Case Study

Pakistan's Water Apportionment Accord of 1991: 25 Years and Beyond

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Abstract: The apportionment of waters of the Indus River System between the provinces of Pakistan is widely hailed as a historic agreement. This agreement (herein referred to as the Accord) was signed into effect in 1991, just over 25 years ago. The Accord lacks a clearly stated objective and hence it is difficult to review the Accord against its objective. This paper presents a detailed thematic review of the Accord and interprets the literature and data sets that have become available over the last 25 years. Although the Accord leaves room for interpretation, which is often biased to a particular perspective, an obvious starting point that has been highlighted in the literature is to improve water accounting in the Indus basin and to clarify and document the Operating Rules. Over the next 25 years, demographic change, socioeconomic change, and climate change in the Indus Basin will place this Accord under increased scrutiny. **DOI: 10.1061/(ASCE)WR.1943-5452.0000831.**

Background

The Islamic Republic of Pakistan is a federal parliamentary republic in South Asia and home to the sixth largest population in the world. The administrative units of the country consist of four provinces—the Punjab, Sindh, Khyber Pakhtunkhwa, and Baluchistan; a capital territory; federally administered tribal areas and autonomous areas of Gilgit-Baltistan; and Azad Jammu and Kashmir, which are disputed with India. Pakistan's principal natural resources are arable land and water, which makes the agricultural sector a significant part of the economy. The agricultural sector, which includes crops, livestock, fisheries, and forestry, accounted for 19.8% of the gross domestic product (GDP) in 2015–2016 and is a source of livelihood for 42.3% of Pakistan's labor force (Government of Pakistan 2016). Approximately 27% of Pakistan's land area is cultivated. Of this cultivated land, the highest proportion is in the province of Punjab (63%), followed by Sindh (18%), with the remainder roughly equally divided between the provinces of Khyber Pakhtunkhwa and Baluchistan (ACO 2010). This earns Punjab its reputation as the breadbasket of Pakistan.

The sustainability of water resources in Pakistan is challenged by many drivers that are extensively reported in the literature (Briscoe and Qamar 2005; Mustafa et al. 2013; Ringler and Anwar 2013; Immerzeel et al. 2010). Pakistan is already a water-stressed country, and its growing population, the primary driver of change, is projected to reach between 238 and 314 million by 2050 (UN Population Division 2012). This in turn has led to rapid urbanization, degradation of the water environment including groundwater depletion, deterioration of water quality, and growing intersectoral competition for water. There remains uncertainty around the exact impact of climate change on inflows into the Indus Basin (Archer et al. 2010; Yu et al. 2013; Condon et al. 2014). Shiekh et al. (2009) reported increasing temperature and precipitation over Pakistan, although there were significant spatial variations. Rees and Collins (2005) and Briscoe and Qamar (2005) summarized expectations of severely reduced water resources due to climate change. Archer et al. (2010), citing Rees and Collins (2005), concluded that runoff will initially increase but, with decreasing glacier mass, will ultimately fall sharply. As aptly summarized by Briscoe and Qamar (2005), "there is no feasible intervention which would enable Pakistan to mobilize appreciably more water than it now uses." Hence the only realistic prospect is better management of the limited water resources.

The use and allocation of water within the Indus basin is heavily affected by the institutions and policies that prevail at the international level, as well as at provincial scales (Yang et al. 2014). Water conflicts between the provinces of Pakistan predate the 1947 partition of India and are a classic example upstream-downstream conflict (IUCN 2010). After 1947, irrigation water was allocated among the provinces through informal, ad hoc arrangements. A number of commissions and committees eventually led to the apportionment of waters of the Indus River System between the Provinces of Pakistan in 1991 (Yang et al. 2014), herein referred to as the Accord. The Accord is a consensus document rather than a law such as the Colorado River Compact (CRC 1922) or the Water Act (Australian Government 2007)—the latter contains the allocation plan for the Murray-Darling River. The Accord consists of 14 clauses and 8 appendixes, signed by the highest officer of each of the four provinces of Pakistan and ratified by the Prime Minister. The Indus River System Authority (IRSA) was established through an Act of Parliament (Government of Pakistan 1992) with the responsibility of implementing the Accord. Although the IRSA Act No. XXII of 1992 makes reference to the Accord, the Accord itself is not an Act of Parliament. The Act explicitly states the role of the IRSA: "Whereas it is expedient to establish the Indus River System Authority for regulating and monitoring the distribution of water sources of Indus River in accordance with the Water Accord" (Government of Pakistan 1992).

The IRSA has representation from all four provinces and the federal government. As of 2003, the IRSA has used Operating

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Rules referred to as the Three-Tier Formula (Khan 2011). Under Article 155 of the Constitution of Pakistan, any complaints about interference with water supplies can be raised with the Council of Common Interest (CCI). The CCI works under the Ministry of Inter Provincial Coordination, and its membership consists of the Prime Minister, four provincial Chief Ministers, and three members to be nominated by Prime Minister (usually cabinet members).

The Accord was signed on March 21, 1991, and hence 2016 marked 25 years. At the time of its signing it was claimed that the "Accord removes the biggest hurdle in the way of national unity and cohesion" (IRSA 2016). However, a number of issues remain unresolved and at times contentious (Sharif 2003). The Friends of Democratic Pakistan (FODP 2012) is of the opinion that "improving the implementation of the 1991 Water Accord is the first institutional measure to take to reduce conflict over much-needed major water infrastructure." The context and dynamics of water-related challenges have changed much since the signing of the Accord. This paper revisits the Accord, examining the diverse views, interpretations, and implementation in order to understand where there is agreement and where there is conflict and the causes of the conflict. This paper looks at the additional knowledge of water apportionment and the data that have become available over the last 25 and how that may inform discussions about and improve management of the Indus Basin. The scope of this research is limited to the Accord itself and does not analyze the institution of the Indus River System Authority or the IRSA Act (Government of Pakistan 1992).

Materials and Methods

This paper reviews the Accord through the thematic structure suggested by Speed et al. (2013). The research draws heavily on the Accord (IRSA 2016) and publicly available data sets shared by the IRSA for the analysis. This paper also draws on the literature (published and unpublished) to present the opinion of water experts, provinces, and other stakeholders on the interpretation and implementation of the Accord.

Analysis and Discussion

Objective of the Accord

The Accord does not have a clearly stated objective. As noted by Speed et al. (2013), explicit objectives are important when interpreting certain provisions and also when reviewing an allocation plan to determine if it is achieving its objectives. A communique issued by the Ministry of Information of the Government of Pakistan (IRSA 2016) after the Accord was ratified provided some insight into the challenges that the Accord was to overcome, namely

- Lack of development of water resources;
- Suboptimal use of additional water made available after construction of the Tarbela reservoir;
- Unrealized economic opportunities; and
- Unrealized employment opportunities.

Overcoming these challenges can be interpreted as an objective of the Accord. Furthermore, the Accord lacks a glossary/definition of terms and terminology, which is often the cause of the varied interpretation of the document. Speed et al. (2013) provided a cautionary note on terminology that any water allocation plan should heed.

Water Resources Subject to the Accord

The first clause of the Accord makes reference to the water resources covered as "Waters of the Indus River System." There is no clarity on the geographic limits of the Waters of the Indus River System and/or whether this includes surface water and/or groundwater. There is an implicit understanding that Waters of the Indus River System encompass the water that flows past a set of gauging stations on the periphery of the Indus River System (known colloquially as the rim stations) and furthermore includes only surface water.

Allocable Water and Water Shares/Entitlements

Quantity of Water

The Accord tabulates the apportioned volumes, reproduced in SI units in Table 1. The total allocable water (herein referred to as the baseline volume) is 144.749 $Gm^3/year$ (billion $m^3/year$). The Accord is the largest intranational water allocation plan by volume, ahead of the Krishna River Basin (58.34 $Gm^3/year$) and the Yellow River Basin (58 $Gm^3/year$). By comparison. the Colorado Compact apportions 18.502 $Gm^3/year$ and the Murray-Darling Basin Plan apportions 1.212 $Gm^3/year$. The Accord itself does not provide any insight into the reliability of this baseline volume figure; however, some insight is provided in this paper. Of this baseline volume, 3.700 $Gm^3/year$ is top-sliced for the Civil Canals of the Khyber Pakthunkhwa province. The Accord makes reference to the North West Frontier Province (NWFP), which was renamed to Khyber Pakthunkhwa Province in 2010, which is the name used in this paper. The Civil Canals are irrigation canals that are managed by civil community/civil society in the Khyber Pakthunkhwa province, as opposed to the state-managed canals. This apportionment to the Civil Canals is an absolute volume, i.e., the first 3.700 Gm^3

Table 1. Apportioned Volumes ($Gm^3/Year$) from Clause 2 of the Accord

	Summer season (April–September)		Winter season (October–March)		Annual	
Province	Volume	Proportion (%)	Volume	Proportion (%)	Volume	Proportion (%)
Punjab	45.725	32.42	23.276	16.50	69.001	48.92
Sindh[a]	41.864	29.68	18.280	12.96	60.145	42.64
Khyber Pakthunkhwa non-Civil Canals	4.293	3.04	2.837	2.01	7.130	5.05
Khyber Pakthunkhwa Civil Canals[b]	2.220	—	1.480	—	3.700	—
Balochistan	3.515	2.49	1.258	0.89	4.774	3.38
Civil Canals top-sliced volume	2.220	—	1.480	—	3.700	—
Apportioned baseline volume	95.397	67.63	45.651	32.37	141.049	100.00
Baseline volume	97.618	—	47.131	—	144.749	—

[a]Including already sanctioned Urban and Industrial uses for Metropolitan Karachi.
[b]Ungauged Civil Canals above the rim stations.

of water is allocated to the Khyber Pakthunkhwa Civil Canals. This does set a precedent for top-slicing a specific volume of water for a particular purpose, but is the only example of top-slicing in the Accord. Herein also lies a slight contradiction. The footnote to Table 1 specifies (reproduced verbatim) that this 3.700 $Gm^3/year$ is for canals above the rim stations, i.e., outside of the presumed limits of the Waters of the Indus River System. If these canals abstract water outside of the water resources subject to the Accord, their inclusion in the Accord is contradictory.

