# Evaluating Transboundary Water sharing benefits with Hydro-Economic Model; Case: Teesta

PhD Research Proposal

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Co Supervisors: **Professor Lin Crase**

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- **Journal Publications**
- Hossen, M.A, Connor, J, & Ahammed, F, 2021 “Review of Hydro-Economic Models (HEMs) focusing on transboundary rivers”, *Water Policy,* vol 23,no 6. pp1359-1374.
- Hossen, M.A, Connor, J, & Ahammed, F, 2021 “Evaluating a Broad Scope of Transboundary Water Sharing Benefits with Hydro-economic Modelling”, *Water Resources Management*.

**List of publications**
**Extended Abstract Presented in Peer Reviewed Conference Proceedings**

Hossen, M.A, Ahammed, F, & Connor, J 2020, ‘The economic value of different types of water uses in the Teesta River of India and Bangladesh’ *AARES 2020*, Perth, Australia.

**Paper Published in Peer Reviewed Conference Proceedings**

- Hossen, M.A, Ahammed, F, & Connor, J 2021, ‘How to Mitigate Transboundary Water Dispute’ *AARES 2021*, Sydney, Australia. Hossen, M.A, Ahammed, F, & Connor, J 2021,
- ‘Potential for benefit Sharing in GBM Basin’ *Australian National Water Conference 2021* (Ozwater ‘21), Adelaide, Australia. Hossen, M.A, Ahammed, F, & Connor, J 2021,
- ‘Water diversion and Ground Water inflow to the Teesta River’ *Hydrology & Water Resources Symposium (HWRS21*), Virtual Symposium, Australia.

# Introduction

- There are more than 260 transboundary rivers in the world
- Traversing around 145 countries
- These rivers are cause of conflict
  - Arab and Israel
  - India and Pakistan
  - India and China
  - America and Mexico
  - Nile, Mekong, and Amu Daria

- Management of rivers is important not for economy but also for peace

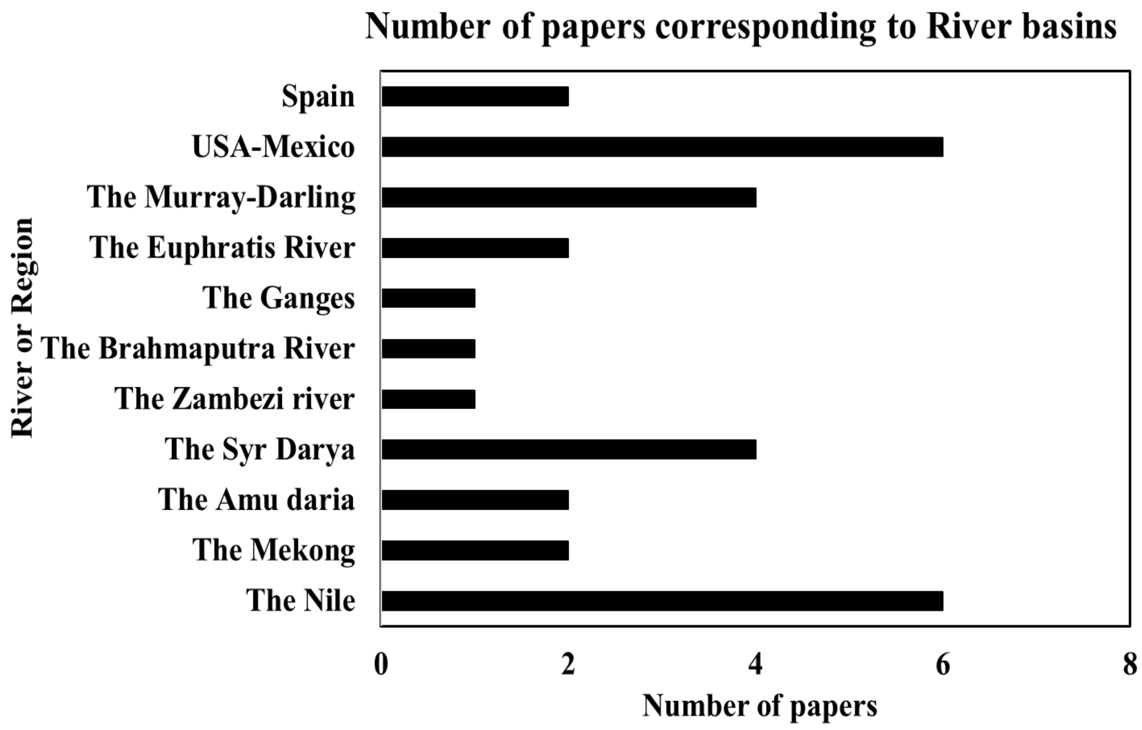
# Hydro-economic models (HEMs)

- HEMs are used to optimize benefits from river basin
- HEMs are also used to analyze water scarcity, drought, and water management problems.
- More than 300 HEMs have been developed worldwide
- Only 25 articles focused on transboundary river water disputes

# HEMs related to transboundary issues

- There are many HEMs for the Nile River that evaluate the river basin’s water sharing disputes.

