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# Flood Risk Management with Transboundary Conflict and Cooperation Dynamics in the Kabul River Basin

**Yar M. Taraky [1], Yongbo Liu [2], Ed McBean [1], Prasad Daggupati [1] and Bahram Gharabaghi [1,*]**

[1] School of Engineering, University of Guelph, Guelph, ON N1G 2W1, Canada; ytaraky@uoguelph.ca (Y.M.T.); emcbean@uoguelph.ca (E.M.); pdaggupa@uoguelph.ca (P.D.)
[2] Department of Geography, Environment & Geomatics, University of Guelph, Guelph, ON N1G 2W1, Canada; lyongbo@uoguelph.ca
* Correspondence: bgharaba@uoguelph.ca; Tel.: +1-(519)-824-4120 (ext. 58451)

**Abstract:** The Kabul River, while having its origin in Afghanistan, has a primary tributary, the Konar River, which originates in Pakistan and enters Afghanistan near Barikot-Arandu. The Kabul River then re-enters Pakistan near Laalpur, Afghanistan making it a true transboundary river. The catastrophic flood events due to major snowmelt events in the Hindu Kush mountains occur every other year, inundating many major urban centers. This study investigates the flood risk under 30 climate and dam management scenarios to assess opportunities for transboundary water management strategy in the Kabul River Basin (KRB). The Soil and Water Assessment Tool (SWAT) is a watershed-scale hydraulic modeling tool that was employed to forecast peak flows to characterize flood inundation areas using the river flood routing modelling tool Hydrologic Engineering Center—Analysis System -HEC-RAS for the Nowshera region. This study shows how integrated transboundary water management in the KRB can play a vital catalyst role with significant socio-economic benefits for both nations. The study proposes a KRB-specific agreement, where flood risk management is a significant driver that can bring both countries to work together under the Equitable Water Resource Utilization Doctrine to save lives in both Afghanistan and Pakistan. The findings show that flood mitigation relying on collaborative efforts for both upstream and downstream riparian states is highly desirable.

**Keywords:** trans-boundary; floods; SWAT; HEC-RAS; Kabul River basin; climate change; proposed dams



**Citation:** Taraky, Y.M.; Liu, Y.; McBean, E.; Daggupati, P.; Gharabaghi, B. Flood Risk Management with Transboundary Conflict and Cooperation Dynamics in the Kabul River Basin. *Water* **2021**, *13*, 1513. https://doi.org/10.3390/w13111513

Academic Editors: Chunhui Li, Zoe Li, Yurui Fan, Celso Augusto Guimarães Santos and Junliang Jin

Received: 30 April 2021
Accepted: 24 May 2021
Published: 27 May 2021



## 1. Introduction

Several studies have focused on the floods in the Kabul River Basin (KRB), given the catastrophic events that have taken place in recent decades. For example, Sayama [1], Khattak [2], and Farooq [3], have studied the 2010 major flood in Peshawar and Nowshera regions of Khyber Pakhtunkhwa (KPK), Pakistan, and studies by Mayar [4], Ahmadzai and McKinna [5], Lashkaripour, Hussaini [6], and Khan [7] on the Afghanistan portion of the KRB. The main agencies responsible for flood risk management, forecasting and prevention in the KRB, on both sides of the Durand Boundary Line (DBL), include the Afghanistan National Disaster Management Authority (ANDMA), Afghanistan National Water Affairs Regulation Authority (NWARA), Pakistan Meteorological Department (PMD), National Disaster Management Authority of Pakistan (NDMA), Federal Flood Commission (FFC) under the Ministry of Water Resources of Pakistan (MWR) and Pakistan Water and Power Development Authority (WAPDA).

There are also several international agencies that are studying the KRB climate and geography as well as providing services to the affected population such as the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), International Centre for Integrated Mountain Development (ICIMOD), World Food Program (FAO), The World Bank Group (WB), and Asian Development Bank (ADB). Most of the studies on flooding maintained their foci on historical events and compared them with the historical return periods.

While studies of historical events are important, issues of transboundary conflict represent a very different focus, and issues of cooperation dynamics are very different and must necessarily reflect the challenges, which are so prevalent in the dynamics of the Kabul River Basin (KRB) where impasses on cooperation must be resolved between Afghanistan and Pakistan. To make real progress resolving the issues of the KRB, there must be progress on 'cooperation dynamics'. Issues must be quantified in terms of risk mitigation, loss of property, human life, and loss of opportunities to use floodwaters productively, storing these floodwaters to preserve them for meaningful uses during dry seasons.

Many factors are contributing to the water security crisis, including sporadic and intense rainfall events, destructive storm surges, increasing populations, and a scarcity of accessible, potable water. Water in the KRB that crosses political boundaries must move away from being treated by states and jurisdictions as an economic and hegemony medium without considering its physical, environmental, and social parameters. On the other hand, in the past 40 years, Afghanistan has experienced a bloody war that has crippled the county's economy and destroyed its infrastructure.

The past 40 years were the years of innovation, exploring nature and building infrastructure that Afghanistan was not able to benefit from. In 2010, the World Bank [8] had identified a series of strategic development options in KRB (Afghanistan), which focuses on the merits of constructing dams for both irrigation and hydropower generation opportunities. The proposed strategy is to construct a combination of small and large dams along the Kabul River and its tributaries [8] to attenuate flooding during high flow seasons and use the captured volumes to increase flows during low flow seasons, allowing the water to be available for beneficial purposes.

However, Pakistan has constructed over a dozen small and large dams downstream of KRB in the past decade and is planning to construct additional large dams on Swat, Panjkora, and Kabul Rivers. Similar, unilateral plans to build 14 additional dams in the Afghanistan portion of the KRB are on the table. Issues of strategy that will capture the opportunities available to both countries are key to making real progress on illustrating 'cooperation dynamics' opportunities.

Some of the intricacies of transboundary water diplomacy, and case studies by Khan [7], Dohrmann [9], Salman [10], (Koff [11], Heinrich [12], Warner [13], Qin [14], Jeuland [15], Chaisemartin [16], Young [17], Bakker [18], and Gari [19] shed light on water-politics and water rights with competing interests. However, there needs to be more attention on the watershed realities of quantitative results based on future climate scenarios and proposed dams in preparing a transboundary policy argument.

KRB is a transboundary international basin with large population. The United Nations General Assembly developed the 2030 Sustainable Development Goals (SDG) which recommends to ensure the sustainable management of water and sanitation for all [17]. Heinrich attribute the complexity of the transboundary water resources management to international treaties and political accountability [12]. While the KRB is not a party to the Indus River Basin (IRB) treaty, the political accountability can start from quantifying the water budget, and providing reasonable grounds for political decision makers to make accountable decisions.

This research uses the quantitative study of the KRB flood mapping under future climate change and qualitative approach discourse to study how the power dynamics may influence the quantitative findings and future developmental paradigm. This study assesses the implications of the four existing large reservoir and the 14 proposed new large reservoirs proposed dams on issues of transboundary flows, reflecting the flow results in three significant scenarios, namely, (a) historical flows and flood inundation analysis, (b) the future flows in two climate scenarios and flood inundation analysis considering existing conditions with no future dams, and, (c) the future flows in two climate scenarios and flood inundation analysis considering the existing and proposed dams in KRB (both Afghanistan and Pakistan portion).

