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Optimizing Pakistan's Water Economy using Hydro-Economic Modeling

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One of the key challenges in trans-boundary rivers management is how fairly you are able to distribute the limited and shared available water among riparian states. Water is the backbone of any country's agriculture and Pakistan is no exception. The scarcity of this resource is rapidly increasing and its outcome can be disastrous especially for the developing countries as stated in the World Wildlife Fund (WWF) report (2012). Pakistan has an extensive irrigation infrastructure referred to the Indus Basin Irrigation System (IBIS). This is the largest contiguous irrigation system in the world. The Indus river system that feeds this irrigation system consists of the main Indus River and its major tributaries – Kabul, Jhelum, Chenab, Ravi and Sutlej Rivers. The existing linear IBMR (Indus Basin Model-Revised) model is a hydro-economic model. It is one of the most comprehensive models built and has been used for planning water distribution for the Indus Basin from last three decades. IBMR is useful for analyzing agro-economic scenarios for various purposes, including the conflict resolution of water distribution among provinces. This study goes further to extend the IBMR for provincial water allocation by imposing the famous bankruptcy rules. Results of the current study show that there are robust and scientifically innovative ways available for providing water to each province. However, our proposed rule allows optimal of water to each province. The inclusion of Bankruptcy Rules in IBMR not only improves the basin wide economic consumer producer surplus but also increases a confidence building measure among the provinces.

Keywords: IBMR, Bankruptcy Rules, GAMS, Water Distribution, Consumer Producer Surplus

1. INTRODUCTION

Water is the most essential element of life and it's one of the most scarce resources on the earth. Although 75%of the earth is covered with water but the percentage of drinkable water is very low. Fresh water constitutes about 2.50% of the total available water on the planet Earth. The remaining water is saline. Unfortunately, most of fresh water is in the form of glaciers and snowfields. In practice, a very minute percentage about 0.007 of the planet's water is accessible to feed and fuel its 6.8 billion inhabitants (Wescoat , 1991).

Water, despite being the lifeblood of agriculture, is getting scarce rapidly. It individually as well as collectively affects a society unlike any other thing. There is no concept of life without water; hence, its influence on human's life is as massive as that of

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a religion or an ideology. Its scarcity and abundance both cause people to migrate. Moreover, its devastating impacts canal so inundate socio-economic and political matters. It is a source of great concern among trans-boundary basins. The agriculture sector's contribution to Gross Domestic Product remains at 21pc but progressive growers agree that given the quantum of surface water utilized in the farm sector, a lot more needs to be done to improve its efficiency. Despite its shortcomings, Pakistan has lesser per hectare yields of wheat, cotton, sugarcane and rice in comparison to countries such as Australia, America, Egypt, Turkey, China, Germany and France as per the Pakistan Ministry of National Food Security and Research 2014-15 statistics (*Pakistan Ministry of National Food Security and Research*, 2014-15). In the following figure, the water consumption pattern of Pakistan has been highlighted and it is evident that 90% of water is being utilized in agriculture sector.