- There are few studies on the Murray-Darling River basin that relate to water sharing.
- HEMs are also relatively well developed on rivers between the USA and Mexico



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# HEMS on MDB

AGRICULTURAL WATER MANAGEMENT 93 (2007) 123–135

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Agricultural Water Management

**Integrated hydrologic–economic modelling for analyzing water acquisition strategies in the Murray River Basin**

*Mohammed Mainuddin*, Mac Kirby, M. Ejaz Qureshi*

*CSIRO Land and Water, GPO Box 1666, Canberra ACT 2601, Australia*

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The Australian Journal of Agricultural and Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

*The Australian Journal of Agricultural and Resource Economics*, 55, pp. 487–499

**Economic effects of water recovery on irrigated agriculture in the Murray-Darling Basin***

Journal of Hydrology 518 (2014) 120–129

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Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Climate change and environmental water reallocation in the Murray–Darling Basin: Impacts on flows, diversions and economic returns to irrigation

CrossMark

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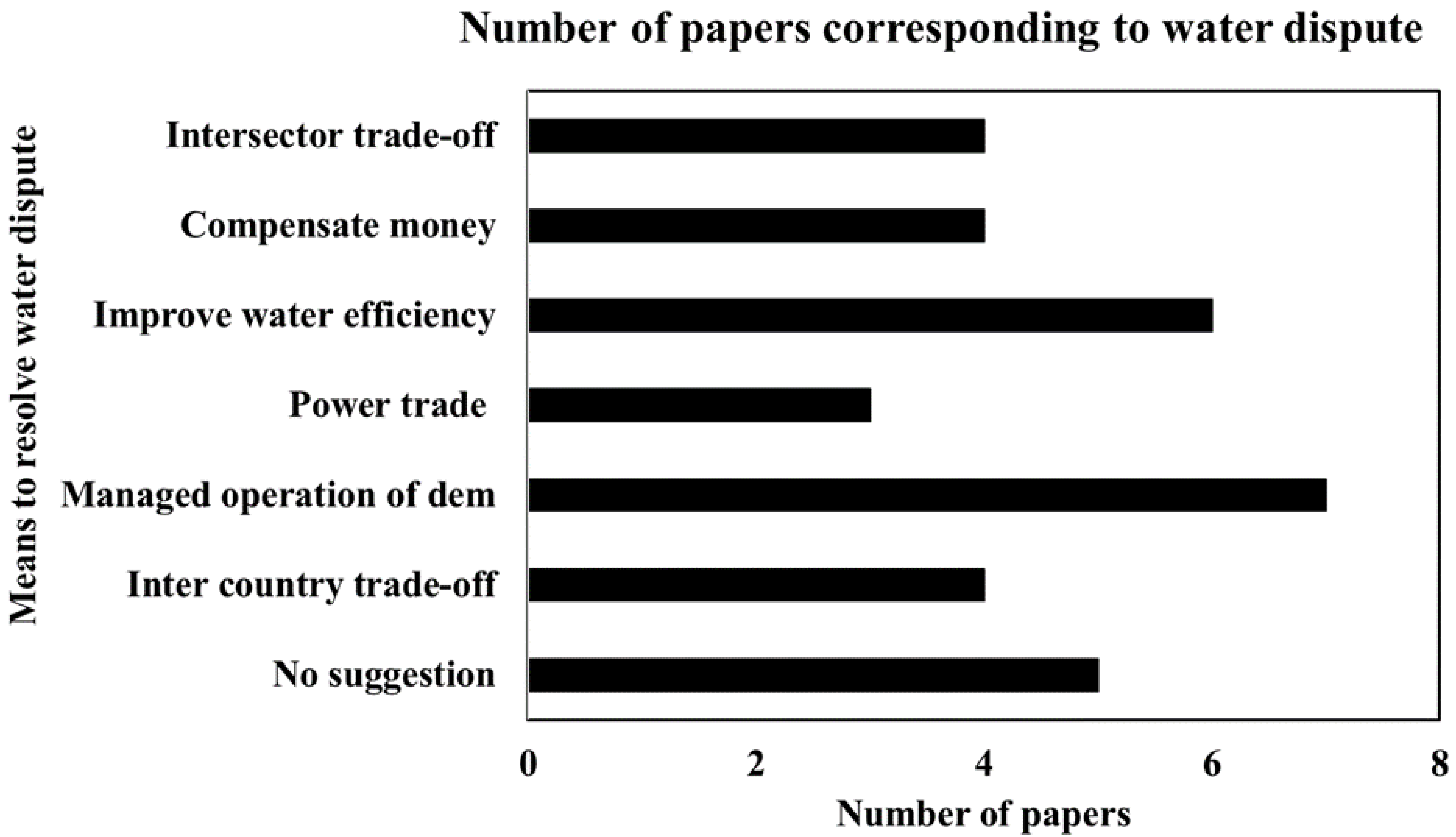
# Dispute Resolution Proposal



# Teesta Hydro-Economic Model

## Model Objective

- To assess water available for agriculture, hydropower, navigation, domestic and e-flow
- Economic value of water for these use
- Assess the potential loss and gain for India and Bangladesh if water is shared