The apportioned baseline volume is the baseline volume net of the apportionment to the Civil Canals, 141.049 $Gm^3/year$. This apportioned baseline volume is then disaggregated spatially over the four provinces of Pakistan and temporally over the summer and winter seasons. Of note is that only the four provinces are apportioned water. The federal capital, federally administered tribal areas, and autonomous areas receive no apportionment. Spatially, the province of Punjab receives the largest apportionment, 48.92%, followed by the province of Sindh. Similarly, when the apportioned baseline volume of 141.049 $Gm^3/year$ is disaggregated by the two seasons, approximately two-thirds is apportioned for the summer season and one-third for the winter season. The Accord itself presents the apportionment in absolute volumes only. The proportions in Table 1 are presented for the purposes of this discussion and are reported as a proportion of the allocated baseline volume of 141.049 $Gm^3/year$.

Although Table 1 is central to the Accord, it is also the starting point of discord. The province of Punjab asserts that at the time of the signing of the Accord, the installed reservoir capacity in Pakistan was 15.6 Gm^3 which has decreased over time due to sedimentation of reservoirs, notwithstanding the increase in reservoir capacity from the Mangla Dam Raising Project. The Punjab further asserts that the apportioned baseline volume is contingent upon further reservoirs being constructed and refers to the intention as specified in the Accord, and hence in the interim water should be apportioned in accordance with Clause 14(b) (the clauses are discussed in detail subsequently). The province of Sindh takes the opposite view that Table 1 is unequivocal without any caveats or conditions and without reference to the construction of additional reservoirs, and furthermore that Clauses 14(a) and 14(b) lay out the apportionment disaggregated by province and by 10-day intervals, and should be interpreted as proportions rather than absolute volumes (FODP 2012).

Level of Assurance and Reliability

Fig. 1 shows the annual volume of water for each year (defined as a winter crop season and a summer crop season from October 1 to March 31, rather than a calendar year) from 1976–1977 to 2014–2015 and the baseline volume of 144.749 $Gm^3/year$. The average inflow was 178.462 $Gm^3/year$ over this period. Condon et al. (2014) cited a comparable figure of 176 $Gm^3/year$, Hussain et al. (2011) cited 175 $Gm^3/year$, and Khan (1999) cited 180 $Gm^3/year$. Fig. 1 shows a drought period during 2000–2003. In the period since 2003–2004 the inflows have recovered, although not to the pre-1990–2000 levels. Whether this is the impact of climate change or simply a cyclical change merits further study. Table 2 shows various distributions fitted to the annual inflow data with the chi-squared, Kolmogorov–Smirnov, and Anderson–Darling tests to determine the goodness of fit. With all three goodness-of-fit tests, the lognormal distribution provides the best fit (rank $= 1$); therefore, the analysis is insensitive to the distribution selected. Using a lognormal distribution, the probability that annual volume will exceed the baseline volume is 90% (90% probability of exceedance). Seligman (2011) used a 75% probability of exceedance and a 60% probability for the Krishna River Basin. Hence for the apportionment of waters of the Indus Rivers, the Accord does follow Golden Rule 4 of Speed et al. (2013): "In stressed or fully allocated systems, a more precautionary approach to allocation should be adopted . . . care should be taken to avoid the common mistake of overestimating the amount of water available in the basin. It is easier to allocate more water at a later stage if it proves that water is available."

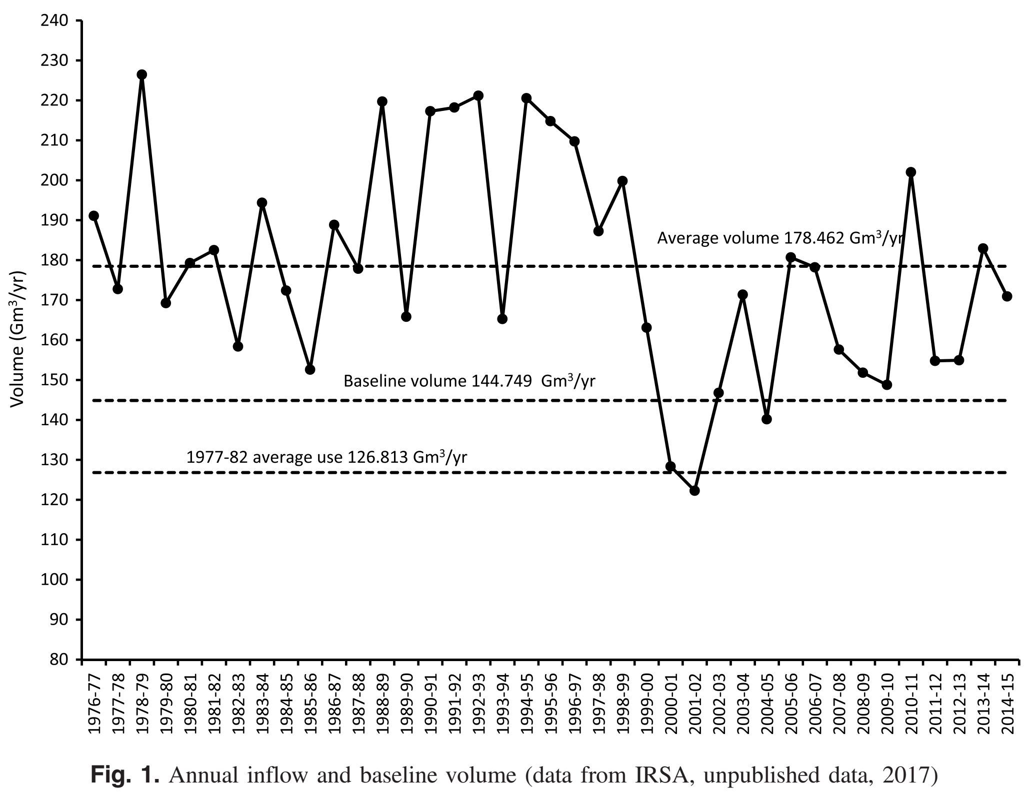

Fig. 1. Annual inflow and baseline volume (data from IRSA, unpublished data, 2017)

Table 2. Fitting Distributions to the Annual Inflow Data

Statistical test	Distribution	Statistic	Rank
Chi-squared	Lognormal	0.16292	1
	Log-Pearson 3	0.38325	2
	Normal	0.49803	3
	Lognormal (3P)	0.52700	4
	Weibull	1.02040	5
	Gumbel Max	1.20860	6
Kolmogorov–Smirnov	Lognormal	0.08153	1
	Log-Pearson 3	0.08430	2
	Normal	0.08979	5
	Lognormal (3P)	0.08855	4
	Weibull	0.11171	6
	Gumbel Max	0.08539	3
Anderson–Darling	Lognormal	0.28554	1
	Log-Pearson 3	0.30034	2
	Normal	0.36509	4
	Lognormal (3P)	0.32447	3
	Weibull	0.69801	6
	Gumbel Max	0.62995	5

Water Quality

The Accord makes no reference to water quality.

Location and Source of Water

The Accord makes no reference to locations from which the water may be taken. Rather, it is implicit in the Accord that each province (presumably defined by respective province geographic boundaries) can use the apportioned share anywhere in the province. The Accord explicitly permits the provinces to reassign water allocated to an area within the province both spatially and temporally.