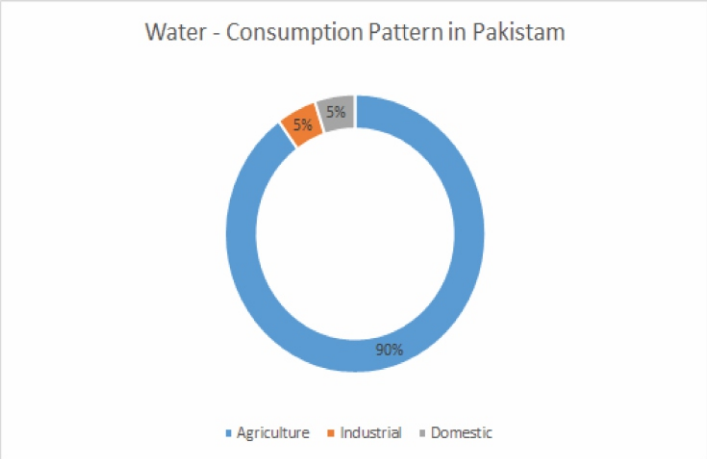

Figure 1: Water Consumption Pattern in Pakistan

Policymakers must leap forward on the integrated water resource management to be equipped to counter the impact of water scarcity. The following categorization shows Pakistan's water problems: inadequate storage, conservation, lack of water efficiency leading to lower per acre productivity, unchecked groundwater abstraction and rationalization of water pricing, canal inefficiency at province level, and contiguous but dilapidated irrigation infrastructure (*Water Sustainability in Pakistan – Key Issues and Challenges*, 2017). Under the Falkenmark Water Stress Indicator, Pakistan is bracketed with countries under water stress, as our per capita water availability remains less than 1, 700 m3. If a country's water availability falls below 1,000m^3, it is considered as a water scarce country. Until 2010, Pakistan's water availability was a meager1, 223m3.

2. LITERATURE REVIEW

River basins are the hydrological units of the planet and play a critical role in the natural functioning of the Earth. River basins are backbone of the country's agriculture and have a lion share to its economy. There are 263 river basins in the world ranging from small, medium and large (Revenga & Tyrrell, 2016). Lakshmi et al. (2018) discussed the 10 major basins (Amazon, California, Colorado, Congo, Danube, Ganga-Brahmaputa, Mekong, Mississipi, Murray-Darling, Nile &Yangtze) w.r.t Precipitation, Vegetation, Evapotranspiration, Total Water, Soil Moisture and Runoff and their variations and impact on the basins economy. According to the UN World Water Development Report (2016), three out of four jobs are globally dependent on water (Lakshmi, Fayne, & Bolten, 2018; Wolf, Natharius, Danielson, Ward, & Pender, 1999; Ward, Scott Borden, Kabo-bah, Fatawu, & Mwinkom, 2019).

O'Mara and Duloy (1984) described the conductive use and discussed its inherent dynamic nature. This paper discusses the Indus Basin Model (IBM) family, structure, model validation and simulation results to access the conjunctive use in Indus irrigation system for alternative policies in detail. The report by Ahmad, Kutcher and Meeraus (1986) assess the impact of the Kalabagh Dam on Pakistan's Agriculture sector. The Agricultural Impact Study (AIS) was launched in September 1985 and its first draft was completed in July 1986. The AIS team comprises of Alexander Meeraus, Chief, DRDSU/World Bank, Mr. Masood Ahmad (DRDSU/World Bank), and Messrs. The detailed analysis and impact assessment of Kalabagh was performed using Indus Basin Model Revised. The report contains all data and listing of GAMS used to access the agricultural impact of Kalabagh DAM.

Bisschop, Candler, Duloy and O'Mara, (1982) and Candler and Norton (1977) discussed the Indus Basin Model in context of two-level linear programming; the presentation of formerly discussed Indus Basin Family and a high level Indus Basin Model description along with some assumption. Instead of presenting mathematical details of IBMR, the author focused on the multi-decision making aspect of model and portrayed the problem as hierarchical decision-making problem. The problem of Basin has been presented as the nested optimization problem and hence, choose to solve using multi-level programming problem. The goal was to maximize the overall Basin income aggregating the individual polygon (53) incomes using multilevel programming.

Ahmad (1993) described the water sources of Pakistan in this report in details. Surface water resources including the depiction of rainfall, snowmelt, and glacier melt and runoff constitutes the river flow. Pre and post storage variability of Indus River Inflow at rim stations, ground water contribution, irrigation losses, river gain and losses, pre and post Tarbela and Mangla, domestic water supply and Industrial water usage in detail.

Wescoat, Halvorsonand Mustafa (2000) have a comprehensive review related to Indus Water System in three eras namely Pre Indus Water Treaty (1947–60) period; Post Indus Water Treaty (1960–75); the Management era (1975–2000). It describes a half-century perspective on Management of Indus Basin focusing crises planning, multi strategies planning to achieve governance goal along with plantation at multiple geographic scales for water management, regional water management to variation pattern. In addition, it also narrates the scientific planning to explore Alternatives for Societal Experimentation with Water and Environmental Management.

Salma, Shah and Rehman (2012) conducted a study to access the rainfall trend across the Pakistan for the period of 30 years i.e. 1976 to 2005. The country has been divided into five zones namely Zone A, Zone B, Zone C, Zone D and Zone E respectively A decreasing trend has been observed which indicates the drought in future and severe droughts have been observed in Southern and Central region of the country. The analysis was performed using Analysis of Variations (ANOVA) along Dennett T3 test and Autoregressive Integrated Moving Averages (ARIMA) model to predict downward moving trend from 2006 to 2030.