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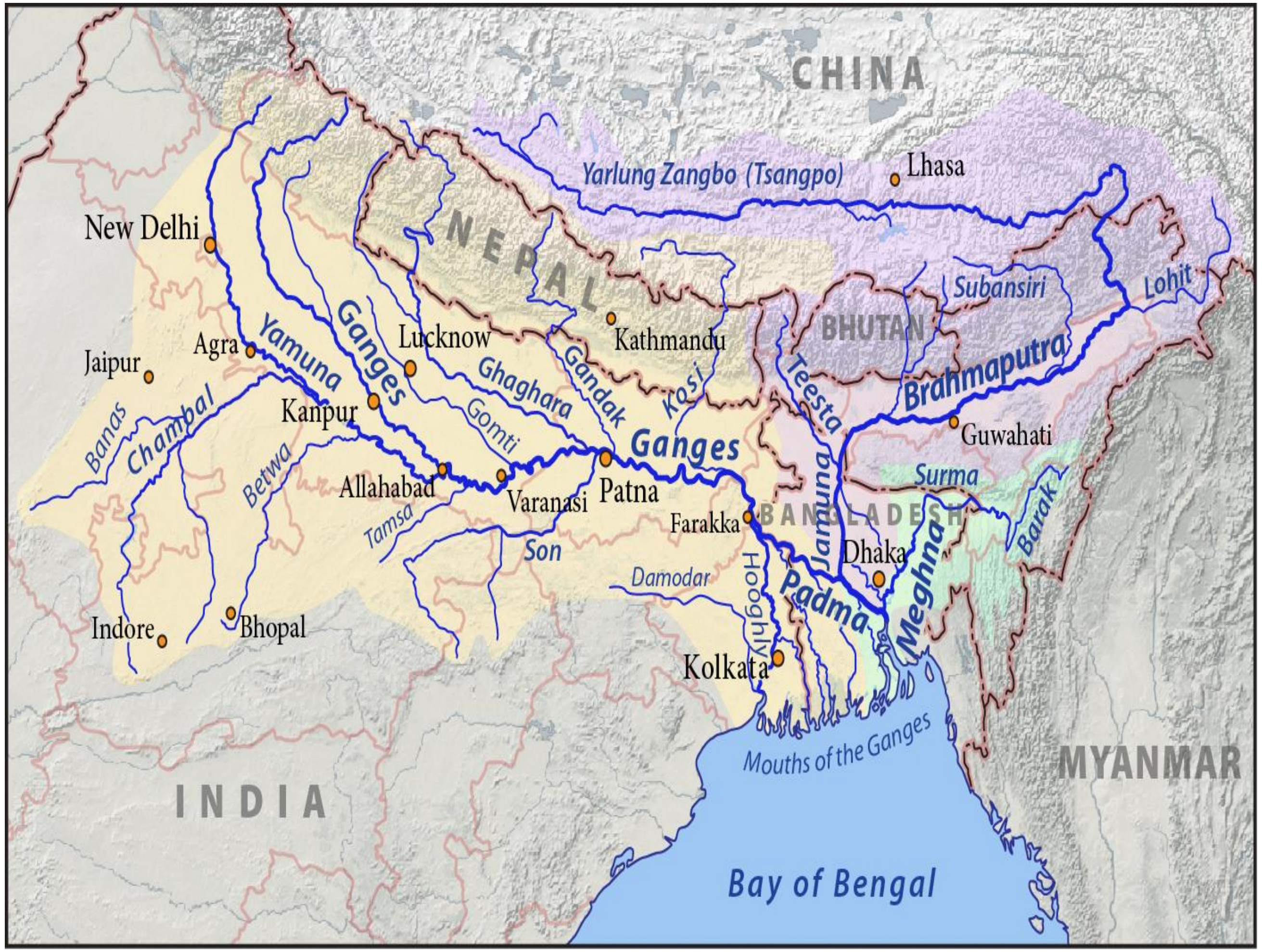
# GBM River System

- India, Nepal, Bhutan and Bangladesh share the Ganges–Brahmaputra–Meghna (GBM) system
- 93% of the GBM basin is located outside Bangladesh (FAO,2011)
- But 92% water pass through Bangladesh
- Being a downstream country, Bangladesh has no control over rivers




Ganges Brahmaputra Meghna (GBM) basin(source Google)



