister Jawaharlal Nehru (India)</td>
<td>David Lilienthal (representing the World Bank)</td>
</tr>
<tr>
<td>1966</td>
<td>Tashkent Declaration</td>
<td>Agreement to withdraw military forces to pre-August 1965 lines and to restore economic and diplomatic relations</td>
<td>President Ayub Khan (Pakistan) and Prime Minister Lal Bahadur Shastri (India)</td>
<td>Prime Minister of the Soviet Union Alexei Kosygin</td>
</tr>
<tr>
<td>1972</td>
<td>Simla Agreement</td>
<td>Ended the war, converted the 1971 cease-fire line to the Line of Control, and outlined principles to govern future bilateral relations</td>
<td>President Zulfiqar Ali Bhutto (Pakistan) and Prime Minister Indira Gandhi (India)</td>
<td>Bilateral agreement</td>
</tr>
<tr>
<td>1973</td>
<td>Delhi Agreement</td>
<td>Allowed the repatriation of prisoners of war and jailed officials</td>
<td>Signed by India, Pakistan, and Bangladesh, but ratified by only India and Pakistan</td>
<td>Trilateral agreement</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Agreements</th>
<th>Description</th>
<th>Prime Ministers</th>
<th>Bilateral agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>Non-Nuclear Aggression Agreement</td>
<td>Agreement to reduce and limit nuclear arms and refrain from attacking or assisting foreign powers to attack each other's nuclear installations and facilities</td>
<td>Prime Ministers Benazir Bhutto (Pakistan) and Rajiv Gandhi (India)</td>
<td>Bilateral agreement</td>
</tr>
<tr>
<td>1999</td>
<td>Lahore Declaration</td>
<td>Articulates mutual understanding of development of nuclear arsenals and unauthorized use of nuclear weapons</td>
<td>Prime Ministers Nawaz Sharif (Pakistan) and Atal Bihari Vajpayee (India)</td>
<td>Bilateral agreement</td>
</tr>
</tbody>
</table>
Appendix B. Atmospheric Back Trajectory Analysis

For the back trajectory analysis, we focused on two cities close to the border: Lahore, Pakistan, and Amritsar, India. Lahore had 11.1 million residents as of the 2017 census,¹ and its mean annual PM$_{2.5}$ concentration was 68 $\mu$g/m$^3$ in 2010.² Amritsar had 1.1 million residents as of the 2011 census,³ and its mean annual PM$_{2.5}$ in Amritsar was 108 $\mu$g/m$^3$ in 2012.⁴ We then explored the potential contribution of source regions on each side of the border to air pollution in Amritsar and Lahore for the premonsoon (spring) and postmonsoon (fall) burning. This analysis illustrates that each city is impacted by within-country and transboundary pollution, and that this effect holds in both the spring and fall seasons.

⁴ World Health Organization, 2018; for reference, the World Health Organization air quality guideline is 10 $\mu$g/m$^3$ for annual PM$_{2.5}$ concentrations; concentrations in each city are an order of magnitude above this air quality guideline.
Figure B.1. Atmospheric Back Trajectories for Amritsar, India, and Lahore, Pakistan, 2010–2014

Amritsar (Spring)      Amritsar (Fall)

Lahore (Spring)      Lahore (Fall)

NOTE: Orange shading indicates portions of trajectories that cross Pakistan before reaching each city; blue shading indicates portions of trajectories that cross India. Black stars denote source regions.


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