Stewart et al. (2018) prepared a comprehensive report related to Indus River System Model (IRSM). The model was also used as a planning tool for water management options in Pakistan, published on 14 Aug 2018. The report was jointly prepared by the Commonwealth Scientific and Industrial Organization (CSIRO) Australia and Sustainable Development Policy Institute (SDPI) Pakistan, funded by Australian government and supported by government of Pakistan. The main purpose of the project was to build capacity and knowledge management in water resource management with prime focus on Integrated Water Resources Management. The existing Indus River Systems IBM/IBMR (O'Mara & Duloy, 1984; Ahmad, Brooke & Kutcher, 1990; Yang, Brown, Yu & Savitsky, 2013) and the Regional Water System Model, RWSM, (Robinson & Gueneau, 2014) have been discussed. IBMR is a hydro economic model where RWSM caters for only hydrology part embedded with more detailed economic model (Kirby & Ahmad, 2015). Kahlown and Majeed, (2003) presented the report related to Water Resources Management in the South Asia with reference to Present and Future Scenarios Prospects and discussed some important facts related to regional per capita water availability, population growth vs. per capita water availability, decreasing live storage capacity of reservoirs, province wise Soil salinity status. Mathematical modeling of the Upper-Indus Glaciers and governing equation were also discussed.

Yu et al. (2013) articulated the impact of climate change in Indus Basin. The author along with his team spent two years in Pakistan and studied the climate changes in the basin. They also worked on Indus Basin Model Revision after 1992, the revision is known as Indus Basin Model Revised 2012 (IBMR-2012). The research resulted in the form of Book that covers all the aspect of Indus Basin viz. Literature Review, Model Equations and results, which reflect the current agro-economic conditions of the country. IBMR (2012) was used to explore impact of climate change for food security and water allocation in Indus Basin. Hydro-climatic parameters sensitivity analysis for the provinces showed that Punjab would affect with least climate change in the future whereas Sind will suffer the most.

Young et al. (2019) comprehensively described the current water resources situation in Pakistan. The report identifies the current challenges of related to water-security, economic and human development and unmitigated risks. Suggestions have been made to address the better management of water resources, infrastructure development and governance.

The Sustainable Development Goals (SDGs) are 17 goals defined by the United Nations General Assembly that provide the blueprint for better and sustainable future for everyone leaving no one behind. The objective was to eliminate the inequality across the planet. The main goals enlisted are No Poverty, Zero Hunger, Quality Education, Clean Water and Sanitation and Climate Action (Doyle & Stiglitz, 2014; Assembly, 2015).

Akhmouch and Clavreul, (2016) emphasized on the water governance. Engaging stakeholder is an integral part of water governance. The authors identified the research gap presenting the major finding of study by Organization for Economic Co-operation and Development (OECD) related to Stakeholder Engagement for Inclusive Water Governance.

Caiand and Cowan (2008) discussed the impact of rising on inflows to Murray-Darling Basin. Austria suffered the history lowest rainfall and drought from 2001 to 2007. Authors established an important relationship between inflows and rise of temperature. 1 degree rise of temperature causes about 15% decrease in annual inflow.

2.1. Indus Basin Model

Indus Basin has a unique and interning composition. Its total area is about 1120000 square kilometers, which constitutes about 54% of the Southeast Asia. It runs through four countries namely Pakistan, India, China and Afghanistan with area of 520,000, 440,000, 88,000 and 72,000 square kilometers respectively (Aqua stat survey, 2011). The broad agribusiness and water system framework alluded to the Indus Basin Irrigation System (IBIS). This is the biggest bordering water system framework on the planet. The normal yearly stream of Indus bowl is around 146 MAF. It has two note worthy capacity repositories specifically Mangla and Tarbela. It consists of 19 barrages, 12 interface canals and 45 noteworthy canal commands. The aggregate length of canals is around 60,000 km and around 120,000 watercourses to irrigate farms. It inundates 16.2 million hectare and contributes about 25% of GDP. Wins about 70% of the export income and utilizes 50% of the workforce straightforwardly and another 20% in a roundabout way (Ahmed, 1990). Indus Basin Model Revised (IBMR) is a Basin wide numerical programming model, written in General Algebraic Modeling System (GAMS). The Indus stream framework comprises of the fundamental Indus River and its significant tributaries: Kabul, Jhelum, Ravi, Sutlej and Chenab. The conceptual model is given below in figure 2. The Indus Basin Model families are described in the subsequent sections.