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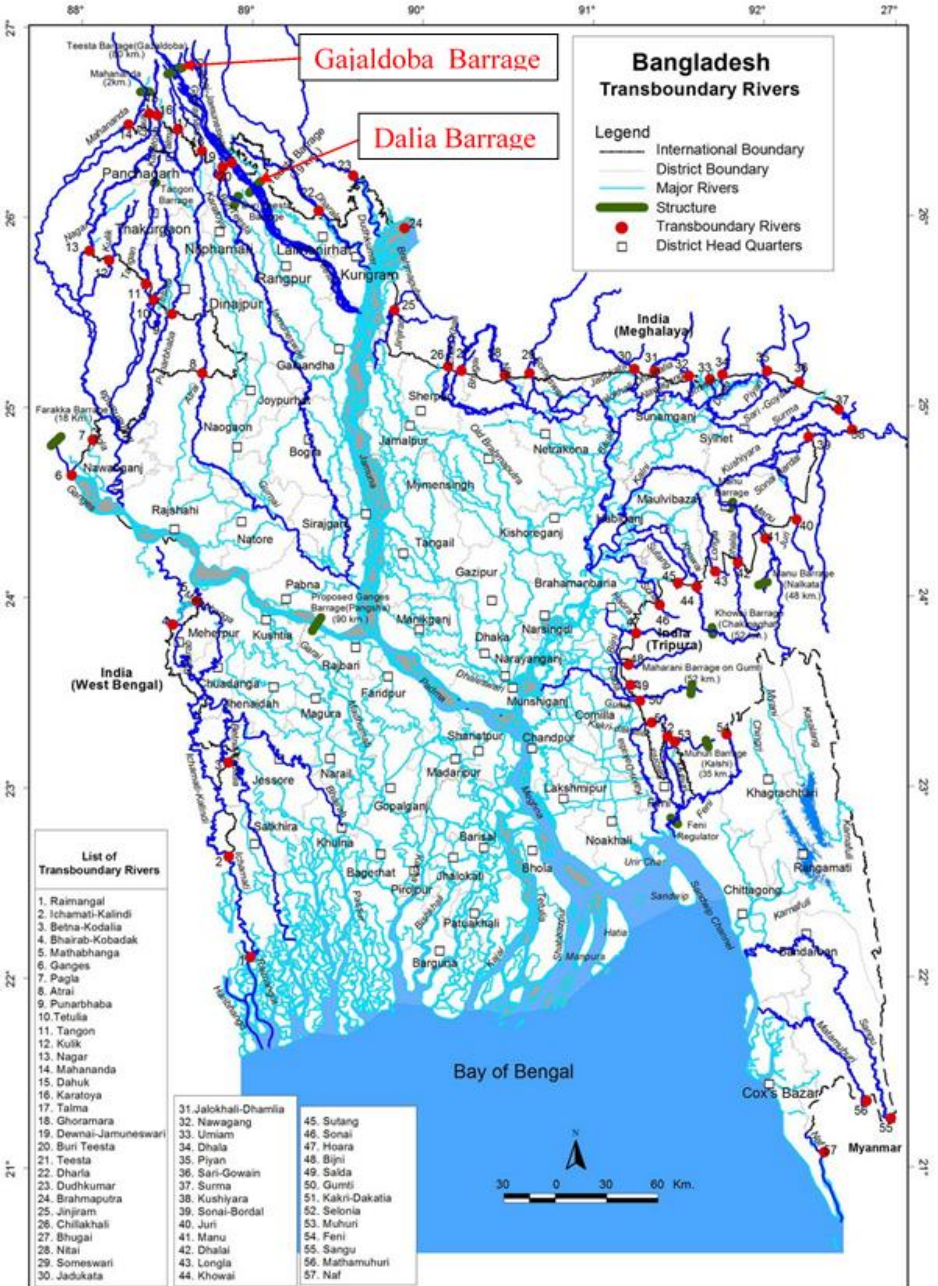
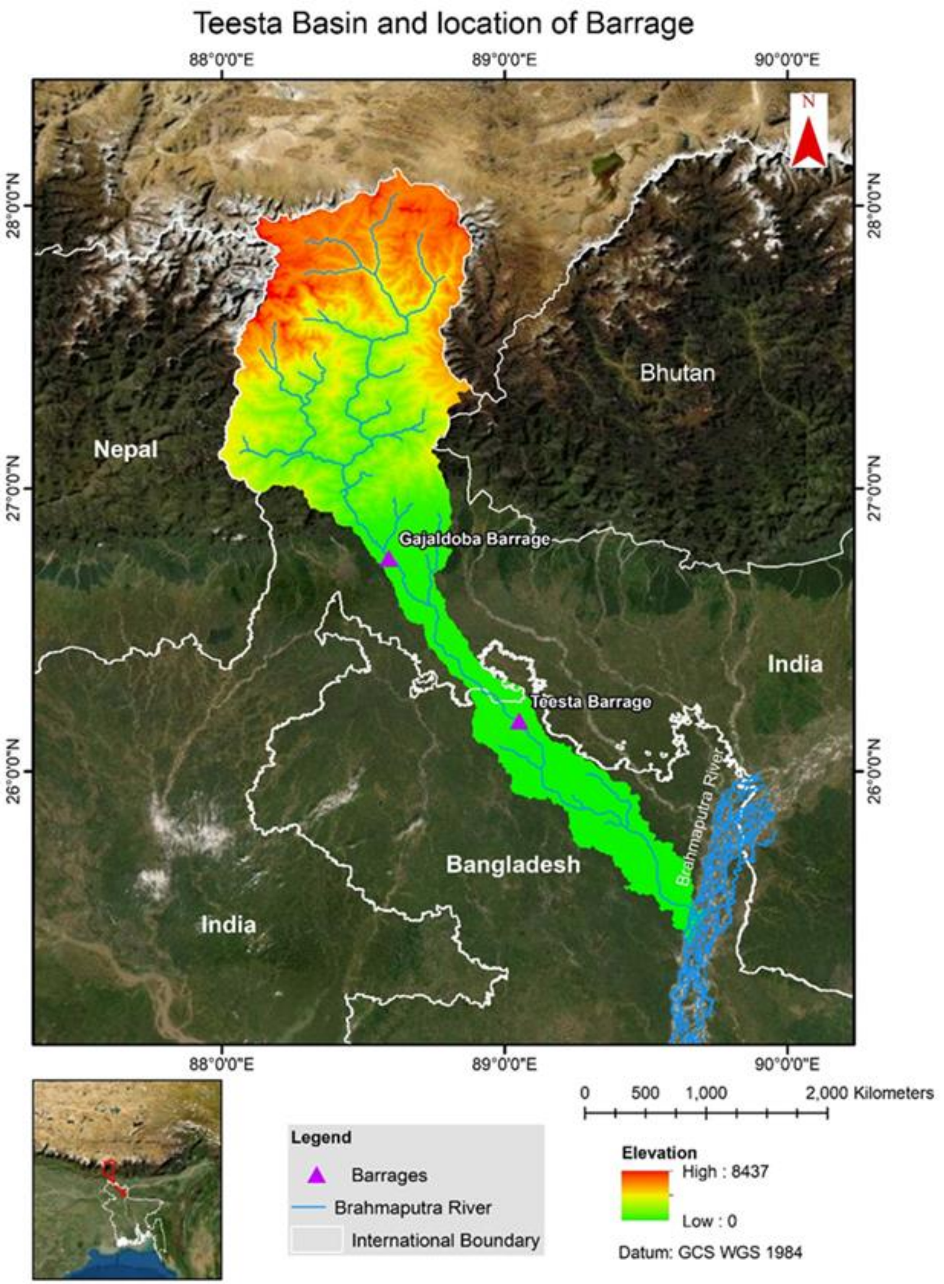
# India Bangladesh Water Dispute