Purpose for Which the Water May Be Used

The Accord does not limit provinces from developing water resources nor does it limit the purpose to which water is put within their respective allocations. The Accord does, however, require that any existing reservoirs within the Indus Basin be operated to prioritize irrigation. The Accord acknowledges "Industrial and Urban Water supplies for Metropolitan city," (sic) which is presumed to be the city of Karachi, because Karachi is explicitly mentioned in the notes to Table 1. The lack of detail or provision of an explicit allocation of water for large urban centers is problematic. With the ever-expanding urban population, water for cities is becoming an increasingly pressing issue. Sindh is home to Karachi, Pakistan's most populous city, with an estimated population of 23.5 million. Furthermore, Sindh claims Karachi is a cosmopolitan city with residents from all provinces of Pakistan, and, unlike many other cities, Karachi cannot rely on groundwater due to water quality issues. Hence Sindh feels that it is unjust to expect the urban water needs of a city as large as Karachi to be fulfilled from the apportionment of the province of Sindh. Here the example of top-slicing for Khyber Pakhtunkhwa Civil Canals is of relevance. There is a clear precedent for top-slicing, and it should be possible to make a similar provision for the large cities of Pakistan. From a Punjab perspective, however, any top slice would mean less apportionment of water for the Punjab. Furthermore, the Punjab, which hosts Lahore as its largest city, is considerably smaller, with a population of 7.5 million. Lahore is supplied with potable water entirely through groundwater. Hence for the Punjab there is no short-term gain in apportioning urban water from surface waters. A more recent development is that an apportionment has been agreed to for potable water (0.179 $\mathrm{Gm}^3/\mathrm{year}$) for the twin cities of Rawalpindi and Islamabad—the former a city in Punjab, and the latter the Federal

Table 3. Apportionment of Balance River Supplies and 1977–1982 Proportions

Province	Clause 2 (%)	Clause 4 (%)	Proportions 1977–1982 (%)
Punjab	48.92	37.00	53.06
Sindh	42.64	37.00	42.37
Khyber Pakthunkhwa	5.05	14.00	2.98
Balochistan	3.38	12.00	1.59

Capital of Pakistan (The News 2016). In this recent development, all four provinces have forsaken a fraction of their apportionment. Each province has agreed to contribute toward this 0.179 $\mathrm{Gm}^3/\mathrm{year}$ in proportions given in the Clause 4 column of Table 3. This means that whereas under the Clause 2 column of Table 3 the Punjab has the largest apportionment (48.92%), forsaking water in the proportions specified in Clause 4 leaves the Punjab the best off (forsakes 37%). Sindh is apportioned 42.64% but forsakes the same 37%. This again creates discord between Punjab and Sindh.

Annual Allocation Rules

The Accord does not define the process for calculating how much water will be available to or has been used by the provinces. Rather, the Accord stipulated that a new institution the Indus River System Authority (IRSA) would be created "for the implementation of this Accord." This institution was created through the IRSA Act, 1992, and it has established a process of estimating flows; however, these estimates are not publicly available.

The Accord does deal explicitly with variability, stating "Balance River supplies (including flood supplies and future storages shall be distributed as below," which is transposed in the Clause 4 column of Table 3. Because there is no definition of terminology in the Accord, the term balance in this clause is subject to interpretation. This is typically interpreted as the volume of water available in excess of the apportioned baseline volume of 144.749 $\mathrm{Gm}^3/\mathrm{year}$. The Punjab often cites the allocation of "balance river supplies" as an example of magnanimity because balance water is apportioned to the Punjab at 37% as opposed to 48.92%, a decrease of 11.92%. For Sindh, balance water is also apportioned at 37%, as opposed to 42.64%, a decrease of only 5.64%. Hence the Punjab uses this argument that for any balance supplies, including any that become available from further reservoirs constructed, the Sindh has more to gain than the Punjab and that it is more in Sindh's interest than the Punjab's for the nation to embark upon the construction of new reservoirs. The Accord also states that "shortages and surpluses" will be accommodated by adjusting allocations pro rata. Unfortunately, there is no definition for the terms shortages or surpluses; how surplus differs from balance also is ambiguous. Furthermore, if surpluses are adjusted pro rata using the Clause 2 column of Table 3, this will lead to a different allocation than if balances are adjusted using the Clause 4 column of Table 3.

From Table 3 it is clear that the Khyber Pakhtunkhwa and Baluchistan provinces should have substantially more to gain from balance supplies. However, the Accord states "any surpluses may be used by another province, but this would not establish rights to such use." This is a use-it-or-lose-it clause and grants an inexorable right for one province to use water unused by another. This clause has been used—particularly by the Punjab—as evidence that water trading (exchange of water between provinces for money) is not permitted/necessary under the Accord. For the provinces of Khyber Pakhtunkhwa and Baluchistan this is a particular issue because, due to geographic constraints, these provinces may not be able to use their apportioned shares. Because any used water flows toward the

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Punjab, the Accord grants the Punjab the right to use this water. For Sindh this is an issue because it feels aggrieved that the Punjab benefits exclusively from this provision. For Khyber Pakhtunkhwa and Baluchistan, the only way to extract value from water is to extract the water and use it for irrigation, hence insofar as possible these provinces embark upon investments in irrigation.

The final clause of the Accord generates the most debate. The clause itself has five subclauses, (a)–(e). Clause 14a states "the system-wise allocation will be worked out separately, on ten daily basis and will be attached with this agreement as part and parcel of it." This statement is fairly benign. As with the issue of environmental flows, the Accord recommends further work. However, unlike the issue of environmental flows, this clause is committal because it explicitly states that the results of this further work will become part of the Accord. The further work was undertaken subsequent to the signing of the Accord and forms appendixes to the Accord. In these appendixes, the apportioned baseline volume is disaggregated by province and by irrigation systems within each province. The apportioned baseline volume is also disaggregated into 36 intervals (each of 10-day duration). The Accord presents this disaggregated apportionment as discharge rather than volume or proportions and therefore some manipulation is required, which introduces some rounding errors and also possibly some anomaly in dividing a calendar month into three 10-day periods. Fig. 2 shows data from the appendixes of the Accord represented as volumes and proportions of the baseline apportioned volume. Allowing for rounding errors, the allocation to each province and to each season in Fig. 2 is identical to that in Table 1. Hence it is clear that Subclause 14a and the appendixes simply disaggregate the baseline apportioned volume temporally and spatially to a finer resolution.

Subclause 14b states that "the system-wise actual average system uses for the period 1977–1982, would form a guide line for developing a future regulation pattern." It is not explicit in the Accord or any of the published or gray literature why this period of 1977–1982 was selected. Tarbela reservoir was commissioned in 1977, which had a major impact on the water resources and management of the Indus Basin System, hence post-1977 is typically considered the post-Tarbela period (Khan 1999). Furthermore, the ultimate commission established to review Pakistan's interprovincial water issues prior to the signing of the Accord was the Haleem Commission of 1983 (IRSA 2016). The Haleem Commission of 1983 used the available post-Tarbela data, i.e., 1977–1982. Most of the recommendations of the Haleem Commission including references to the period 1977–1982 were incorporated in the Accord.

Subclause 14b also states "these ten daily uses would be adjusted pro-rata to correspond to the indicated seasonal allocations of the different canal systems and would form the basis for sharing shortages and surpluses on all Pakistan basis" (sic). The Punjab interprets these two subclauses as meaning that the proportions of 1977–1982 should be used whenever there is a shortage. Furthermore, the Punjab interprets a shortage as meaning inflow volume less than the baseline volume (144.749 $Gm^3/year$), and that under such circumstances apportioning should be based on the proportions of 1977–1982 period. Sindh disputes this interpretation

Province	Irrigation System	Summer season		Winter season	
		Gm^3	Proportion	Gm^3	Proportion
Punjab	FIC	13.80	9.77%	8.801	6.23%
	M-R Int	1.531	1.08%	0.123	0.09%
	CBDC	0.914	0.65%	0.654	0.46%
	Sutlej Valley Canals Upper	7.789	5.52%	3.963	2.81%
	Sutlej Valley Canals Lower	3.790	2.68%	1.938	1.37%
	Trimmu	2.654	1.88%	1.457	1.03%
	Pajnad	4.197	2.97%	1.876	1.33%
	Thal	2.926	2.07%	2.185	1.55%
	Taunsa	5.172	3.66%	1.852	1.31%
	Chashma Right Bank Canal	0.691	0.49%	0.444	0.31%
	Greater Thal	2.308	1.63%		0.00%
	Punjab seasonal total	**45.773**	**32.42%**	**23.294**	**16.50%**
	Punjab annual total	**69.067 Gm^3/yr (48.92%)**			
Sindh	Guddu Barrage System	9.592	6.79%	2.136	1.51%
	Sukkur Barrage System	22.096	15.65%	12.764	9.04%
	Kotri Barrage System	10.209	7.23%	3.395	2.40%
	Sindh seasonal total	**41.897**	**29.67%**	**18.294**	**12.96%**
	Sindh annual total	**60.191 Gm^3/yr (42.63%)**			
Khyber Paktunkhwa	Swat Canals	1.580	1.12%	1.000	0.71%
	Kabul River Canals	0.469	0.33%	0.346	0.24%
	Indus Canals	2.099	1.49%	1.383	0.98%
	Other Canals	0.148	0.10%	0.136	0.10%
	Civil Canals				
	Khyber Paktunkhwa seasonal total	**4.296**	**3.04%**	**2.864**	**2.03%**
	Khyber Paktunkhwa annual total	**7.130 Gm^3/yr (5.07%)**			
Baluchistan	Sukkur Barrage System	0.7530	0.53%	0.390	0.22%
	Guddu Barrage System	2.7651	1.96%	0.951	0.67%
	Baluchistan seasonal total	**3.518**	**2.49%**	**1.259**	**0.89%**
	Baluchistan annual total	**4.777 Gm^3/yr (3.38%)**			
	Total	**95.483**	**67.63%**	**45.711**	**32.37%**
	Grand Total	**141.194 Gm^3/yr**			

Fig. 2. Disaggregation of apportionment by systems

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and takes a position that the apportionment is as defined in Table 1 and when the inflow volume falls below 144.749 $Gm^3/year$, this clause clearly states that "shortage" should be adjusted pro-rata amongst the province. The Sindh takes the view that Subclauses 14a and 14b simply disaggregate the baseline apportioned volume and does not introduce a different apportionment for shortages. The analysis in Fig. 2 does support the interpretation of Sindh.