2.2. Indus Basin Standard Model (IBM) 1981-1982

The Development work on Indus Basin Model was initiated in 1976 which resulted in the form of first model in 1982 with many research publications. The model was based on popular Chac study of Mexico Basin (Goreux & Manne, 1973) and employed linear programing model for irrigated agriculture of Pakistan.

Figure 2: Conceptual Model of IBMR2012

In addition to this, the model catered for fresh and saline water conjunctive use of surface and ground water. Soon it was realized that the model (IBM) could be used to analyze resource usage, crop pattern and farmer income. The model was also used to analyze the Left Bank Outfall Drain project funded by World Bank and on Farm Water Management Project. It was the first ever model jointly developed by World Bank and WAPDA. It has 53 Irrigated Regions also known as Polygons. It was written in Formula Translation Language (FORTRAN) and has 8000 Constraints.

2.3. Indus Basin Model Revised (IBMR) 1985-1986

The model went through periodic revisions and used to analyze many World Bank sponsored projects. The model was not handed over to Pakistan because of the three main reasons: First, the model was large and very complicated and required the most advanced technology of the time only available in US. Second, the model was programmed in FORTRAN that had highly complex architecture and required experts to execute and obtain the results. Third, at that time, no facility was available in Pakistan to train the staff on the model. Until 1985, several models including IBM were assessed to analyze the impact of Kalabagh DAM on the agricultural economy of Pakistan. IBM was an ultimate choice if it could be optimized. In 1986, the model went through a major revision and was updated for analysis of proposed Kalabagh DAM. For the Kalabagh version, the resource inventory was made harmonious to 1980 data for year 2000 projection. The Agro-Climatic Zones (ACZ) are linked together via the surface storage and distribution model(Kutcher, 1976). Major storage reservoirs namely Tarbela, Mangla, Chasma have been incorporated in this revision. Some version of IBMR also included Kalabagh for future planning. In this major revision, the concept of ACZ was introduced and Indus Basin now modeled with 9 ACZs instead of 53 polygons. The 9 Agro-Climatic are namely Punjab Mixed-Wheat (PMW),Punjab Rice-Wheat (PRW),Punjab Sugarcane-Wheat (PSW),Punjab Cotton-Wheat (PCW), Sind Cotton - Wheat North (SCWN), Sind Cotton - Wheat South(SCWS),Sind Rice-Wheat North(SRWN),Sind Rice-Wheat South (SRWS),and North-West Frontier Province(NWFP).Large number of constraints related to ground water equilibrium has been deleted and farm level income/expenses replaced with the price-endogenous demand supply structure. The previous model was rewritten in General Algebraic Modeling System (GAMS). GAMS was specially designed to program such models. The newly born model was named as the Indus Basin Model Revised (IBMR) in literature. In contrary to previous model, the whole basin now divided into 9 Agro-Climatic zones (ACZ) and 45 command areas and has 2500 constraints. One of the major features introduced in this model was the proposed Kalabagh DAM work and the model was used as future projections (Ahmad et al., 1986 : 1990). It is worth mentioning that the Indus basin model was a critical test model for GAMS environment itself. It is one of the largest and difficult models ever tested on GAMS at that time. Indus Basin Model is developed by Work Bank to address the water dependent economy of Pakistan. The data used for calculations are obtained from Indus Basin Model Revised 2012 (IBMR2012) jointly developed by

WAPDA and World Bank.