Given these contexts, the potential for transboundary cooperation and equitable water resources utilization is examined in this study. It also examines the transboundary intricacies considering the development goals of both Afghanistan and Pakistan, the power dynamics, and describes the complexities of each riparian country's conflicts and opportunities, the benefits and risks of dams, and the best possible doctrine for water resources utilization.

## 2. Cooperation Dynamics within a Changing Climate

Two primary attributes within the KRB hydrological cycle will influence future flow regimes and flood frequencies. These include (a) the climate change impacts on the future flow regime and changes in the precipitation patterns, (b) the implications of many proposed future dams planned on both the Afghanistan and Pakistan sides of the KRB. The implications of the flow patterns in the KRB are profound, including the fact that the KRB contributes ~12% of the Indus River's mean annual flows [5].

### 2.1. Study Area

The Kabul River originates from the Sanglakh Range northwest of Kabul City and flows eastward and runs through Kabul City and Jalalabad City before it crosses the Durand Boundary Line (DBL) near Laalpur, Nangarhar Province, Afghanistan (Figure 1). It then flows further, about 140 km, and empties into the Indus River at Attock. The Konar River is the largest tributary of the Kabul River that originates in the Hindu Kush mountains near Northern Chitral, where the mountains store large deposits of permanent glaciers and annual snow. The Kabul River's other major tributaries include the Logar River, Panjshir River, Alengaar River, Swat River, Bara River, Jindi River, and Kalpani River.

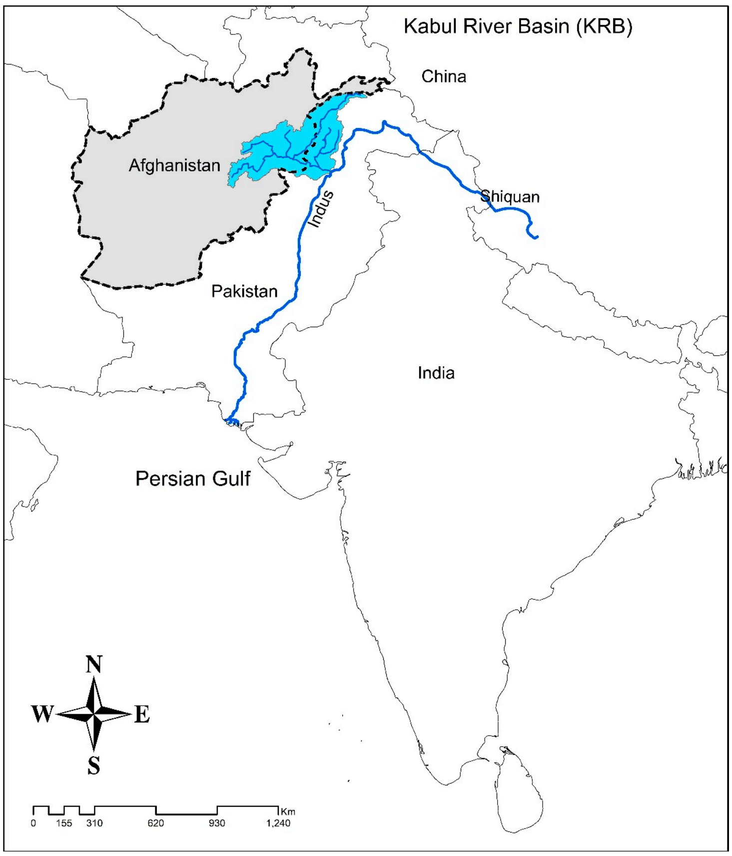


**Figure 1.** Location of the Kabul River Basin.

However, before the River empties into the Indus River, there are four major urban areas: Peshawar, Charsaddah, Kheshgi, and Nowshera, ~40 km west of the Indus River junction. The Swat River joins the Kabul River ~35 km west of Nowshera that further intensifies the flow. The River's flow capacity as influenced by decreasing hydraulic radius at the mentioned urban centers is often reduced, creating hazardous situations during flooding and peak flows. The total KRB area is 92,269 km$^2$, which is shared between Afghanistan and Pakistan. This study's KRB area is 86,870 km$^2$, with the basin outlet located west of Nowshera City, east of the Swat River and Kabul River junction accounting for the bulk of water from Kabul and Swat Rivers.

Over 5,000,000 inhabitants populate the area in four major urban centers, Peshawar, Charsaddah, Kheshgi, and Nowshera. The KRB is home to almost 35% of Afghanistan's population. Approximately 9,000,000 people directly share the water resources of the KRB both in Afghanistan and Pakistan [20].

The elevation in the KRB Afghanistan ranges from 250 to 7600 m based on the 30 m DEM with steeper slopes and gorges in its headwater region and bare portions in the downstream River reaches. The annual average precipitation in the basin is about 459 mm [1,21]. The highest rainfall occurs during spring (March to May), with a highly variable precipitation pattern amongst nearby regions. Similarly, the annual average temperature of the KRB is about 8 °C. The array of existing and proposed dams in the KRB (Afghanistan and Pakistan) is listed in Table 1, with locations of each, as included in Figure 2.

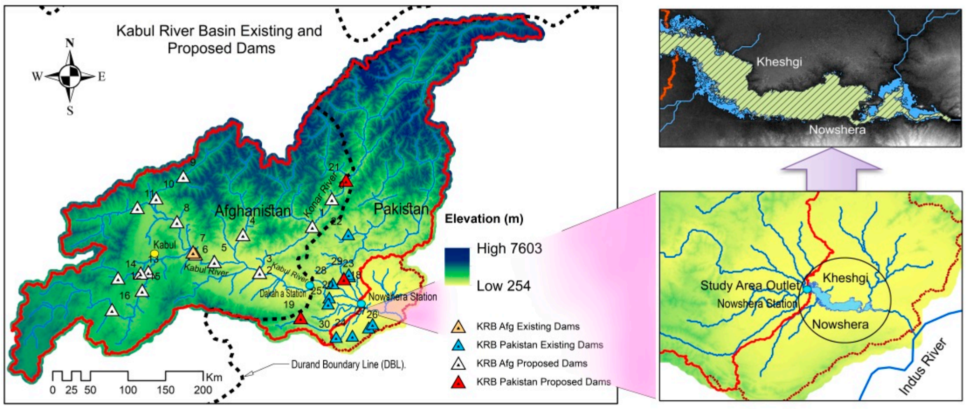


**Figure 2.** Location of the existing and proposed new dams within the KRB.

## *2.2. Data Availability*

Daily rainfall and temperature data for baseline and future periods of the KRB were accessed for six high resolution (0.25°) Global Circulation Models (GCMs) from the 5th Coupled Model Inter-comparison Project (CMIP5), Regional Integrated Multi-hazard Early Warning System's (RIMES) portal (RIMES, 2019). After careful analysis of the changes of average seasonal temperature in 2025–2049, 2050–2074 and 2075–2099 compared to 1990–2014 baseline data for the six GCMs in the KRB the climate data from the CCSM-4 GSM were identified to be more realistic under the KRB conditions and hence were used to study the climate change impact of flow regimes in the basin.

To assess the implications of various future climate change scenarios and the operational impacts of the array of potential future dam scenarios, the Soil Water Assessment Tool (SWAT) modelling was employed. The SWAT Calibration and Uncertainty Procedures (SWAT-CUP) developed by Abbaspour [22], were used for parameter sensitivity analysis and model calibration of the KRB SWAT model. In this study, the SWAT Modelling output peak flow data were used in the HEC-RAS modelling as input data to determine the flood inundation area under different historical and climate change scenarios. For details of data collection, SWAT modelling, data sensitivity analysis, and calibration refer to Supplementary Materials.