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# The Teesta Water Dispute

- Drought and flood consecutively
- Fishermen, boatmen migrated to other areas/professions
- 21 millions people affected (Islam,2016)
- Affecting agriculture, fisheries, navigation and environment

**Drought**


**Flood**



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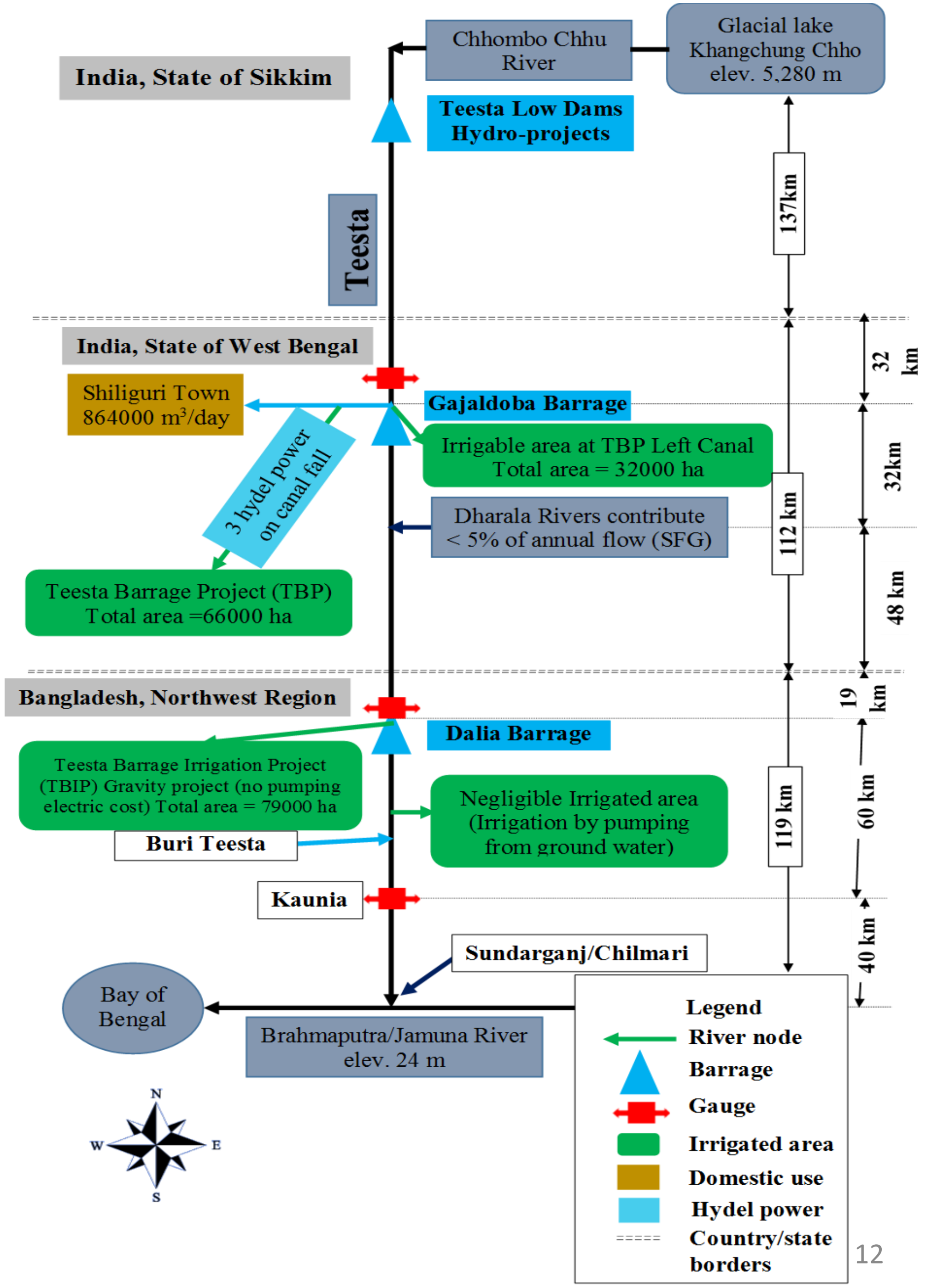
# Simplified Network of Teesta

- The model was coded in General General Algebraic Modeling System (GAMS) which is a non-linear, optimization model.
- $\max Z = \sum_{i,j,t} BEN\_Ag_{i,j,t} + \sum_{t} BEN\_Hydro_{t,l} + \sum_{i,t} BEN\_M_{t,l}$ (4.1



# Set (Flows, Time, Crop, Locations)

gamside: C:\Users\hosmy025\Documents\gamsdir\projdir\gmsproj.gpr - [D:\Sensitivity Cases\Case 1 Teesta HEM base 200

File Edit Search Windows Utilities Model Libraries Help

GAMS

Case 1 Teesta HEM base 2008-09 on 02.05.2020.lst | Case 1 Teesta HEM base 2008-09 on 02.05.2020.gms

```
****************Section 1************************************************************

SETS

*************************************************************************************
 i  Flows location of important nodes in Teesta Basin--Gajaldoba to Brahmaputra
*************************************************************************************

/
Flow_Gajaldoba       Flow at  Gajaldoba                          inflow(i)
Flow-Dalia           Flow at  Dalia
Flow_Kaunia          Flow at  Kaunia

TST_idi     Diversion at Testa Barrage Project India              divert(i)
TST_idb     Diversion at Teesta Barrage Irrigation Project Bangladesh
TST_ef      Environmental flow at outlet
TST_mds     Municipal diversion for shiliguri town
/

muse  municipal use
 /STS_u      Shiliguri town use
 /

t time
 /

2008Nov01
2008Nov02
2008Nov03
2008Dec01
2008Dec02
```