Table 3 also compares the apportionment to provinces under Clause 2, Clause 4, and the proportions used during the 1977–1982 period; the latter period is often referred to as Clause 14b because it is one interpretation of 14b and/or historical uses. Any reversion to 1977–1982 proportions benefits the Punjab the most and disadvantages the smaller provinces because their use was rather modest over the 1977–1982 period—largely because of underdeveloped infrastructure. Sindh is modestly disadvantaged in any reversion to an apportionment based on use over the 1977–1982 period. There is a recognition even at IRSA that it would be unacceptable to revert the apportionments of Khyber Paktunkhwa or Baluchistan to the 1977–1982 period. Hence within the Operating Rules, Khyber Pakhtunkhwa and Baluchistan are exempt by IRSA from shortages. This rule is also contested by Sindh as not stipulated in the Accord.

Environmental Flows

A key environmental flow in the Indus Basin is the flow to the Arabian Sea below Kotri Barrage in the Sindh, which is the last barrage along the Indus. For the Sindh, flows to the sea are critical, whereas the other provinces perceive this as a Sindh issue. The Accord noted that Sindh had proposed 12.333 $Gm^3/year$ for environmental flows downstream of Kotri Barrage. The signatories to the Accord agreed that there is a need for a minimum flow to the sea for environmental flows; however, the signatories did not agree on the quantity, and deferred the decision to further studies. The Accord did not bind the signatories to the findings of any particular commissioned study and/or to how such flows might be accommodated. An international panel of experts was constituted and reported (Gonzalez et al. 2005) that a minimum continuous discharge to the sea of 141.69 $m^3\,s^{-1}$ (4.444 $Gm^3/year$) should be maintained, with an occasional surcharge such that over any 5-year period 30.861 $Gm^3/year$ is released to the sea. Gippel (2015) was particularly critical of the flow regime of Gonzalez et al. (2005) for its lack of supporting scientific analysis. Gippel (2015) did not make specific flow regime recommendations for environmental flows, but in reviewing earlier literature showed the diversity of views—partly as a result of the diversity of the objectives of environmental flows. For Sindh it would be advantageous for any environmental flow volume to be top-sliced from the baseline volume, akin to the Khyber Pakhtunkhwa Civil Canals apportionment, on the grounds that the environmental flows and maintaining ecosystems services benefits the entire nation and not just Sindh. For the other provinces, and the Punjab in particular, any top-slicing would mean less apportionment, and hence they would prefer to see environmental flows as a part of the Sindh apportionment. What is clear is that the Accord makes no explicit apportionment for environmental flows or for any other ecosystems service.

Fig. 3 shows the annual volume measured at Kotri Barrage and assumed to be flow to the Arabian Sea, which can be compared with the environmental flow of 4.444 $Gm^3/year$ recommended by Gonzalez et al. (2005). Until 1999–2000, the volume flowing into the Arabian Sea consistently exceeded the recommended environmental flow. From 1999–2000 onward the volumes released into the sea have occasionally fallen below this threshold. Fig. 3 also shows the 5-year moving sum; this has consistently remained greater than the 30.861 Gm^3 recommended by Gonzalez et al. (2005). This kind of analysis is often used by Punjab to make a strong case for the development of additional reservoirs. Although Sindh has not formally accepted or refuted the recommendation of Gonazalez et al. (2005), the operation of the Indus Basin is by and large in compliance with these recommendations. On the other hand, if Sindh holds its position on 12.335 $Gm^3/year$ for environmental flows, the basin operation is not in compliance with this threshold for environmental flows.

Fig. 4 shows the annual volume released to the Arabian Sea at Kotri Barrage as a function of the annual inflow. Fig. 4 also reports

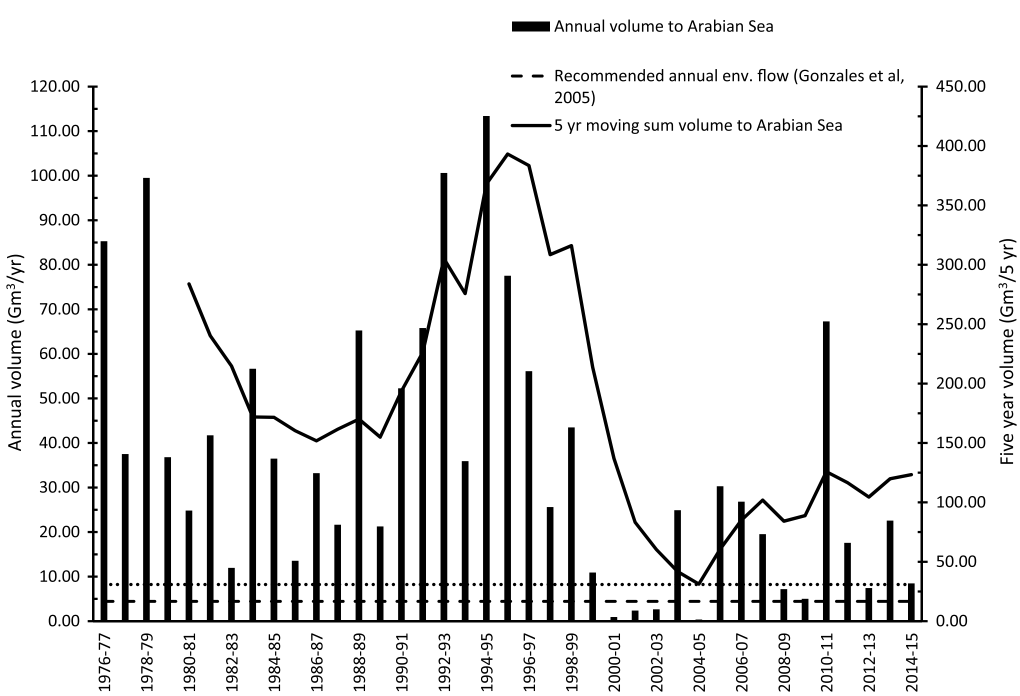

Fig. 3. Flow to the Arabian Sea from the Indus River (data from IRSA, unpublished data, 2017)

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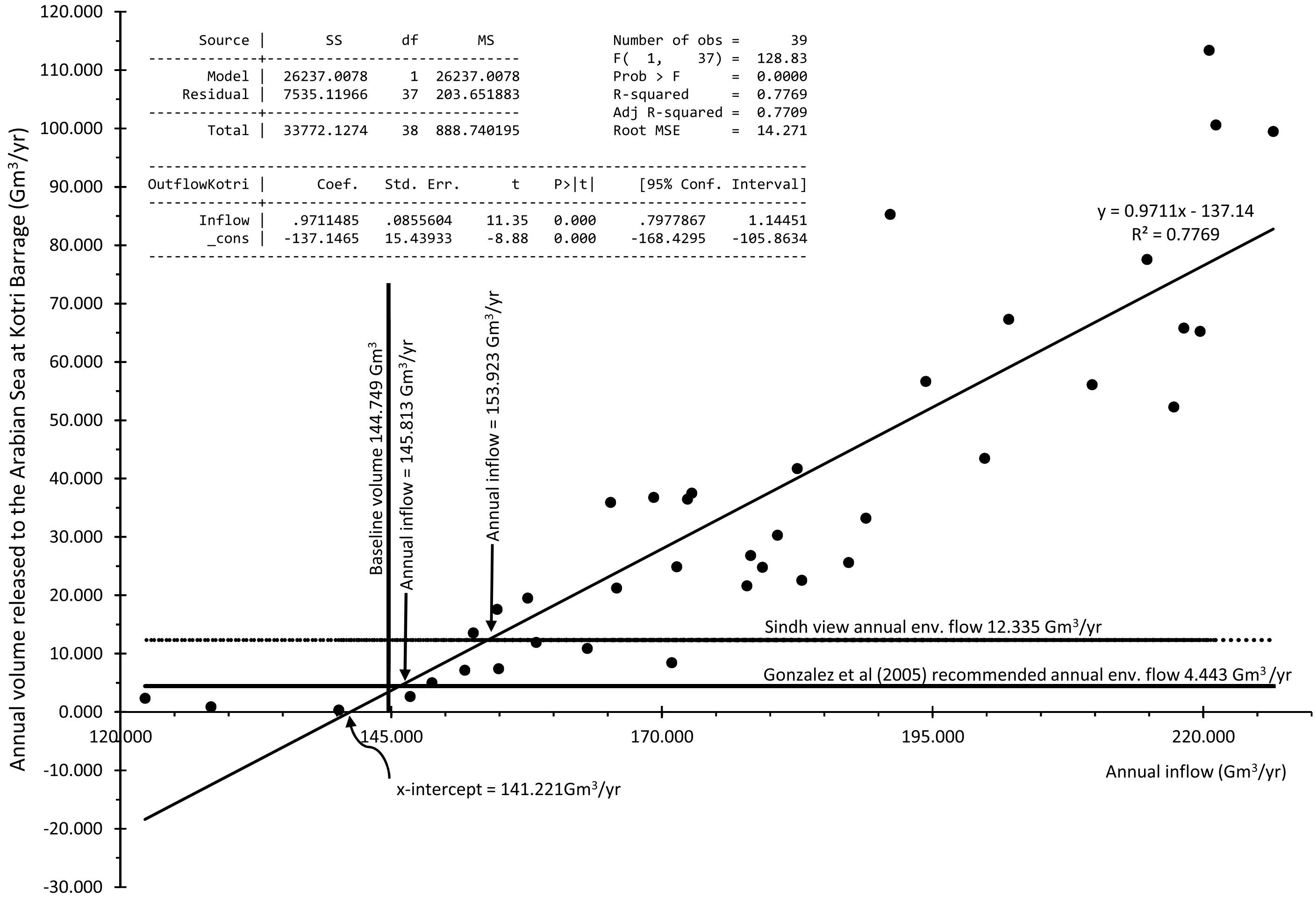