**Table 1.** Existing and proposed dams in the KRB (Afghanistan and Pakistan).

| No. | Name of the Dam | Existing or Proposed | Country | Height | Gross Storage | Hydroelectric Power |
|---|---|---|---|---|---|---|
| | | | | (m) | $Mm^3$ | MW |
| 1 | Barak | Proposed | Afghanistan | 155 | 530 | 100 |
| 2 | Panjshir | Proposed | Afghanistan | 180 | 1300 | 100 |
| 3 | Konar A | Proposed | Afghanistan | 75 | 1212 | 366 |
| 4 | Totumdara | Proposed | Afghanistan | 135 | 410 | 75 |
| 5 | Baghdara | Proposed | Afghanistan | 40 | 400 | 210 |
| 6 | Konar B | Proposed | Afghanistan | 75 | 73 | 81 |
| 7 | Laghman | Proposed | Afghanistan | 80 | 405 | 44 |
| 8 | Naghlu | Existing | Afghanistan | 110 | 550 | 75 |
| 9 | Sarobi | Existing | Afghanistan | 52 | 51 | 11 |
| 10 | Sarobi | Proposed | Afghanistan | 200 | 196 | 210 |
| 11 | Darunta | Existing | Afghanistan | 75 | 220 | 100 |
| 12 | Kama | Proposed | Afghanistan | 23 | 73 | 40 |
| 13 | Hajijan | Proposed | Afghanistan | 50 | 220 | 0 |
| 14 | Gat | Proposed | Afghanistan | 85 | 500 | 0 |
| 15 | Tangi Wardag | Proposed | Afghanistan | 20 | 350 | 0 |
| 16 | Shahtoot | Proposed | Afghanistan | 113 | 250 | 0 |
| 17 | Kajab | Proposed | Afghanistan | 85 | 400 | 0 |
| 18 | Mohmand | Proposed | Pakistan | 213 | 560 | 740 |
| 19 | Bara | Proposed | Pakistan | 92 | 105 | 6 |
| 20 | Warsak | Existing | Pakistan | 76 | 31.0 | 243 |
| 21 | Mirkhani | Proposed | Pakistan | 120 | - | 410 |
| 22 | Raghagan | Existing | Pakistan | 16 | 2 | 0 |
| 23 | Palai | Existing | Pakistan | 28 | 8 | 0 |
| 24 | Aza Khel | Existing | Pakistan | 23 | 28 | 0 |
| 25 | Mullagori Khonari | Existing | Pakistan | 38 | 12 | 0 |
| 26 | Cherat | Existing | Pakistan | 33 | 10 | 0 |
| 27 | Jabba Tar | Existing | Pakistan | 18 | 15 | 0 |
| 28 | Abdul Shukur | Existing | Pakistan | 32 | 1 | 0 |
| 29 | Moto Shah | Existing | Pakistan | 30 | 2 | 0 |
| 30 | Zao | Existing | Pakistan | 26 | 1 | 0 |

### *2.3. Land Use and Soil Types*

The Kabul River Basin's primary land use is mixed grassland (34%), and sparsely vegetated barren land (31%). There have been changes in urbanization in the past 20 years. Since 2002, the croplands and urban lands have increased while the forest cover areas have decreased [23]. Despite urbanization, major areas in KRB experience vertical infiltration during flood events due to the soil layers' permeability.

The mountainous regions of the KRB are covered with shallow Leptsols that still allow the water to percolate to the soil until it reaches saturation [1]. Plains in the Basin, however, are covered with terrestrial lacustrine sediments [24] followed by loess underlain by sand and gravel aquifer layers [1].

### *2.4. Snow and Glacier Covering Area*

Out of the total KRB Study area, ~78.5% of the basin is covered with annual snow, and ~21.5% of the lands are bare and are not experiencing snowfall. Up to 73% of the runoff is generated from the snowmelt and glacial melting [25,26]. The KRB glaciers area was included in the SWAT modelling, and the glacier retreat modelling was conducted during the modelling. The results indicate that glaciers retreat will accelerate in the third quarter of the century under RCP8.5 scenario. By the end of the century, the total glacier retreat is estimated to be 20.3%. The KRB study area permanent glacier area is ~3.3%.

## 3. Methodology

This research uses the KRB flood mapping under future climate change to study how the power dynamics may influence the future developmental paradigm. We assessed the implications of the proposed series of new large dams in the KRB on issues of transboundary flows, reflecting on the flood flows in three scenarios, namely, (i) the historic climate flood flows with existing dams, (ii) the future climate flood flows with existing dams and (iii) the future climate flood flows with the existing and proposed new series of large dams.

The study methodology consists of three parts.

1. We used a watershed-scale hydrologic model SWAT to generate different flood flow scenarios in the KRB. We used the Global Weather Data (GWD), including precipitation, temperature, solar radiation, wind speed, and relative air moisture from 1979 to 2014 obtained from NCEP CFSR in the SWAT model calibration. The SWAT Calibration and Uncertainty Procedures (SWAT-CUP) developed by Abbaspour et al. (2004) were used for parameter sensitivity analysis and model calibration of the KRB SWAT model. In this study, the sequential uncertainty fitting (SUFI2) algorithm was used [22]. With global sensitivity analyses of 100 SWAT-CUP runs considering the Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe, 1970) as the objective function. SWAT-CUP identified 29 sensitive parameters corresponding to the t-test (see Table S1 in the Supplementary Materials). Three criteria, namely model bias, the NSE, and the determination coefficient ($R^2$), were used to evaluate the model performance at flow monitoring stations statistically. The model performance over the 2008 and 2013 calibration period at the Dakah station (Figure 2) showed a model bias of 3.4%, with the NSE of 0.74, and $R^2$ of 0.80 (see Figure S1 and Table S1 in the Supplementary Materials).
2. In this study, Hydrologic Engineering Center (HEC) River Analysis System (RAS) was used to develop the flood inundation maps under different historic and future climate scenarios with and without the proposed dams. HEC-RAS was developed by the United States Army Corps of Engineers [27]. The urban area of Nowshera was chosen as case study to determine the flood flow impacts. The HEC-RAS model was calibrated using the 2010 flood event in Nowshera based on the observed water level and satellite-based flood inundation imagery. The main calibration parameters in the HEC-RAS model, include the Manning's Roughness Coefficient and the river channel geometry and slope (obtained from the Digital levelation Maps). Manning's Roughness Coefficient values used in this research for different Kabul River zones were 0.04 and 0.15 for the main channel and the flood plains [2]).
3. The flood flow predictions of various historic and future climate and dam scenarios from the calibrated SWAT model was then used as input data for the HEC-RAS model to simulate the flood inundation areas. The results of the flood inundation modelling were used as technical evidence to address some of the issues related to the policy implications of power dynamics in transboundary water resources management, transboundary impacts on flood mitigation, water and transboundary cooperation uncertainties, KRB transboundary conflict and opportunities, and Benefits and Risks of proposed series of new large Dams in the KRB.

The overall study process tree is shown in Figure 3.

The HEC-RAS model results were also calibrated for historical floods between 1990 and 2014. The HEC-RAS flood model was used to simulate the design of flood events based on the observed depth values and satellite-based flood extent. The HEC-RAS modelling tool used the DEM and the reaches to conduct subcritical, supercritical, and mixed flow regime flows analyses.