# Parameter (known values)

gamside: C:\Users\hosmy025\Documents\gamsdir\projdir\gmsproj.gpr - [D:\Sensitivity Cases\Case 1 Teesta HEM base 200

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GAMS

Case 1 Teesta HEM base 2008-09 on 02.05.2020.lst | Case 1 Teesta HEM base 2008-09 on 02.05.2020.gms

```
/
****************Section 2*************************************************************

Table inflow(t,l) flow of the river by time and location
$offlisting
$ondelim
$include D:\Hydro-economic models\Teesta HEMs by GAMS\THEM\Inflowcum2008-09.csv
*$include G:\University pc\PhD Research\Hydro-economic models\indatacum.csv
*$include c:\tuhin\gams\indatacum.csv
$offdelim
$onlisting;
Table gwflow(t,l) flow of the river by time and location
$offlisting
$ondelim
$include D:\Hydro-economic models\Teesta HEMs by GAMS\THEM\GWflowcum2008-09.csv
*$include c:\tuhin\gams\GWflowcum.csv
$offdelim
$onlisting;
**************************************************************************************
Parameter  eflow(t,l) minimum environmental flow that should be maintained  ;
eflow(t,l) = 0.2* (inflow(t,l) + gwflow(t,l))   ;
Parameter  rev_f(t,l) 10 days fisheries benefit(US$)for each cumec flow;
*For 60km length, Fisheries benefit =TK 72,616 per month per cumec flow=72616/(3
*If flow is less than 50 cumec, benefit is zero (Ref Riaz akhter Mollick, 2014)
rev_f(t,l)= 351.005;
Parameter  rev_n(t,l) 10 days navigation benefit(US$)for each cumec flow;
*For 60km length, Navigation benefit =TK 7150 per month per cumec flow=7150/(3*6
*if flow is less than 24 cum benefit is zero (Ref Riaz akhter Mollick, 2014)
rev_n(t,l)= 34.56;
Parameter Dem_m(i)  10days Water demand of Shiliguri city  in m3
*Population in 2011 5,13,264. Total Water required fo 10 days (135*5,13,264*10)/
/TST_mds      692906.4 /
Parameter T_Dem_m(i,t)  Total Water demand acccounting growing Shiliguri city po
T_Dem_m(i,t) $ (ord(t) le 12) = Dem_m(i);
T_Dem_m(i,t) $ (ord(t) gt 12) = Dem_m(i) * (1 + .03);
display T_dem_m;
```

# Parameter

```
/TST_mds    0.125 /
parameter slope_elasticity(i,t)  estiamted slope elasticity of demand ;
slope_elasticity('TST_mds',t) = p_elasticity('TST_mds')*mw_price_10('TST_mds')/T_Dem_m('TST_mds',t);
display slope_elasticity;
*parameter  F_Dem_m(i,t) Future water demand acccounting price elasticity ;
*F_Dem_m(i,t)= T_Dem_m(i,t)+p_elasticity_p(i)*m_price_10_p(i);
Parameter Intercept_a(i,t);
Intercept_a('TST_mds',t)=mw_price_10('TST_mds')+slope_elasticity('TST_mds',t)*T_Dem_m('TST_mds',t);
Display Intercept_a;
Table Wd_cr(i,j,t)   Total crop water demand (m3 per hectre) for 10 days period
*source for india: The status of water resources in West Bengal by Kalyan Rudra, 2017
*source for BD TBIP project authority(Amlesh, agriculture officer) and mullick et all 2010

                     2008Nov01   2008Nov02   2008Nov03   2008Dec01   2008Dec02   2008Dec03   2009Jan01
TST_idi.Boro_IN        85          125         156         325         350         400         1000
TST_idi.Wheat_IN       6.5         25          37.5        80.5        86          100         280
TST_idi.Potato_IN      6.5         25          37.5        80.5        86          100         280
TST_idi.WVeg_IN        15.5        25          40          90          92.5        109         260
TST_idb.Boro_BD        35          75          132.75      300         350         375         814
TST_idb.Wheat_BD       6.5         10          12.5        30.5        45.5        75.5        230
TST_idb.Potato_BD      15.5        25          40          90          100         109         260
TST_idb.WVeg_BD        15.5        25          40          90          100         109         260
TST_idb.Tobacco_BD     0           0           0           0           57          100         240
```

1: 1 Insert

# Variables (Unknown values)

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File Edit Search Windows Utilities Model Libraries Help

GAMS

Case 1 Teesta HEM base 2008-09 on 02.05.2020.lst | Case 1 Teesta HEM base 2008-09 on 02.05.2020.gms

```
PARAMETER
*****************************************************************************************
*  Land  Block:  land in irrigation is measured in ha
*****************************************************************************************

LANDRHS_t(i)         Total cultivable land
  /
   TST_idi      66000
  TST_idb      79000

 /
*********Section 3**********************************************************************
Variables
Z                   Total benefit
TWD_cr(i,j,t)       Total water demand in m3 for each crop
REV_ag(i,j,t)       Revenue from each crop

Hectre_country(i,t)
;
Positive variables
HECTRES_v(i,j,t)     agricultural land
Outflow(t,l)         Outflow from the node
T_GWflow_Vol(l)
*TWDiv_cr(i,j,t)      total water divert for each crop
GWP_cr(i,j,t)       total Ground Water pumped in m3 for each crop
RWD_cr(i,j,t)       total water demand met by river water in m3 from Teesta for each crop
T_GWP(i)            Total area irrigated by ground water
T_RWD(i)            Total area irrigated by surface or river water
T_WD(i)
```