Fig. 4. Volume released to the Arabian Sea as a function of inflow volume (data from IRSA, unpublished data, 2017)

the statistics for the ordinary least-squares regression between these two variables. The strong correlation ($R^2 = 0.777$) shows that 77% of the variance in the annual volume flowing past Kotri Barrage is explained by inflow. The coefficient of annual inflow and the constant in the regression are both significant ($p < 0.05$). These results are logical, because one would expect inflow to be a strong explanatory variable of outflow. The regression has an x-intercept of 141.38 $Gm^3/year$. From this it can be inferred that flow downstream of Kotri Barrage will only occur if the inflow to the system exceeds 141.38 $Gm^3/year$. At the baseline volume of 144.749 $Gm^3/year$, 3.410 $Gm^3/year$ would be released to the sea annually, which is slightly less than the 4.443 $Gm^3/year$ recommended by Gonzalez et al. (2005). Rather, the annual inflows would need to equal or exceed 145.813 $Gm^3/year$ to ensure that the environmental flow recommended by Gonzalez et al. (2005) is equaled or exceeded. For environmental flows to equal or exceed 12.335 $Gm^3/year$—the assertion made by Sindh in the Accord—inflows would need to exceed 153.923 $Gm^3/year$. There is an 81% probability of exceedance of an inflow of 153.923 $Gm^3/year$. Hence the assertion made by Sindh can be fulfilled with the caveat that environmental flows may fall below the threshold value of 12.335 $Gm^3/year$ on average once every 5 years.

Related to environmental flows is the flow required for drainage of the vast Indus Basin Irrigation System. A key piece of drainage infrastructure is the Left Bank Outfall Drain (LBOD), designed to drain 336,000 ha of the lower Indus (Gunn 1986). The Accord states "the requirements of LBOD will be met out of the flood supplies in accordance with the agreed sharing formula." The term flood supplies is undefined and the agreed sharing formula is again undefined and often interpreted as the apportionment of Table 1. As a result, any water requirement for drainage is interpreted as being included in the Sindh apportionment. This again creates discord, particularly between the Punjab and the Sindh, the latter claiming that by virtue of their position as lower-riparian adjacent to the sea, Sindh has to take the responsibility for managing the evacuation of drainage water and salts from the Indus Basin on behalf of the nation and not just of the province. The Punjab takes the view that the LBOD services the Sindh only and not Punjab (or the nation) and hence is a Sindh requirement. Without a clear definition of terminology, the Accord remains ambiguous, and drainage needs are poorly served.

Infrastructure Development

Clause 6 of the Accord reads "The need for storages, wherever feasible on the Indus and other rivers was admitted and recognized by the participants for planned future agriculture development," which may appear relatively benign and agreeable. However, this is presented by Punjab as irrefutable evidence that unless additional storage capacity becomes available (over and above that available at the time of signing the Accord), the apportionment cannot be invoked and Subclause 14b (the Punjab interpretation of Subclause 14b) must be invoked. Other provinces, Sindh in particular, take the position that Clause 6 does not add any proviso or caveat to the apportionment, and in the event that available annual volumes are in excess of or less than the baseline volume, Subclause 14b (the Sindh interpretation of Subclause 14b) addresses this issue. At face value, this clause can be interpreted as a message from the signatories to emphasize the need for investment in storage on the Indus.

Operating Rules

The Accord does not specify detailed Operating Rules, only that an institution (IRSA) will be created to define the Operating Rules. Speed et al. (2013) articulated that it may not be appropriate to include detailed Operating Rules in a water allocation plan, but that some operational requirements or principles should be included, which the Accord does provide, and which were discussed previously. Condon et al. (2014) provided a treatise of how the Accord has been implemented since 1991. The FODP (2012) commented that implementation of the Accord is "not without ongoing disagreement. The IRSA itself provides some detail on the IRSA Operating Rules, often described as a three-tier rule (Fig. 5). The Operating Rules are defined as a function of "water availability," which is a forecast of the volume of water that will be available to allocate to the provinces for the next crop season. The two threshold values of the Operating Rules are the average water use from 1977–1982 of 126.813 $Gm^3/year$ and the baseline volume of 144.749 $Gm^3/year$—hence two thresholds and three tiers.

Fig. 6(a) shows the Operating Rules compared with the Accord for the Punjab. The x-axis represents the inflow volume and the y-axis shows the apportioned volume to the Punjab. Interpreting Clauses 2 and 14 of the Accord yields a straight line [Fig. 6(a)]. Interpreting Clauses 2 and 4 of the Accord yields a breakpoint at the 144.749 $Gm^3/year$ threshold. This interpretation results in two straight lines with the breakpoint. The Operating Rules are more complex. When the inflow is less than the 126.813 $Gm^3/year$ threshold—Tier 1—the Operating Rules apportion 53.06% to the Punjab. The Operating Rules do not top-slice any volume for the Civil Canals of Khyber Pakhtunkhwa within this tier, hence there is a significant difference between the Operating Rules and the Accord. When the inflow exceeds the 126.813 $Gm^3/year$ threshold but is less than the 144.749 $Gm^3/year$ threshold—Tier 2—the Operating Rules state that "actual average system uses are protected," which is interpreted to mean that any Tier 1 allocation is preserved. In Tier 2 the first 3.700 $Gm^3/year$ is top-sliced for the Civil Canals. The Operating Rules then apportion 49.82%, which is identical to the Accord. Hence the Operating Rules and Accord lines in Fig. 6(a) are parallel within Tier 2, with the Operating Rules line higher as a carry-over from Tier 1. When inflow exceeds the 144.749 $Gm^3/year$ threshold—Tier 3—the Operating Rules are identical to the Accord Clauses 2 and 4. In Tier 3 the Operating Rules do not specify that any Tier 2 allocation is preserved, and therefore there is an abrupt decrease in allocation. This is unlikely to be the practice because it implies that for a slight increase in inflow around the 144.749 $Gm^3/year$ threshold, the allocation to the Punjab would decrease by approximately 5 $Gm^3/year$. The footnote in Fig. 5 "KPK and Balochistan are exempted from shortages" was not included in the analysis shown in Fig. 6(a). This condition would bring the Operating Rules in Tier 1 and Tier 2 nearer to the Accord. However, without further elaboration/clarification of this footnote, this condition is mathematically indeterminate.

Fig. 6(a) also shows reported data during the post-Accord era. Most of the reported data are in Tier 3, supporting the analysis that the probability of exceedance of the baseline volume is 90%. The reported volume used by Punjab is always less than the apportioned volume irrespective of the interpretation of the Accord or the IRSA Operating Rules. This suggests that even when inflows are relatively abundant, there is a physical constraint (total irrigation canal capacity) that prevents the use the apportioned volume. However, a canal capacity constraint does not explain why this phenomenon is also observed in Tier 1 and Tier 2 when the inflows are more modest and there is more incentive to utilize the entire allocation. Fig. 6(a) also shows a piecewise linear regression where the slope and intercept of both regression lines and the breakpoint are estimated using maximum likelihood. The regression line exhibits a break at 162.430 $Gm^3/year$, suggesting that up to this inflow volume the Punjab can take advantage of increased allocation, and thereafter irrigation system capacity constraints limit the ability to take advantage of any increased allocation.

The reported 1977–1982 use by the Punjab is 67.287 $Gm^3/year$ [Fig. 6(a)]. During 1991–2015 the Punjab used at most 66.583 $Gm^3/year$. This suggests that the use of water by the Punjab has decreased since the 1977–1982 period, which unfortunately leads to recriminations of underreporting. The FODP (2012) reported that "the method for estimating water availability is outmoded and depends on correlations with prior irrigation season deliveries. IRSA sensibly adapts these estimates as the season goes." Punjab contends that it is consistently allocated less than 67.287 $Gm^3/year$ (average 1977–1982 use). The readily accessible data for Punjab from 2010–2011 to 2016–2017 show that the IRSA allocated on average 3.64% less water than the 1977–1982 averages. Over the period 1993–2014 Punjab reported using 8.69% less than the 1977–1982 averages. Therefore water allocation alone does not explain this discrepancy.