The modelling approach benefitted from the Shared Vision Planning (SVP). Palmer [27] identified the specific transboundary cooperation agent and conflict that may influence the peak flows. The literature review of the KRB and the Afghanistan and Pakistan transboundary relationship was used to identify several agents that will impact the future peak flows downstream, as identified by Khan [28]. The future dams and climate scenarios are chosen to evaluate and examine the intricacies of conflict and cooperation in this transboundary basin in light of the quantitative findings.

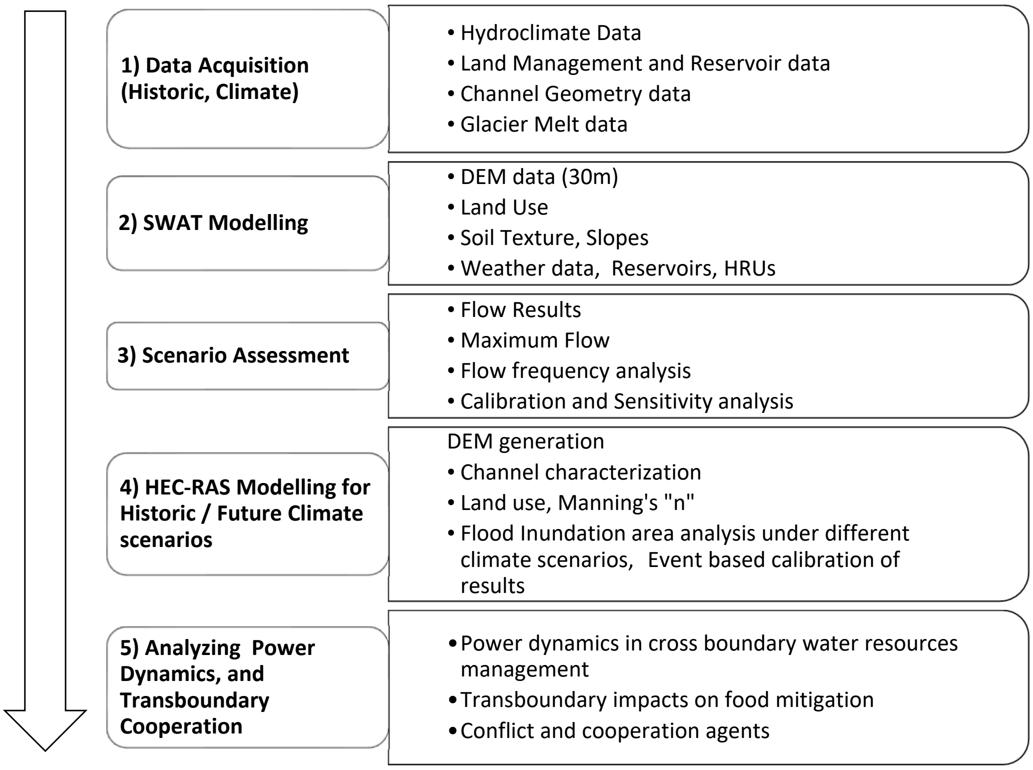


**Figure 3.** Modelling and conceptualization process.

## 4. Results

SWAT modelling results of various climate change scenarios show that Spring, Summer, and Autumn precipitation will increase by 24.1%, 20.4%, and 28.3%, respectively, while the winter precipitation will decline by 29.8% for the RCP 8.5 scenario. Such marked variabilities were also reported by other studies in the region [28–30]. Changes in annual precipitation, snow, and glacial melting in the spring and summer periods will increase flood frequencies in the near future compared to baseline conditions.

### *4.1. Peak Flow Results with and without Future Dams*

The effect of climate change and the proposed dams on the peak flood flows are presented in Table 2 under three scenarios. The three peak flow scenarios presented in Table 2, includes the (peak flow 1) scenario under historical flows with existing dams and the current climate scenario (peak flow 2) with existing dams and future water demand (the Community Climate System Model version 4—CCSM4 climate data); and the (peak flow 3) scenario with both existing and proposed dams and the future water demand (CCSM4 climate data).

The results show that under the existing and proposed dams with future water demand scenarios using the CCSM4 climate model data, all dam scenarios will result in flood reduction. (Table 3, see 'relative change 2′).

The comparison indicates a 61.9% increase in flooding in a 50-year return period (RCP4.5) and a 77.4% increase in flooding in a 50-year return period (RCP8.5) under existing dams and future flow scenarios. The results show a higher increase in flood peaks for CCSM4 RCP8.5 compared to CCSM4 RCP4.5. (Table 2).

**Table 2.** Peak flows for the current and future climate and dam scenarios.

| RCP. | Return Period (year) | Peak Flow (1) ($m^3/s$) | Peak Flow (2) ($m^3/s$) | Peak Flow (3) ($m^3/s$) |
|---|---|---|---|---|
| Climate | | Historical 1990–2014 | CCSM4 2025–2099 | CCSM4 2025–2099 |
| 4.5 | 2 | 2078 | 2506 | 1875 |
| | 5 | 2726 | 3799 | 2560 |
| | 10 | 3217 | 4777 | 3077 |
| | 25 | 3707 | 5750 | 3562 |
| | 50 | 4355 | 7049 | 4280 |
| | 100 | 4846 | 8027 | 4798 |
| 8.5 | 2 | 2078 | 2795 | 1842 |
| | 5 | 2726 | 4199 | 2691 |
| | 10 | 3217 | 5261 | 3333 |
| | 25 | 3707 | 6664 | 4181 |
| | 50 | 4355 | 7726 | 4823 |
| | 100 | 4846 | 8788 | 5465 |

**Table 3.** Flood peak flow and the inundation area for three climate periods.

| RCP | Return Period (year) | Flood Flow [0] ($m^3/s$) | Flood Inundation Area [0] ($km^2$) | Flood Flow [1] ($m^3/s$) | Flood Inundation Area [1] ($km^2$) | Flood Flow [2] ($m^3/s$) | Flood Inundation Area [2] ($km^2$) |
|---|---|---|---|---|---|---|---|
| 4.5 | 2 | 2764 | 84 | 3333 | 101 | 2493 | 76 |
| | 5 | 3626 | 155 | 5053 | 164 | 3404 | 110 |
| | 10 | 4279 | 183 | 6353 | 216 | 4093 | 139 |
| | 25 | 4930 | 211 | 7648 | 270 | 4737 | 167 |
| | 50 | 5792 | 248 | 9375 | 341 | 5693 | 207 |
| | 100 | 6445 | 276 | 10,676 | 398 | 6382 | 238 |
| 8.5 | 2 | 2764 | 84 | 3717 | 113 | 2450 | 74 |
| | 5 | 3626 | 155 | 5585 | 249 | 3579 | 160 |
| | 10 | 4279 | 183 | 6997 | 310 | 4433 | 196 |
| | 25 | 4930 | 211 | 8863 | 389 | 5561 | 244 |
| | 50 | 5792 | 248 | 10,276 | 450 | 6415 | 281 |
| | 100 | 6445 | 276 | 11,688 | 555 | 7268 | 345 |

Note: Flood flow [0]—Flood flows based on historical (1990–2014) climate and existing dam condition; Flood flow [1]—Simulated flood flows based on CCSM4 (2025–2099) climate data, existing dams and associated future water demands; Flood flow [2]—Simulated flood flows based on CCSM4 (2025–2099) climate data, existing and proposed dams and associated water demands, Flood inundation area [0]—The flood inundation from flood flow [0], Flood inundation area [1]—The flood inundation from flood flow [1], Flood inundation area [2]—The flood inundation from flood flow [2].