2.4. Indus Basin Model Revised III (IBMR)-1992

In March 1989, the first workshop was held at WAPDA to train 16 officials from WAPDA and other Federal and Provincial institutions. The purpose of the workshop was to train the participants on computer fundamentals, modeling techniques related agriculture and water resources and exposure to GAMS. In the same year, August 1989, the second workshop was held at WAPDA house. Again, sixteen participants, working on Water Sector Investment Planning Study (WSIPS), attended the workshop. The IBMR went through a revision again in 1988-89 for use by the WSIP. For the first time in its long history, the model was transferred to computers in Pakistan and local analysts were trained in its use. In revised version, the basin has been organized into 12 ACZs instead of 9 and 45 command areas. The 12 ACZs were categorized as NWMW, NWKS, PMW, PCWW, PCWE, PSW, PRW, SCWN, SCWS, SRWN, SRWS and BRW. For the first time in the history of IBMR, Baluchistan was included and it was also written in GAMS and had 2000 constrains (Ahmad & Kutcher, 1992).

2.5. Indus Basin Model Revised IV (IBMR)-2012

It is the latest revision of IBMR available so far. It comprises of 12 Agro-Climatic Zones (ACZ); two for KPK, five for Punjab, four for Sind and one for Baluchistan. To optimize the complex process related to water's allocation, 26 GAMS equations have been used in the IBMR. The model contains the most latest available Social Accounting Matrix (SAM) for year 2009-2010. The revised model was used for the assessment the of climate change for water allocation and food security related challenges. The results obtained from IBMR 2012, showed that Sind would be the most vulnerable province to face the climate change impact. An interim update to IBMR was made in 2002 using 1999-2002 data to incorporate 1991 Inter-Provincial Water Accord agreed and signed by all four provinces. IBMR 2012 used the hydrologic data of year 2008-2009. The main object was to maximize the Consumer Producer Surplus (CPS) for the entire basin using demand-supply relationship (Yu et al., 2013). The Summary of Indus Basin Model family is given in the below table:

Table 1

Family of Indus Basin Models

IBM Family	Features
Indus Basin Standard Model (IBM) –1981-82	53 Irrigated Regions (Polygons),8000 Constraints, FORTRAN Language
Indus Basin Model Revised (IBMR) – 1985-86	9 Agro Climatic Zones (ACZs), 45 Canal Commands (CC), 2500 Constraints , GAMS Language
Indus Basin Model Revised – III (IBM-III) - 1992	12 ACZs, 45 CC, 2000 Constraints, GAMS Language, 26 GAMS equations to optimize
Indus Basin Model Revised – IV (IBM-IV)- 2012	The complex processes related to water allocation and economic activities.

2.6. Bankruptcy Rules

Water is a scarce resource and its distribution among the stakeholders is a key challenge. The situation becomes more intense when there are external parties involved in it. Pakistan is facing the same situation. Its average annual water availability is about 132.02 MAF and demand is 149.71 MAF so, there is a deficit of 17.69 MAF of water. Indus River system is a major source of water for Agriculture in Pakistan. It is a trans-boundary basin and flows across the four countries (Varis, Tor-tajada, & Biswas, 2008). Similarly, it shares waters among four provinces of Pakistan namely KPK, Punjab, Sind and Baluchistan. As availability is less than the demand therefore, there is always situation of miss trust and unpleasant situation among the provinces. Currently, water is being distributed among the provinces as per Indus River System Authority (IRSA). For fair and efficient reallocation of water; we need some rules, which do not depend on riparian states contribution, or upper and lower riparian rights. The allocation should be fair, acceptable and robust which can address spatial and temporal variability of water throughout the year. Bankruptcy Rules answer the above question. There are many bankruptcy rules, which are used for asset allocation when demand is higher than the available asset. Most common bankruptcy rules are Proportional Rule (PR), Constraint Equal Award Rule (CEA), Constraint Equal Loss Rule (CEL) and Hojjat Mianabadi Rules. Every bankruptcy rule has advantages over other. Depending upon current availability and demand of water, we may choose an appropriate rule (Mianabadi, Mostert, Pande & van de Giesen, 2015; Ansink & Weikard, 2012; Mianabadi, Mostert, Zarghami & van de Giesen, 2014; Oftadeh, Shourian, & Saghafian, 2016). The solutions obtained from bankruptcy rules are feasible, unique, fair, robust and acceptable. The comparison of these rules has been given under results section.