Fig. 6(b) is similar to Fig. 6(a), but for the province of Sindh. In general there is little difference between interpretations of the Accord and the Operating Rules. Again, the analysis in Fig. 6(b) does not include the footnote to the Operating Rules that "KPK and Balochistan are exempted from shortages." Including this condition would reduce the Operating Rules line in Tier 1 of Fig. 6(b) to a level below the line labelled Accord Clause 2 and 14. This is particularly why Sindh holds the view that the Operating Rules are not in compliance with the Accord and disadvantage Sindh. In Tier 2 the first 3.500 $Gm^3/year$ is top-sliced for the Khyber Pakhtunkhwa province, and thereafter the Operating Rules and Accord are parallel and overlap. Within Tier 3 there are again two possible interpretations of the Accord, and the Operating Rules coincide with the Accord Clauses 2 and 4. The observed data for Sindh display a similar pattern to that for the Punjab. Again, all reported data fell below interpretations of the Accord or the Operating Rules even when inflows were at their lowest in 2001, at approximately

Present Distribution Mechanism of IRSA
(THREE TIER FORMULA SINCE 2003)

- ***Scenario I***
  - –Water Availability < Actual Average System Uses 77-82
  - –Distributed as per 14 (b) of the WAA 1991
- ***Scenario II***
  - –Water Availability > Actual Average System Uses 77-82 but < Para 2 of WAA 1991
  - –Actual Average System Uses are protected
  - –Balance available as per Para 2 i.e. 10-daily approved by CCI
- ***Scenario III***
  - –Water Availability > Para 2 of WAA 1991
  - –Para 2 i.e. 10-daily approved by CCI are protected
  - –Balance as per Para 4 of the WAA 1991

Note: KPK & Balochistan are exempted from shortages

Fig. 5. Accord, Operating Rules, and reported data

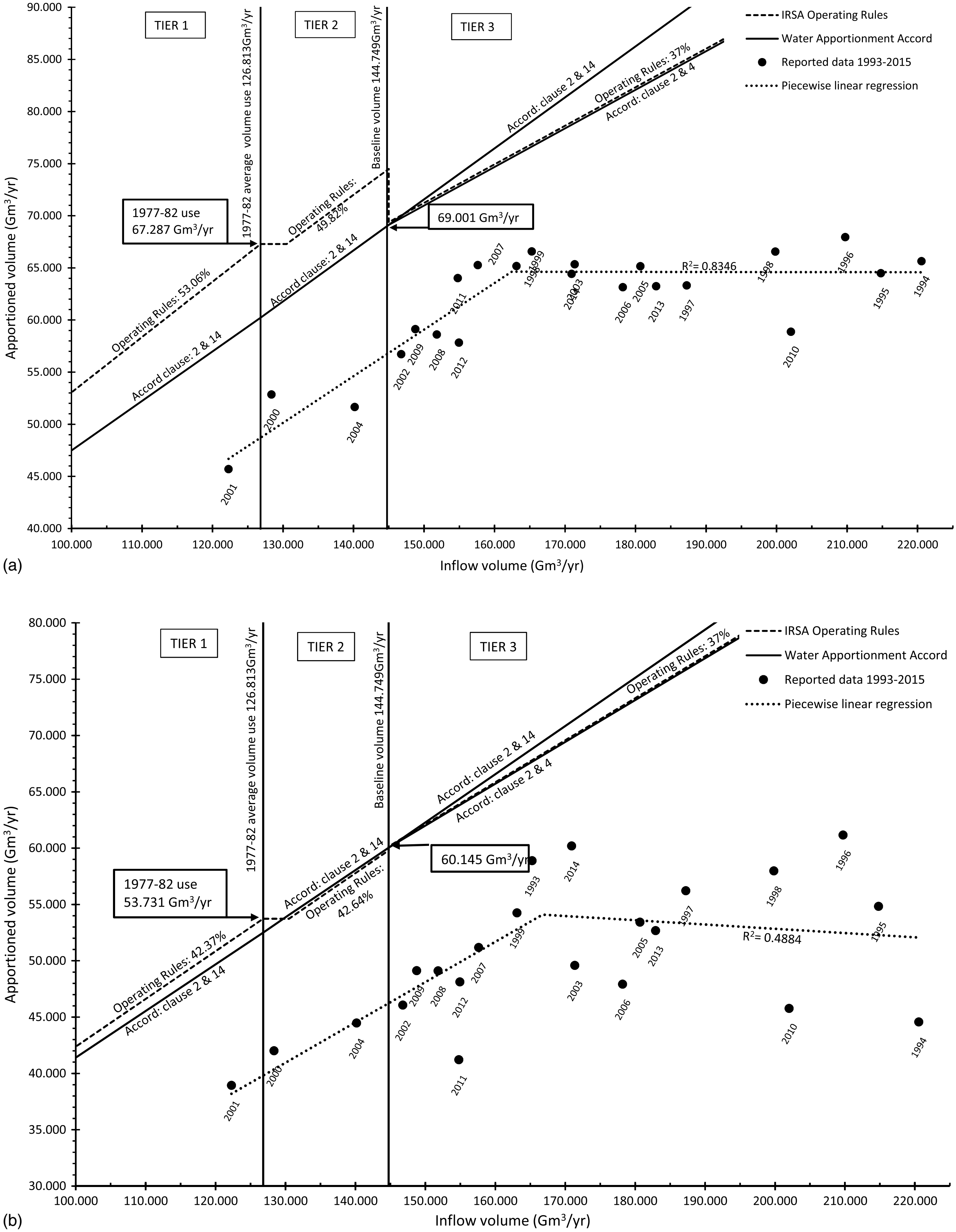

Fig. 6. Accord, Operating Rules, and reported data (data from IRSA, unpublished data, 2017): (a) Punjab; (b) Sindh; (c) Khyber Pakhtunkhwa; (d) Baluchistan

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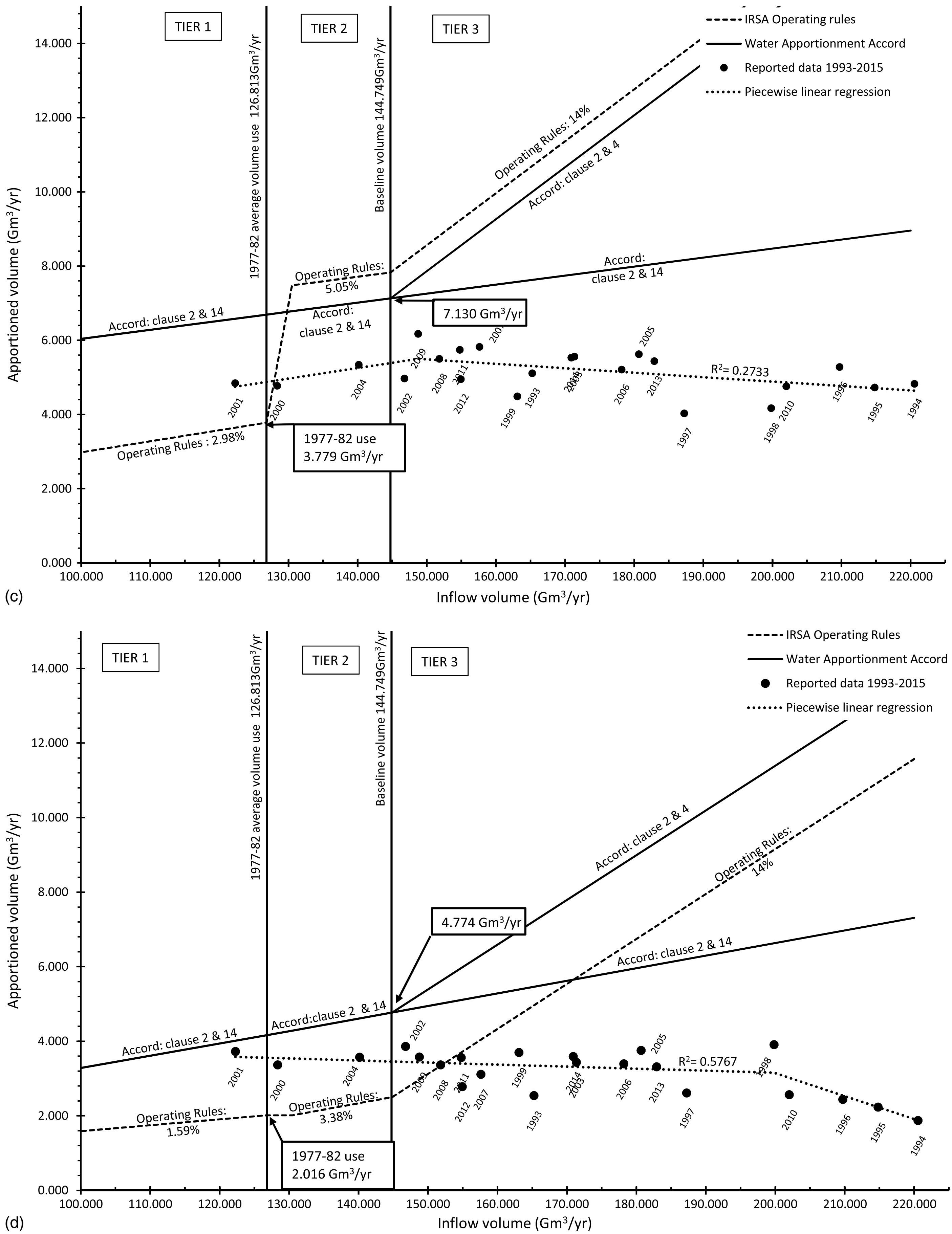

Fig. 6. (*Continued.*)

122 Gm^3/year, once again suggesting a constraint on using the apportioned volume. A piecewise linear regression estimates the breakpoint at 166.770 Gm^3/year, which is similar to that of the Punjab. The data for Sindh show considerably more variation than those for the Punjab, and the R^2 value drops to 0.4884 from 0.8346 for the Punjab, indicating considerably less explanatory power of the regression for the case of Sindh. Unlike the reported data for the Punjab, the maximum volume of water diverted by Sindh during 1991–2015 exceeded the 1977–1982 average use of 53.731 Gm^3/year in a number of years, which is more intuitive.