### *4.2. Flood Inundation Extent from Various Flow Inputs*

The HEC-RAS modelling generated the flood inundation 1D water surface area based on the DEM maps, land cover basin network data, and the SWAT model results under various climate and dam scenarios. The water surface maps along with the MODIS satellite maps were superimposed in Arc GIS and Auto CAD to characterize the different flood inundation maps and areas, as shown in Figure 4.

The urban area of Nowshera was chosen to determine the flood flow impacts under all future climate scenarios. Nowshera, along with Kheshgi, Charsaddah, Peshawar and other towns, constitutes the urban downstream of the Kabul River where the whole of Kabul River flow, including the Swat River (a tributary of the Kabul River), joins the main Kabul River west of Nowshera.

The flood inundation maps for historical, flood flows, future peak flow with existing dams, and future peak flow with proposed dams were calibrated with the MODIS imagery for the 2010 flood in Nowshera and data from existing historical floods. The simulated flood event of the 2010 flooding against the MODIS, SRTM ASTER DEM and ALOS and World DEM is shown in Figure 4. The resulting flood inundation area for different flow inputs and return periods are shown in Table 3.

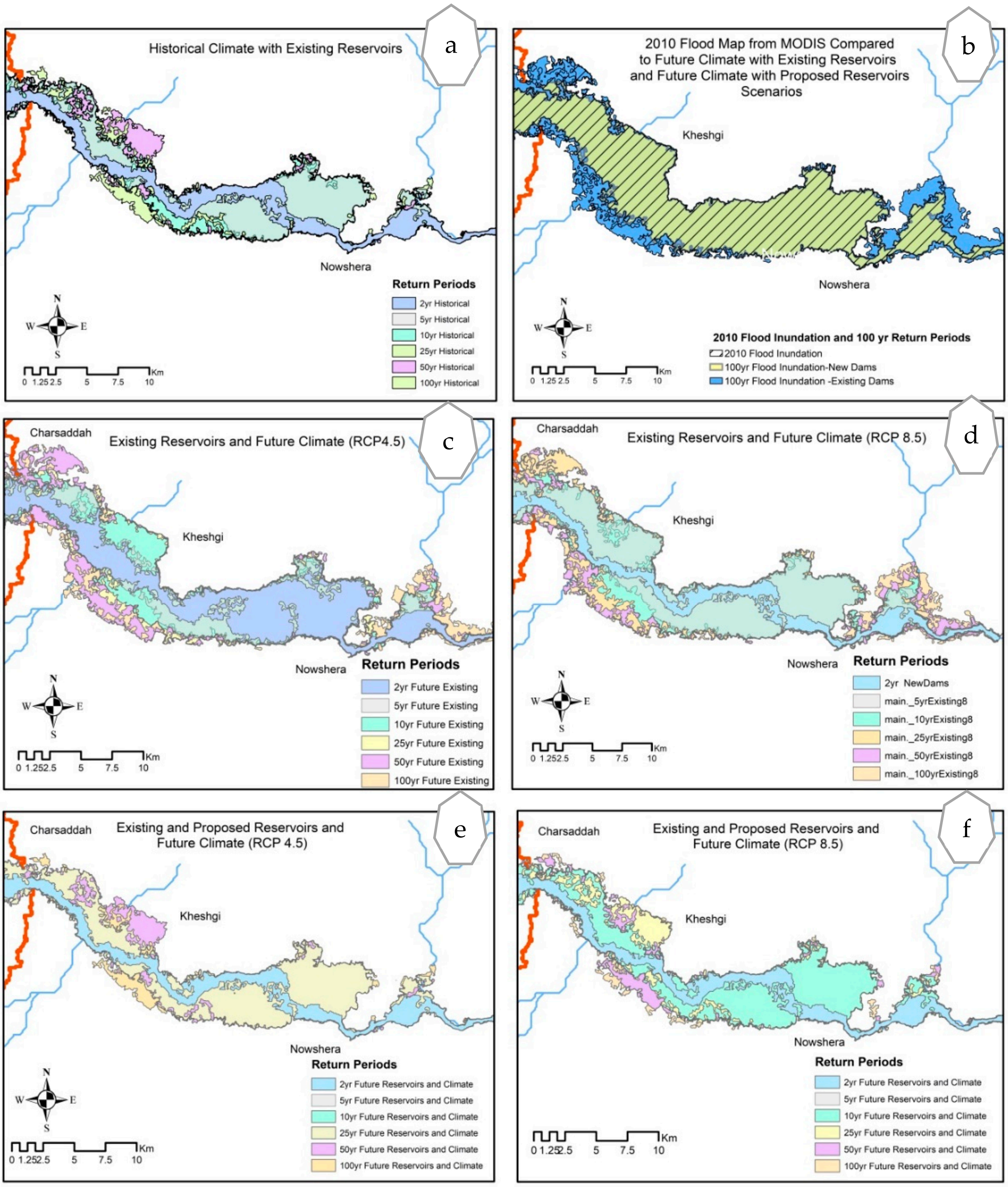


**Figure 4.** Flood inundation map for the Kabul River at Nowshera for various climate and dam scenarios for various return periods; (**a**) Flood inundation map under current climate and existing dams for various return periods, (**b**) 2010 MODIS flood inundation imagery compared to the simulated 100 year flood inundation map for the existing and proposed dams, (**c**) flood inundation under existing dams and future climate RCP 4.5 scenario, (**d**) existing dams and future climate under RCP 8.5 scenario, (**e**) flood inundation under existing dams and future climate under RCP 4.5 scenario, and (**f**) flood inundation under proposed dams and future climate conditions RCP 8.5 scenario.

The flood inundation analyses indicate that if no dams are built, the flood frequencies and intensity will likely increase under different climate scenarios. The effects of future urbanization in the Kabul River's vicinity have not been considered. For situations where dams are built, and these operating dams contain the peak flow, the flood inundation areas in Nowshera are listed in Table 4.

**Table 4.** Transboundary ontological and epistemic uncertainties related to flood prevention.

| Uncertainty | Type of Uncertainty | Response Approach |
|---|---|---|
| Ontological uncertainty | Precipitation variability | Joint monitoring institutions and stations' data exchange |
| | Flood frequencies, magnitude and duration | Region-based and town-based flood magnitude forecasting based on previous precedents and new encroachments |
| | Glacier melt variability | KRB specific glacier missions and expeditions |
| | Sediment flux variabilities | Analysis of sediment transport in the floodwater and design of sediment retention structures |
| | Contaminant transport and fate | Study of the contamination of the floodwater, turbidity analysis, chemical and biological contaminant studies at the basin level |
| Epistemic uncertainty | Flood early warning mechanism | Joint transboundary flood warning system planning, region-specific and time-bound system design by each side |
| | Emergency response | Transboundary emergency response, provision of first aid |
| | Temporary sandbag (levee) plans and implementation | Design of temporary sandbag and retaining wall plans at the basin level |
| | Recovery program uncertainties | Development of recovery plans at basin level, emergency recovery, seasonal recovery, long term economic recovery plans on bi-partisan basis |
| | Trans boundary peak flow monitoring | Development of technical and institutional peak flow monitoring mechanisms accessible to both sides |
| | Institutional capacity building and synchronization | Coordination of efforts at the basin level to address seasonal floods before each flood season, the inauguration of joint KRB specific commissions |

Under existing dam conditions, the future climate scenario cases show a 17% to 31% increase in flood inundation area in the 2 years and 100 years return periods under RCP 4.5 in the Nowshera area due to snow glacier melt and precipitation pattern variability. The increase in flood inundation under RCP 8.5 will be between 26% and 50% in a 2-year and 100-year return period event.