# Equations

gamside: C:\Users\hosmy025\Documents\gamsdir\projdir\gmsproj.gpr - [D:\Sensitivity Cases\Case 1 Teesta HEM base 2008-09 on 02.05.2020.gms]

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Case 1 Teesta HEM base 2008-09 on 02.05.2020.lst | Case 1 Teesta HEM base 2008-09 on 02.05.2020.gms

```
 T_Ben_fish(l)..       T_BEN_f(l)=e=sum((t),Ben_f(t,l));
 G_T_Ben_fish..        G_T_BEN_f=e=sum((l),T_BEN_f(l));
 Total_Vol_Outflow(l).. T_Vol_Outflow(l)=e=10*24*3600*sum(t,Outflow(t,l));

*Ben_navigation(t,l).. BEN_n(t,l)=e=(-0.001*(Outflow(t,l))*(Outflow(t,l))+0.477*(Outflow(t,l))-2.24);
 Ben_navigation(t,l).. BEN_n(t,l) =e=max(0,rev_n(t,l)*(Outflow(t,l)-24));
 T_Ben_navigation(l)..  T_BEN_n(l)=e=sum((t),BEN_n(t,l));
 G_T_Ben_navigation..   G_T_BEN_n=e=sum((l),T_BEN_n(l));
*Therefore the environmental benefit of diverted water is equally divided into two, 50% for India and 50% for Bangladesh
 Ben_env_India(t,'Gajaldoba')..  Ben_env_In(t,'Gajaldoba')=e=ben_env(t,'Gajaldoba')*(10*24*3600)*Hydro_divert(t,'Gajaldoba');
 T_Ben_env_India(l)..            T_Ben_env_In('Gajaldoba')=e=0.5*sum((t),Ben_env_In(t,'Gajaldoba'));
 Ben_env_Bangladesh(t,l)..       Ben_env_Bd(t,'Kaunia')=e=ben_env(t,l)*(10*24*3600)*Outflow(t,'Kaunia');
 T_Ben_env_Bangladesh(l)..       T_Ben_env_Bd('Kaunia')=e=sum((t),Ben_env_Bd(t,'Kaunia'));

 Ben_dredging_In(t,l)..     Ben_dredg_In(t,'Gajaldoba')=e= 2/3*Ben_dredging(t)*Inflation_Factor(t)*outflow(t,'Gajaldoba')/inflow( t,'Gajaldoba');
 T_Ben_dredging_In(l)..     T_Ben_dredg_In('Gajaldoba')=e=sum((t),Ben_dredg_In(t,'Gajaldoba'));
 Ben_dredging_Bd(t,l)..     Ben_dredg_Bd(t,'Dalia') =e= Ben_dredging(t)*Inflation_Factor(t)*outflow(t,'Dalia')/[inflow(t,'Gajaldoba')+gwflow(t,'Dalia')];
 T_Ben_dredging_Bd(l)..     T_Ben_dredg_Bd('Dalia')=e=sum((t),Ben_dredg_Bd(t,'Dalia'));

 Ben_municipal(i,t)..   BEN_m('TST_mds',t)=e=.5*(Intercept_a('TST_mds',t)-mw_price_10('TST_mds'))*T_Dem_m('TST_mds',t) ;
 T_Ben_municipal(i)..   T_BEN_m('TST_mds')=e=sum(t,BEN_m('TST_mds',t)) ;

*  G_T_Ben_India..       G_T_Ben_In=e=T_BEN_f('Gajaldoba')+T_BEN_ag('idi')+T_BEN_m('TST_mds')+T_BEN_hydro;

 Obj..    Z=E= G_T_BEN_ag + T_BEN_hydro+T_BEN_m('TST_mds');
*Obj..    Z=E= G_T_BEN_ag + T_BEN_hydro+T_BEN_m('TST_mds');
* Obj..    Z=E= sum[t, sum(l,T_Ben_f(t,l)) + sum(l,T_Ben_n(t,l))+ T_Ben_m(t)]+ T_Ben_ag;
***************Section 5*************************************************
MODEL Teesta
/obj, Land,GWP_crop, TWD_crop, Divert_Gajaldoba, WB_Gajaldoba,WB_Dalia,WB_Kaunia,Con1,T_GWPump,T_RWDidert,T_WDemand,Total_GWFlow_Vol,  Pro_hydropower, Turbinecount, Revenue_cr, Ben_agri, T_Ben_Agri,
 G_T_BEN_agri, Ben_hydropower,T_Ben_hydropower,  T_Hydro_divert,T_Hydro_divert_Vol, Ben_fish,T_Ben_fish, G_T_Ben_fish,Total_Vol_Outflow, Ben_navigation, T_Ben_navigation,G_T_Ben_navigation,
Ben_env_Bangladesh,T_Ben_env_Bangladesh, Ben_env_India,T_Ben_env_India,  Ben_municipal, Ben_dredging_Bd,T_Ben_dredging_Bd,Ben_dredging_In,T_Ben_dredging_In,T_Ben_municipal,Cropmix /;
*ANTIGONE, BARON, COUENNE, LINDO or SCIP
*options minlp=BARON;
SOLVE  Teesta using dnlp maximizing Z;

Display TWD_cr.l,Cropmix.l, Turb.l,GWP_cr.l, RWD_cr.l,Outflow.l, REV_ag.l,PRO_hydro.l, HECTRES_v.l,T_GWP.l,T_RWD.l,T_WD.l, BEN_ag.l,T_BEN_ag.l,G_T_BEN_ag.l, BEN_hydro.l,T_BEN_hydro.l,T_Hydro_div.l,
T_Hydro_div_v.l, BEN_f.l,T_BEN_f.l, G_T_BEN_f.l,T_Vol_Outflow.l, T_GWflow_Vol.l, T_BEN_n.l,G_T_BEN_n.l, BEN_n.l, Ben_env_Bd.l,T_Ben_env_Bd.l,Ben_env_In.l, T_Ben_env_In.l,Ben_dredg_Bd.l,
T_Ben_dredg_Bd.l,Ben_dredg_In.l, T_Ben_dredg_In.l, Z.l,BEN_m.l, T_BEN_m.l;
```