Fig. 6(c) compares the Accord and IRSA Operating Rules for the Khyber Pakhtunkhwa. For Tier 1 (inflow less than 126.813 Gm^3/year), the Operating Rules allocate considerably less than does the Accord, hence the footnote to the Operating Rules that exempt Khyber Pakhtunkhwa from any shortages. Implementing this footnote would make the Operating Rules near or identical to the Accord Clauses 2 and 14. The footnote is not implemented in Fig. 6(c) because it is mathematically indeterminate. In Tier 2 the Operating Rules allocate the first 3.700 Gm^3/year to Khyber Pakhtunkhwa—hence the substantial increase in the allocation. Thereafter, the Operating Rules run parallel to the Accord. In Tier 3 there again are two interpretations of the Accord. The Operating Rules run parallel to the interpretation of Accord Clauses 2 and 4; however, the absolute difference from Tier 1 appears in both Tier 2 and Tier 3. This anomaly in the Operating Rules is very evident for the Khyber Pakhtunkhwa. The reported volume used by the Khyber Pakhtunkhwa is again below the allocated volume, notwithstanding any interpretation of the Accord or Operating Rules. The piecewise linear regression for data from the Khyber Pakhtunkhwa has comparatively poor explanatory power $R^2 = 0.2733$. With that caveat, the regression does estimate a breakpoint at 148.761 Gm^3/year, which is considerably less than that for the Punjab and Sindh, suggesting that Khyber Pakhtunkhwa has less capacity to use an increased allocation. This breakpoint is nearly identical to the baseline volume of 144.749 Gm^3/year. The reported volume used by the Khyber Pakhtunkhwa over the 1991–2015 period was greater than the 3.779 Gm^3/year of the 1977–1982 period, largely because of the development of irrigation infrastructure.

Fig. 6(d) shows the Accord and Operating Rules for Baluchistan. The trends are very similar to those in Fig. 6(c) for Khyber Pakhtunkhwa. In Tier 1 the Operating Rules allocate less water than does the Accord; however, this difference would decrease if the footnote to the Operating Rules were applied. In Tier 2 the first 3.700 Gm^3/year is allocated to Khyber Pakhtunkhwa, and therefore Baluchistan receives no additional allocation in this range (similar to the Punjab and Sindh). Thereafter, the Operating Rules run parallel to the Accord. In Tier 3 the Accord can be interpreted in two ways. The Operating Rules run parallel to the interpretation of the Accord Clauses 2 and 14. The recorded volume used by Baluchistan was generally below the allocated volumes. In Tier 1 and Tier 2, the volume used is greater than that allocated by the Operating Rules, but this has to be considered with caution because the footnote to the Operating Rules was not applied in Fig. 6(d). The piecewise linear regression has $R^2 = 0.5767$, indicating reasonable explanatory power. The regression estimates the breakpoint at 199.817 Gm^3/year, and unlike for other provinces, both segments have a negative slope. However, the p-value for the slope of the first segment is 0.252, indicating that the slope is insignificant. This suggests that Baluchistan cannot take advantage of any additional allocation. The negative slope of the second segment may be better explained using time as the explanatory variable. The data points are for 1994–1996 and suggest that improvements in infrastructure led to an increase in the use of allocated water. As with Khyber Pakhtunkhwa, the volume of water used by Baluchistan in the 1991–2015 period exceeded the 1977–1982 period use of 2.016 Gm^3/year due to investments in irrigation infrastructure.

Interpreting Figs. 5(a–d) in the context of climate change, if inflows and water availability were to increase in the short term, the provinces are constrained by the capacity of irrigation systems—which varies between provinces—and any further inflow and corresponding allocation cannot be utilized by the provinces. Furthermore, if in the medium to longer term climate change predictions hold and subsequently there is a reduction in inflow, this will rekindle the dispute of 2000–2003 over sharing shortages, especially between the provinces of Punjab and Sindh.

Monitoring and Reporting

The Accord does not prescribe what data are to be collected or by whom, or how the data are to be reported. The practice that has evolved is that canal withdrawal data are collected by the Irrigation Departments of the provinces and river flow data and reservoir storage data are collected by the Water and Power Development Authority. The IRSA provides a very simple basin-level water accounting that, unlike that used in the Indus Basin Model Revised (IBMR) by Yang et al. (2013) or Yu et al. (2013), does not explicitly account for precipitation, evaporation, groundwater, and so on. The IRSA simply account for inflows and outflows (flows into irrigation systems). Fig. 7 shows the difference in inflows and outflows in water accounting (volume balance error) expressed as a percentage of the baseline volume 144.749 Gm^3/year as reported by IRSA and referred to in the vernacular as losses/gains. In 2014–2015, the volume balance error reached 36.082 Gm^3/year, or approximately 25% of the baseline volume. To put this in context, Pakistan has an estimated national reservoir capacity of 17.294 Gm^3/year. This inability to account for approximately 25% of Pakistan's annual water resource is twice the capacity of all reservoirs, and provides space for mistrust and conspiracy theories. Fig. 7 also shows a linear regression of the volume balance error with time. In this linear model, time can explain only approximately 30% of the variation of the volume balance error ($R^2 = 0.3334$). However, both the intercept and slope are significant ($p < 0.05$). This regression suggests that over the next 25 years, Pakistan will be reporting approximately one-third of its annual water resources as losses/gains.

Khan (1999) offered a number of hypotheses for the volume balance error: evaporation, consumptive use, infiltration to the groundwater, rainfall, and ungauged streams/catchments. The inaccuracy and unreliability of flow measurements is often blamed for the volume balance error, particularly at irrigation systems, which in turn has led to attempts and investments to improve flow measurements (Bhatti et al. 2017). Another view is that the cause is deliberate or accidental misreporting, ranging from arithmetic errors, poorly calibrated rating curves, and gauges in disrepair to deliberate underreporting because correct reporting may show that a province has exceeded its apportionment. Then there is the water accounting itself. Water accounting by IRSA accounts for inflow and outflow only and assumes that evaporation from water surfaces, infiltration to groundwater, and abstraction from the Indus River other than at irrigation systems are negligible. It is unsurprising that Briscoe and Qamar (2005) stated "there is no higher priority for water management in Pakistan than to move aggressively in putting in place a totally transparent, impartial system for implementation of the Accord" and articulated three requirements that

1. A rigorous, calibrated system for measuring water inflows, storages, and outflows be put in place;

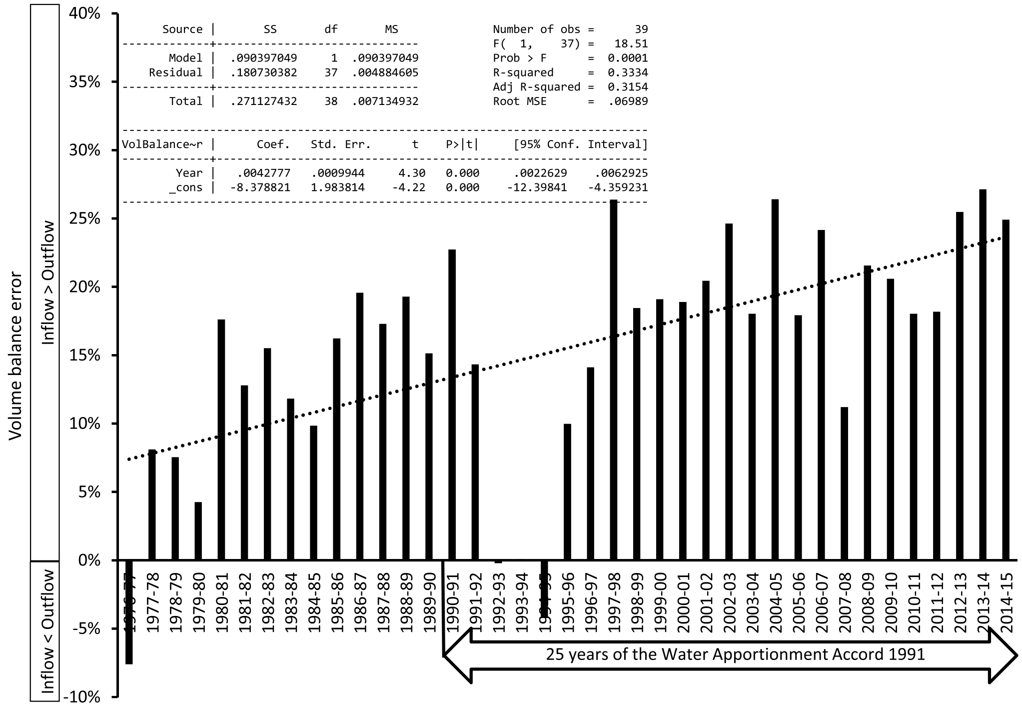

Fig. 7. Volume balance error (data from IRSA, unpublished data, 2017)

2. The measurement system be audited by a party which is not only scrupulously independent and impartial but is seen to be so by all parties; and
3. Reporting must be totally transparent and available in real time for all parties to scrutinize.