The results in Table 3 show that the proposed dams will significantly reduce the flood inundation area. Under RCP 4.5, the flood inundation area in Nowshera will be reduced by 25% and 40% during a 2-year and 100-year return period flood. The flood inundation area will be further reduced by 34% and 38% during a 2-year and 100-year return period flood under RCP 8.5. The results clearly indicate the importance of dams with net economic gains on both sides of the DBL.

## 5. Discussion

Many studies have concentrated on the historical records of the flood inundation in Kabul, Nowshera, Peshawar, and Charsaddah. Most studies proposed drastic measures to decrease the frequency of flooding by adopting collaborative water resources management and to take steps towards the KRB treaty. On the other hand, Gari conducted a study about the application of equitable water resource utilization in the Nile River basin [19]. Gari's survey was about the applicability of the Principles of equitable water resource utilization as highlighted in Article 5 of the 1997 UN Convention on the Law of Non-navigational Uses of International Watercourses (UNWC).

An interesting part of Gari's survey was the opinion of the Egyptian experts on the Nile River basin and how their opinions significantly differed from the opinion of over 207 international experts. Egypt is a downstream state of the Nile River basin. The different opinion of the Egyptian experts on the Nile River water resources management shows the complexity of the situation and how competing interests, political pressure, and unilateralism influence technical opinions.

The discourse on transboundary water resources has three ways of thinking: (a) Lack of technical information or epistemic limitations [12], (b) Lack of a working transboundary agreement on water resources management, and (c) Hegemonic behavior of the strongest member of the basin.

There are a number of international templates for countries with shared watersheds, such as the United Nations Watercourses Convention (UNWC) and the UN Sustainable Development Goal (SDG-2030). Article 6 of the UNWC outlines a series of actions to enable equitable water resource usage [19]. The UN SDG-2030 proposes a series of templates to identify the degree (Indicators 6.5.1) and proportion (Indicators 6.5.2) of the transboundary water resources management, including flood risk management.

While Chaisemartin proposes the amendment to the SDG indicators to make them more flexible and applicable to the specific basins [16], these indicators and templates will provide the grounds for using the technical findings as to the basis for any transboundary cooperation.

This study's quantitative results reveal the potential for decreased flood frequencies under the future dam and climate scenarios. The findings indicate that the retention of flood flows in the dams will address the seasonal thirst of agricultural lands on either side and will increase the low flow in dry seasons. The economic benefits of the dam options are substantial. However, finding solutions to complex transboundary power dynamics, flood mitigation, and prevention of unilateral water resources utilization including the danger of dam construction race is complicated.

Assessing the implications of transboundary conflict and cooperation dynamics are very challenging, but only if resolved will these translate into progress and the potential for implementation be realized. However, suppose the results can be distributed to the two parties (Afghanistan and Pakistan), in that case, the opportunity exists to really make progress on establishing a cooperative water resources environment that can enable cooperation on other bilateral issues.

While introducing hydro-infrastructure is a positive measure to reduce the flood frequencies and conservation of water resources, this is a sensitive topic in the transboundary KRB where the intricacies of the post-war grace period for Afghanistan development may be challenged by its neighbor [31].

Since the KRB is a shared transboundary basin with many socio-economic, political and power dynamics, major flood prevention infrastructure projects, while benefitting flood routing, will impact areas downstream in the KRB. It might also be beneficial to use the example of the holistic and intra-basin water stress and flooding as proposed for the Ganges and Brahmaputra River basin between India and Bangladesh [32] as part of the communication to establish the merits of the situation for the KRB. Therefore, it is important to assess the power dynamics, the transboundary conflict and cooperation, and the risks and benefits associated with the future dams in KRB in basin-wide water resources distribution.

### 5.1. Power Dynamics in Transboundary Water Resources Management

While resource scarcity is the cause of power dynamics in regional resource allocation, in the KRB, there exists a demand-induced scarcity [9]. There exists a notion that Afghanistan may compensates for its structural power deficit by relying on its vast water resources and international support [33]. However the agricultural expansion on the Pakistan side of KRB in the past 50 years was three times more than that of the agricultural expansion on the Afghanistan side of KRB [23,34]. Afghanistan's water resources are severely underutilized. Afghanistan is producing ~622 MW of electricity, of which only 350 MW is generated from hydro turbine generation [35]. On the other hand, ~35% of Pakistan's electricity is produced by fossil [21], and the country is ~5000 MW or ~25% short of its energy sufficiency [35,36]. Only ~25% of the population has access to hydropower in Afghanistan [37]. With the potential to generate over 2870 MW of electricity in the Afghanistan portion of KRB, it is evident that Afghanistan is lagging in meeting its hydropower needs and opportunities. Afghanistan is 3524 MW or 75% short of its energy sufficiency. Considering the current realities and the regional precedents of both the Tigris and Euphrates [38] and the Ganges-Brahmaputra River System [32], it is crucial to adopt the bilateral water resources sharing scheme doctrine that is specific to the KRB.

It is also recorded that the bulk of the KRB water is not utilized in the KRB (Afghanistan and/or Pakistan); rather, the flows are channeled into the Indus River for further water intake downstream. While the cities and towns in the vicinity of the KRB (Kabul, Charikar, Pole Alam, Jalalabad, Peshawar, Nowshera, Charsaddah, Kheshgi) are experiencing biannual flood situations, the bulk of the water is channeled to flow downstream into the Indus River for further use downstream.

The Kabul River annual augmentation into the Indus River varies between ~28.6 billion $m^3$ and ~34.5 billion $m^3$ [28]. Considering the progressive expansion of irrigated land in the Pakistan portion of KRB and planned expansion of the irrigated land on the Afghanistan side of KRB, the water stress is going to increase in the coming decades due to the channeling of the water resources.

A long-term solution will be to reach a KRB-specific agreement between the neighboring (i) Khyber Pakhtunkhwa Government that is entirely located in the KRB and (ii) the Afghan government. The equitable utilization of water resources in this part of the world has three major segments, (a) consensus is necessary to further develop the water resources management to better the people on both sides of the DBL as a region with growing cultural and economic relations, including KRB-specific clauses, (b) meeting Afghanistan's needs for hydropower and irrigation infrastructure, which are lagging in many aspects of the hydro infrastructure and water resources management due to the prolonged civil war, (c) putting the water resources management and cooperation best practices into the service of other bilateral issues such as transit, trade, transportation, regional integration between South Asia and Central Asia and transboundary economic zones.