2.7. Proportional Rule (PR)

According to Proportional Rule, asset is divided among the stakeholders as per their claims and mathematically it can be formulated as:

$$x_i = \lambda c_i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

where

$$\lambda = \frac{E}{C}$$

The objective function can be written as: Maximize

$$\lambda Pt - \prod_{i=1}^{m} \lambda Pi,t \ \ \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

Subject to:

$$\lambda_{Pi,t} = S_{i,t}/C_{i,t} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

$$\lambda_{Pi,t} \ \leq \lambda_{Pt} \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (4)$$

2.8. Constraint Equal Award Rule (CEA)

This rule ensures the equal division of available asset provided no one get more than its claim. Mathematically it can be represented as:

$$x_i = \min(\lambda, c_i)\,; where \sum(\min(\lambda, c_i) = E \quad \dots \quad \dots \quad \dots \quad (5)$$

The objective function can be written as:

Maximize

$$\lambda_{CEAt} - \frac{\{\prod_{i=1}^{m} \lambda_{CEAi,t}\}}{(\lambda_{\{CEAt\}})^{\{m-1\}}}\ \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

Subject to

$$\lambda_{(CEAi,t)} = S_{i,t} \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

$$\lambda_{\{CEAi,t\}} \leq \lambda_{CEAt} \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (8)$$

This rule is supposed to favor the lower claims, normally belonging to weaker beneficiaries who can be more affected by losses.

2.9. Constraint Equal LOSS Rule (CEL)

CEL allocates each claimant a share of the asset such that their losses in comparison with their claims are equal, subject to no claimant receiving a negative allocation.

$$x_i = \max(0, c_i - \lambda)$$

$$where \sum(\max(0, c_i - \lambda)) = E \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

The objective function can be written as:
Maximize

$$\lambda_{CELt} - \frac{\{\prod_{i=1}^{m} \lambda_{Pi,t}\}}{(\lambda)^{\{m-1\}}}\ \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (10)$$

$$\lambda_{(CEAi,t)} = C_{i,t} - S_{i,t} \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

$$\lambda_{CELi,t} \leq \lambda_{CELt} \forall i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (12)$$

where λ = L/n.

2.10. Talmud Rule (TR)

According to Talmud rule,no stakeholder will receive more than 50 % of her claim if asset is less than half of the total claim, and no-one will lose more than half of her claim if the asset is more than half the total claim.

$$x_i^{Tal} = \{\ CEA\left(\frac{1}{2}c_i, E\right), if\ E < \frac{D}{2}$$

$$(\frac{c_i}{2} + CEA\left(\frac{c_i}{2}, E - \frac{C}{2}\right), otherwise \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (13)$$

wherex_i, c_i, E and C are individual allocation, claim, total asset and total claims respectively.

2.11. Piniles Rule (PR)

The Piniles Rule is a combination of CEA and CEL. The rule uses CEA variant when total asset is less than half of total demand and the variant of CEL is used otherwise.

$$x_i^{Pin} = \{ CEA\left(\frac{1}{2}c_i, E\right), if\ E < \frac{D}{2}$$

$$\frac{(c_i}{2} + x_i^{CEL}\left(\frac{c_i}{2}, E - \frac{D}{2}\right), otherwise \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

wherex_i, c_i, E and C are individual allocation, claim, total asset and total claims respectively.

2.12. Hojjat Mainabadi (MIA)

Hojjat Mainabadi (MIA) Rule is based on agent contribution. Every agent will get reward as per its contribution. Mathematically it can be formulated as:

$$D = C - E \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (15)$$

$$d_i = \left(1 - \frac{a_i}{\sum a_i}\right) * D\ \forall i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (16)$$

$$x_i = c_i - d_i\ \forall i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (17)$$

$$x_i = c_i - \frac{\left[\left(1 - \frac{a_i}{\sum a_i}\right) * D\right]}{n-1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (18)$$

wherea_i, d_i, c_i, D, E and C are individual asset, loss, claim, total deficit, total asset and total claims respectively.

3. RESEARCH METHODOLOGY

In this research, the real time data for Indus River System at rim stations for the year 1922-2010 have been used. Different exceedance probabilities have been calculated and used for water distributions among the different provinces of Pakistan using IRSA Rules. Bankruptcy rules namely Proportional Rule, Constraints Equal Award Rule, Constraint Equal Loss Rule and Hojjat Mianabadi Rule have been employed for water distribution among the provinces. Microsoft Excel and GAMS Studio win 64 25.1.3 have been used for calculations and optimizations. The results of allocations using IBM, IRSA and Bankruptcy Rules have presented in the Result section.