Yu et al. (2013) examined water allocation between provinces that would maximize economic benefit and also concluded that investments need to be made in systems to measure flows effectively and transparently alongside capacity building of IRSA. The subject of water accounting in the Indus Basin merits a detailed study in its own right and is the subject of ongoing research by the authors. Preliminary results suggest that the water accounting may account for most of the volume balance error rather than errors in reporting or measurements. Hence the assertions and conclusions made in this paper would remain valid.

Review

The Accord does not provide any explicit review date or end date and is assumed to be perpetual, much like the Colorado Compact, although the latter explicitly states that it is in perpetuity. The Accord has been afforded quasi-religious status from its inception, stating that it "should be religiously implemented and there should be openness in dealing with all issues." (IRSA 2016). This was further reinforced: "The Water Accord 1991 is sacrosanct and has to be implemented in letter and spirit." (Government of Pakistan, "Report of technical committee on water resources," unpublished report, 2005). Given the status afforded to the Accord, this makes any suggestions of a review a very challenging task.

Conclusions and Recommendations

This Accord has remained unchanged over the last quarter of a century, and without a concerted effort the status quo will remain. The question is whether the status quo will serve well for the next 25 years. The Accord lacks a clearly stated objective. The objective of the Accord can at best be assumed from supplementary documents, and therefore it is difficult to summarize whether the Accord has accomplished what it was supposed to without making sweeping assumptions. This research has shown that on a number of thematic issues—e.g., objectives, environmental flows, urban water, water quality, and terminology—the Accord does not provide a strong framework within which to operate. The literature suggests that Operating Rules can and often do remain outside of formal apportionment plans; however, for the Indus Basin the Operating Rules lack clarity and appear to be at odds with the Accord. Finally, the water balance of the Indus Basin lacks accuracy and a large volume of water is unaccounted for (accounted for as losses/gains).

Nonetheless, the Accord remains a seminal agreement between the provinces of Pakistan on the subject of sharing of waters of the Indus River. There is no doubt that water apportionment between the provinces of Pakistan is a complex issue with multiple facets—historical, political, social, cultural, biophysical, and engineering, just to name a few. The starting point to improve apportionment of water between the provinces of Pakistan would not be to revise the Accord but rather to work within the Accord. An obvious starting point is to improve water accounting in the Indus Basin (which includes but is not limited to flow measurement at key installations). A clear set of annual or biannual water accounts similar to those released by other river basin authorities would go some way to reducing mistrust between stakeholders. A slightly more challenging issue, but again within the framework of the Accord, would be to improve the Operating Rules and ensure that these are well documented. For all the shortcomings of the Accord, it would be prudent to work within the Accord before embarking upon any revisions to the Accord itself.

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References

ACO (Agricultural Census Organization). (2010). "Agriculture Census 2010 Pakistan report." ⟨http://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/Country_info_2010/Reports/Reports_5/PAK_ENG_REP_2010.pdf⟩ (Sep. 11, 2017).

Archer, D. R., Forsythe, N., Fowler, H. J., and Shah, S. M. (2010). "Sustainability of water resources management in the Indus Basin under changing climatic and socio-economic conditions." *Hydrol. Earth Syst. Sci.*, 14(8), 1669–1680.

Australian Government. (2007). "Water act: Federal Register of Legislation." ⟨https://www.legislation.gov.au/Series/C2007A00137⟩ (Feb. 13, 2017).

Bhatti, M. T., Anwar, A. A., Shah, A. A., and Aslam, M. (2017). "Revisiting telemetry in Pakistan's Indus basin irrigation system." *J. Irrig. Drain. Eng.*, in press.

Briscoe, J., and Qamar, U. (2005). *Pakistan's water economy: Running dry*, Oxford University Press, Oxford, U.K.

Condon, M., Kriens, D., Lohani, A., and Sattar, E. (2014). "Challenge and response in the Indus Basin." *Water Policy*, 16(S1), 58.

CRC (Colorado River Compact). (1922). "Agreement of governing the allocation of the water rights to the river's water among the parties of the interstate compact." ⟨https://www.usbr.gov/lc/region/pao/pdfiles/crcompct.pdf⟩ (Feb. 13, 2017).

FODP (Friends of Democratic Pakistan). (2012). "A productive and water secure Pakistan." ⟨http://www.waterinfo.net.pk/?q=node/1324⟩ (Sep. 5, 2016).

Gippel, C. (2015). "Lower Indus River: Review of environmental flows to maintain the ecosystem downstream of Kotri Barrage." Fluvial Systems, Stockton, NSW, Australia, 2295.

Gonzalez, F. J., Basson, T., and Schultz, B. (2005). "Final report of international panel of experts for review of studies on water escapages below Kotri Barrage." Federal Flood Commission Pakistan/Delft, Netherlands.

Government of Pakistan. (1992). "Indus River System Authority Act, 1992 (Act No. XXII of 1992)." ⟨http://www.irispunjab.gov.pk/Economic%20Surveys-New/Economic%20Survey%202015-16.pdf⟩ (Sep. 11, 2017).

Government of Pakistan. (2016). "Highlights: Pakistan economic survey, 2015-16." Economic Adviser's Wing, Finance Division, Islamabad, ⟨http://www.irispunjab.gov.pk/Economic%20Surveys-New/Economic%20Survey%202015-16.pdf⟩ (Sep. 5, 2016).

Gunn, P. D. (1986). "Disposal of saline drainage water and storm discharge from left bank outfall drain, Pakistan." *Hydraulic design in water resources engineering: Land drainage*, Springer, Berlin, 487–496.

Hussain, I, Hussain, Z., Sial, M. H., Akram, W., and Farhan, M. F. (2011). "Water balance, supply and demand and irrigation efficiency of Indus Basin." *Pak. Econ. Soc. Rev.*, 49(1), 13–38.

Immerzeel, W. W., van Beek, L. P. H., and Bierkens, M. F. P. (2010). "Climate change will affect the Asian water towers." *Science*, 328(5984), 1382–1385.

IRSA (Indus River System Authority). (2016). "Apportionment of waters of Indus River System between the provinces of Pakistan." ⟨http://www.pakirsa.gov.pk/WAA.aspx⟩ (Sep. 9, 2017).

IUCN (International Union for Conservation of Nature). (2010). "Pakistan water apportionment accord for resolving inter-provincial water conflicts: Policy issues and options." ⟨https://cmsdata.iucn.org/downloads/pk_ulr_d4.pdf⟩ (Sep. 9, 2017).

Khan, A. R. (1999). "An analysis of the surface water resources and water delivery systems in the Indus Basin." ⟨https://cgspace.cgiar.org/handle/10568/39615⟩ (Sep. 8, 2017).

Khan, R. I. A. (2011). "Water apportionment accord 1991, Indus River system authority." ⟨http://www.uaf.edu.pk/golden_jubilee/downloads/presentations/Rao%20Irshad%2010.01.11-Chairman%20IRSA.ppt⟩ (Sep. 11, 2017).

Mustafa, D., Akhtar, M., and Nasrallah, N. (2013). *Understanding Pakistan water-security nexus*, United States Institute of Peace, Washington, DC.

Rees, H. G., and Collins, D. N. (2005). "Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming." *Hydrol. Process*, 20(10), 2157–2169.

Ringler, C., and Anwar, A. (2013). "Water for food security: Challenges for Pakistan." *Water Int.*, 38(5), 505–514.

Seligman, D. (2011). "Resolving interstate water conflicts: A comparison of the way India and the United States address disputes on interstate rivers." *Working Paper Series Serial No.IWP/WP/No.2/2011*, Institute of Water Policy, Lee Kuan Yew School of Public Policy, National Univ. of Singapore, Singapore.

Sharif, H. (2003). "Inter Province water distribution conflict in Pakistan." ⟨http://www.intermedia.org.pk/pdf/pak_afghan/Humaira_Sharif_Research_Paper.pdf⟩ (Sep. 9, 2017).

Sheikh, M. M., Manzoor, N., Adnan, M., Ashraf, J., and Khan, A. M. (2009). "Climate profile and past climate changes in Pakistan." *Research Rep. No. GCISC-RR-01*, Global Change Impact Study Centre, Islamabad, Pakistan.

Speed, R., Li, Y., Le Quesne, T., Pegram, G., and Zhiwei, Z. (2013). "Basin water allocation planning: Principles, procedures and approaches for basin allocation planning." ⟨https://www.adb.org/sites/default/files/publication/30247/basin-water-allocation-planning.pdf⟩ (Feb. 3, 2017).

The News. (2016). "Twin cities to get water share from Indus River." ⟨https://www.thenews.com.pk/print/105681-Twin-cities-to-get-water-share-from-Indus-River⟩ (Aug. 23, 2016).

United Nations Population Division. (2012). "World population prospects 2017." ⟨http://esa.un.org/unpd/wpp/unpp/panel_population.htm⟩ (Feb. 13, 2017).

Yang, Y.-C. E., Brown, C., Yu, W., Wescoat, J., and Ringler, C. (2014). "Water governance and adaptation to climate change in the Indus River Basin." *J. Hydrol.*, 519, 2527–2537.

Yang, Y.-C. E., Brown, C. M., Yu, W. H., and Savitsky, A. (2013). "An introduction to the IBMR, a hydro-economic model for climate change impact assessment in Pakistan's Indus River basin." *Water Int.*, 38(5), 632–650.

Yu, W., et al. (2013). *The Indus Basin of Pakistan: The impacts of climate risks on water and agriculture*, World Bank, Washington, DC.