*5.2. Transboundary Impacts on Flood Mitigation*

The KRB is a unique basin with multitudinous historical and political contexts. The basin is divided by the Durand Boundary Line (DBL), which has been the source of intense disagreements between Afghanistan and the British Empire, and subsequently Pakistan, since its creation in 1947. Bracken [39] describes three types of borders that affect Flood Risk Management (FRM). These include (a) the physical border, which are boundaries with physical elements such as rivers and mountains, (b) the conceptual border, which include approaches and concepts of the water resources management or flood management, and (c) the administrative border, which encompasses the policy approach and interpretation towards flood risk management [39]. DBL does not fit with any of these descriptions.

There is no agreed-upon institutional arrangement between the two riparian states to identify the boundaries and scope, nor has there been any conceptual arrangement between the local administrations and organizations on both sides of the DBL such as described for the Scottish and English boundary [38] as an example. The physical boundary is also missing since no major physical natural element is separating the two regions of KRB.

The lack of a working agreement on flood control and water conservation has not benefitted the KRB on either side of the DBL (Afghanistan and Pakistan). Seasonal flooding is a geographical phenomenon, with flooding at locations throughout the entire KRB area. Seasonal floods negatively influence most major cities and adjacent agricultural lands in the KRB. To utilize the water resources within the KRB boundaries, a working mechanism must be agreed upon between the two riparian states within the current geopolitical policy framework.

The Kabul River is considered a multinational river that crosses through a boundary but is joining another international river—the Indus River. The riparian control of water resources in this basin may be governed by several accepted and historical principles, namely (a) the principle of absolute sovereignty, also called the Harmon Doctrine, (b) the principle of absolute territorial integrity, (c) the principle of prior appropriation, (d) the principle of restricted territorial integrity, (e) the principle of community interest, and (f) the principle of equitable utilization [9]. Each of the listed principles have had their use and interpretation during different water-related encounters [9]. Many principles are obsolete and are no longer accepted by international law frameworks; however, some countries are using these principles to justify their positions on water resource utilization.

Warner [16] benefited from the studies by Wendt [40], and Buzan and Weave [41] who identified three schools of thought in transboundary water resource utilization. These schools of thoughts are: (1) anarchy, or whoever has power, decides, (b) mature anarchy or neo-institutionalism, where interests decide, and (c) security community or integration-ism, where context and integration with others decide [16]. These thoughts are in many ways aligned to the Dohrmann [9] description of doctrines in water resources utilization.

Among the many definitions of water usage principles, the Kabul River is best suited for the principle of equitable utilization of water resources. The basin has vast water resources distributed inadequately. Uneven flow is causing water scarcity during the dry season and flood situations during the high flow seasons. One of the negative impacts of unilateral water resource utilization is the unplanned crop selection and agricultural land development on both sides of the DBL, resulting in exacerbated water consumption and agricultural land expansion. Sneyd [42] describes crops such as cotton, sugarcane and wheat as water-intensive in arid geography. Considering the potential increase in irrigation, water demand due to climate change is an important consideration in transboundary water management as a multi-stakeholder optimization problem with complex constraints and criteria [43,44].

The HEC-RAS modelling results indicate many-fold benefits of the water retention structures such as dams and barrages, as any flow over 2000 $m^3/s$ will cause flooding in the overpopulated areas of downstream Peshawar, Kheshgi, Nowshera, and Charsaddah. The reduction in the river trans-sections (hydraulic radius) often results in flooding and property damage and loss of human life. The SWAT and HEC-RAS results show that the construction of water storage sites will reduce flood frequencies. The transboundary water resources agreement will retain up to (40.2%) of floodwaters in the dams that will serve as a flood routing mechanism. The agreement will retain up to 63% of the water resources within the basin.

In the case of the Meuse River cooperation between The Netherlands and Belgium, the transboundary cooperation in the water resources areas offset the power asymmetry [16] when territorial influence fades away, and the issue-linkage replaces the river-linkage. Transboundary cooperation between Afghanistan and Pakistan on the dam construction and management along the DBL and particularly on the Konar River is an essential step towards peaceful and inclusive resource management. This River alone can produce up to 2025 MW of electricity [7,8].

The demand for hydropower in the eastern provinces of Konar, Laghman, Nuristan and Nangarhar of Afghanistan will not exceed 1000 MW in the next 25 years [8]. Hence, it is evident that with the development of dams and electricity production, Pakistan will be the primary customer for the excess electricity [8]. Engaging Pakistan in water resources management in the KRB will ease tensions on the trade and transit that travel via Pakistan's major highways and railways. This exchange of benefits will be based on mutual commitment and cooperation.

### 5.3. Water and Transboundary Cooperation Uncertainties

The KRB, like any other transboundary basin, is under the influence of uncertainties. These uncertainties are two-fold. Uncertainty related to ontological (variability), as described by Heinric [12], as in the case study of Lake Ontario and St. Lawrence River. Variability may include precipitation, streamflow, climate variability, and glacial melting.

The second group of uncertainties is related to epistemic variability or knowledge gap, including technical information, management practices, and political uncertainty. Some phenomena encompass both uncertainties, such as land-use change. Some parameters of the KRB uncertainties are listed in Table 4.

In the example of the hydro politics between Turkey, Iraq, and Syria, Dohrmann concludes that despite the water scarcity and unilateral utilization of water resources by Turkey as an upstream country, the water issue is not the only, and not even the largest, transboundary conflict in the trilateral relationship [9]. Daggupati, however, indicates that unilateral water utilization without consultation with the downstream partners in the Tigris and Euphrates basin has caused significant depletion of water resources in Iraq and Syria [38]. Naf describes water as national security and territorial integrity issue [45].

In the KRB context, the issue is about mitigating floods and peak flows rather than reducing the average annual flow. Water resources management does not govern Afghanistan and Pakistan's bilateral relations. However, bilateral relations are governed by an array of other transboundary issues that drag water diplomacy into these disagreements. The no-decision paradigm contributes to the unilateral water resources utilization [46] and pushes the two states to the Harmon's Doctrine. Some major transboundary agents that influence water diplomacy are listed in Table 5.

**Table 5.** KRB transboundary conflict and opportunities.

| The Issue | Brief Description | Who Controls the Issue? | Opportunity or Risk | Overarching Opportunities for Cooperation |
|---|---|---|---|---|
| Water resources | Weak upstream and stronger downstream states (the opposite of Turkey, Iraq and Syria) | Afghanistan | Opportunity for Pakistan | Water resources are the primary catalyst in other areas of bilateral cooperation |
| Transit | Pakistan holds the gate to sea transit of Afghan goods and the gate to conduct trade with India | Pakistan | Opportunity for Pakistan | Revenue to Pakistan, Political pressure mechanism for Pakistan |
| Trade | Pakistan is the largest trade partner of Afghanistan | Pakistan | Opportunity for both countries | Up to USD $10 Bln, trade potentials in the next 10 years |
| Durand Boundary Line | The DBL is formally not recognized by Afghanistan | Afghanistan | Risk of continued tensions | People diplomacy and soft boundary until the DBL issue is settled, establishment of economic zones in the vicinity |
| Ethnic Connectivity | The Pashtun minority in Pakistan consider themselves as Afghans | Afghanistan | Opportunity for Afghanistan | Ethnic connectivity can add value to transboundary cooperation (local business, free trade zones, visa-free entry, investment incentives, and water incentives to KPK) |
| Regional Complexity | Afghanistan is the proxy land for the Indo Pakistani conflict | Pakistan | Opportunity for Pakistan | Enabling South Asian trade route (Central Asia, Afghanistan, Pakistan India), Energy transmission routes such as the (CASA-1000), (TAPI) regional connectivity projects |

Afghanistan's ambitions in the planning and construction of dams along the Kabul River may be categorized as counter-hegemony by Pakistan. Afghanistan's effort to secure a grace period in its dam construction after 40 years of war [30] can be described as catching up with late development rather than displaying hydro hegemony. Due to prolonged civil war and foreign interventions, there is an international consensus that Afghanistan has lagged in meeting its developmental goals, including flood risk management. However, Afghanistan's unilateral efforts to build the proposed dams can also be categorized as influencing power simultaneously as challenging power.