4. RESULTS AND DISCUSSION

The results of the study have been presented in the subsequent sections.

4.1. Water Distribution using IBMR2012

Table 2

Water Distribution using IBMR2012

Province	Demand	Allocation	Deficit
KPK	10.730	8.250	2.480
Punjab	69.020	62.480	6.540
Sind	6 1.840	55.300	6.540
Balch	8.110	5.990	2.120
Total	149.700	132.020	17.680

The above table shows water distribution using IBMR 2012 according to para 4 of IRSA Rules. All the numbers presented in the table are in MAF. Last row of the table shows total demand, water allocation as per IRSA rule and total deficit respectively.

4.2. Water Distribution using IRSA Rules

Table 3

Water Distribution using IRSA Rules

Province	Para2	%	Para4	%	Para14	%
KPK	9.259	5.060	20.160	14.00	2.950	2.980
Punjab	89.524	48.920	53.280	37.000	52.529	53.060
Sind	78.0312	42.64	53.280	37.000	41.9463	42.37
Balch	6.185	3.380	17.280	12.000	1.574	1.590
Total	183	100	144	100	99	100

The above table depicts the water distribution among the provinces in three different situations where Min. Max. and Avg. inflows are 99,183,144 MAF respectively (Khan, 2018). IRSA rules para 2, 4 and 14 are used for water distribution among the provinces (Hassan et al., 2019).

4.3. Water Distribution using Bankruptcy Rules

Table 4

Water Distribution using Bankruptcy Rules

Province	Pro	CEA	CEL	MA
KPK	9.460	10.730	6.310	5.200
Punjab	60.870	56.590	64.600	65.290
Sind	54.540	56.590	57.420	58.410
Balch	7.150	8.110	3.690	2.480
Total	132.020	132.020	132.020	132.020

In the above table, various Bankruptcy Rules like Proportional Rule (Pro), Constraint Equal Award Rule (CEA), Constraint Equal Loss (CEL) and Mianabadi Rule have been used for water allocation for average available water i.e. 132.02 MAF.

4.4. Qualitative Comparison using Different Rules

Table 5

Bankruptcy Rules Comparison

KPK	CEA	PRO	CEL	MA
Punjab	MA	CEL	PRO	CEA
Sind	MA	CEL	PRO	CEA
Balch	CEA	PRO	CEL	MA

This table shows the comparison of different Bankruptcy rules and it can be seen that for smaller provinces, CEL rule gives more promising results. On the other Mianabadi Rule favors the larger claims in our case Punjab and Sind.

Table 6

CPS (Million Rupees) Calculation using Bankruptcy Rules

Model	IRSA	MIA	PRO
wsiszn	102224.971	122302.265	122438.082
wsisnn	92563.216	116980.089	108304.158

4.5. CPS Comparison

Consumer Producer Surplus using IRSA, MA and Pro rules have been calculated and presented in table 6. It can be seen from results using Bankruptcy Rules, CPS has improved as compared to IRSA Rules. *Wsiszn*is the agroclimatic zones model with non-linear objective and *wsisnn* IBMR model with water network non-linear respectively used in IBMR.

5. CONCLUSION AND IMPLICATION

This paper presents the comparison of various water distribution schemes namely IRSA Rules and Bankruptcy Rules for Indus Basin of Pakistan As per results discussed in previous section, bankruptcy rules provide significant increase in basin-wide income and can be an alternate option for water allocation problem for trans-boundary basins. Water distribution using bankruptcy rule could be an alternate step towards confidence building among stakeholders. We may introduce some economic shocks like province productivity (ROI) other than population and area to be irrigated. It has been observed from the results presented in the Table 6 that profit has been increased 19.640% and 19.773% using Mianabadi (MIA) and Proportional Rule (PRO) using linear cost function and 26.379% and 17.006% using non-linear cost function respectively. Crop selection can be another parameter and we may associate some weighting function. Along with economic factor, we may take confidence-building measure to increase inter-provincial trust and create awareness to use scientific knowledge in this regard.

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