In the first case, Afghanistan may initiate the dam projects to reduce the flood frequencies, increase agricultural land, hydropower generation, and increase low flow. This may force Pakistan to comply and start bargaining for other cooperative measures such as trade and transit.

By contrast, this action can be described as a challenging power that will result in counter-hegemony by Pakistan and involve adequate countermeasures such as scrapping the Afghanistan–Pakistan Transit Trade Agreement (APTTA) or similar retaliatory measures along the Chitral River.

Since multiple factors contribute to the water security crisis [47–52], such as rainfall variability, floods, and population water demand [11], it must be quantified in a manner to seek the economic benefit at the basin level, rather than using the water as a hegemony and influence medium. The early agreement on recognizing the changing climate and flow regimes and curb the ever-increasing flood frequencies may change the power dynamics altogether.

Water cooperation will affect the transit and trade between the two countries. In this case, continued collaboration may ease the boundary tensions and agree on softer border reactions and trans-cultural trade and interactions between the people of both countries with similar cultural and social backgrounds. For downstream flood frequency, reduction and low flow increase, a KRB-specific water resources agreement will be a viable solution to keep most of the water resources within the KRB and keep both sides committed to bilateral agreements.

### *5.4. Benefits and Risks of Proposed Dams*

The SWAT modelling results and the HEC-RAS flood inundation analysis indicate the importance of dams in the geographically and socially complex KRB terrain. The reduction of ~25% in flood inundations in the Nowshera alone is a strong economic development opportunity. Over six major Afghanistan and Pakistan cities are in the vicinity of seasonal floods. Rapid population growth in the cities makes them more vulnerable to seasonal floods. The reduction of the flood frequency return period from 10 years to 50 years indicates the opportunity of the dam scenario benefits.

A brief economic analysis of the dam initiative was conducted. The World Bank [8] document and WAPDA projects calculated the capital costs of all proposed dams in Afghanistan and Pakistan's sides of the KRB to be ~US$15 Bln. The proposed dams' net economic benefits, including flood prevention, agricultural land development, and hydropower sale, will generate over US$1Bln. annually.

The KRB proposed dams initiative will ensure the benefits if Pakistan is on board in its implementation. The Khyber Pakhtunkhwa province's involvement, a direct downstream beneficiary of the KRB water resources development, will open new horizons for transboundary cooperation.

The proposed dams also have potential risks, categorized into two portions, (a) perceived risks and (b) potential risks, which should be identified and mitigated before proceeding with the dam scenarios on both sides of the DBL.

## 6. Conclusions

Flash flooding is a major problem in the KRB on both sides of DBL. This is due to KRB's geography below the Hindu Kush Himalayan (HKH) Mountains but is heightened by global climate change with predicted heavy downpour in the spring months rain-on-snow events resulting. This study provides a quantitative analysis of the flood risk in the KRB under the existing and future climate scenarios. Further population growth, particularly in the urban areas, will increase urban land use, making them vulnerable to seasonal floods.

The SWAT modelling KRB flows were used in the HEC-RAS model for mapping flood inundations. The study has considered the developmental goals in Afghanistan and Pakistan while accounting for future agricultural land expansion trends. The results show that increased air temperatures and glacier melt influence the increase in flood frequencies. In case no future dams are built, the flood inundation compared to historical records will increase between (+17%) to (+31%) in RCP 4.5 flow scenarios and between (+26%) to (+50%) in RCP8.5 scenarios. In the case of future planned dams, the flood inundation reduction of between (−25%) to (−40%) in RCP 4.5 flow scenarios and between (−34%) and (−38%) in RCP 8.5 flow scenarios are forecast for the Nowshera and Kheshgi regions.

Pakistan is also planning a series of dams in the KRB. A balanced and cooperative hydropower generation politics may end the dependency of Afghanistan and Pakistan on coal and fossil fuel electricity generation. A balanced and cooperative dam construction policy may prevent the dam construction race.

From a power balance perspective, it is evident that the doctrine of equitable utilization of water resources should be adopted in lieu of Harmon's Doctrine. In the case of unilateral utilization of water resources by either country, they may lose many opportunities in trade, transit, and trans-cultural integration of the people on both sides of the DBL. Looking at the realities between the two countries, Afghanistan and Pakistan should agree on the KRB specific agreement where Khyber Pakhtunkhwa (KPK) is directly affected by the KRB flooding. Limits on the agricultural land expansion, balanced water retention structures, and water intake need to be put in place on both sides. Similarly, limits on the flow volumes to the Indus River must be placed.

Although climate change increases water availability, this increase will deplete the snowpack budget at the HKH Mountains' origin in KRB at a higher pace in the long term. Such increases are projected to be driven by accelerated glacier melt (up to −20.3% under RCP4.5 and −21.6% under RCP8.5) at the headwater region of the KRB. Keeping in mind that the glaciers constitute up to 3.3% of the KRB area, their melting will increase the low flows.

Based on the historical floods and the level of destruction, it is estimated that the dams' construction is an economically justifiable decision. The study indicated that the amortization of the dams would be paid off in ~15 years. Both countries cooperate in flood warning, hydropower transmission, data exchange, and riverbanks monitoring. The study identified significant transboundary conflict and cooperation opportunities that are an integral part of the transboundary relationship.

These technical quantitative and qualitative findings of the study are a timely contribution towards understanding the future impact (under climate change) of dam development and flood frequency reduction in light of Afghanistan and Pakistan's developmental goals and power dynamics. The availability of the modelling results and a robust understanding of the water resources status of the KRB in current and future cases will be necessary information for water resources planners and managers in both riparian states.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/w13111513/s1. Figure S1: Measured and SWAT model calculated daily Kabul River flows at the Nowshera station, and Table S1: Major runoff and flow parameters in the KRB SWAT modelling.

**Author Contributions:** Conceptualization, Y.M.T., E.M., B.G.; methodology, Y.M.T., E.M., P.D., Y.L., B.G.; modelling, Y.M.T., Y.L., formal analysis, Y.M.T., E.M., P.D., Y.L., B.G.; resources, E.M., B.G.; data curation, Y.M.T.; writing—original draft preparation, Y.M.T., E.M., P.D., Y.L., B.G.; writing—review and editing, Y.M.T., E.M., B.G.; visualization, Y.M.T.; supervision, E.M., P.D., Y.L., B.G.; funding acquisition, E.M. and B.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by NSERC Discovery Grant (#400675 and #400677).

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

**Acknowledgments:** The authors acknowledge the contribution of the following agencies that provided recent data for this study: Ministry of Energy and Water of Afghanistan. Directorate of Water Resources; Pakistan Water and Power Development Authority (WAPDA); Ministry of Agriculture, Irrigation and Livestock of Afghanistan; International Centre for Integrated Mountain Development (ICIMOD)—Afghanistan office; and World Food Program (FAO).

**Conflicts of Interest:** The authors declare there are no competing interests.

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