# Scenario Development

| Scenario | Water sharing |
|---|---|
| 1(Baseline/Current) | 70% for India, 30% for BD, 0% for river flow |
| 2 (Water Sharing Scenario, Proposed agreement) | 40% for India, 40% for BD, 20% for river flow. India will maximize hydropower |
| | |

Potential loss and gain for both BD and India was computed



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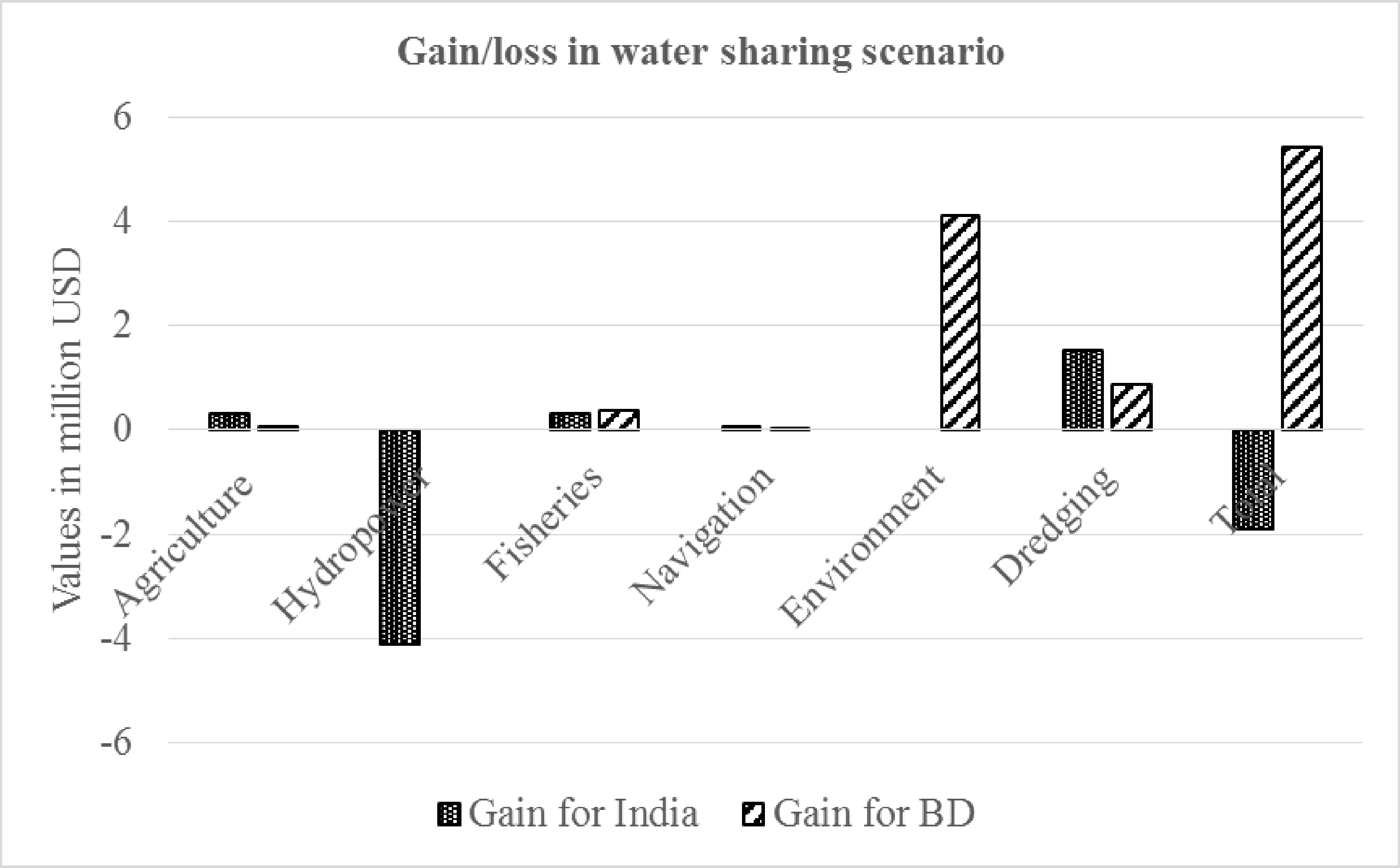
# Result Hydro-Economic Model(Value in US$)

## Hydropower loss is 16.25 MWh for 6 months (70.2GWh)

| | Values are in 2019 thousand USD | | | | | |
|---|---|---|---|---|---|---|
| | **Base Scenario (2008-09)** | | **Water Sharing Scenario (2008-09)** | | **Gain for India** | **Gain for BD** |
| | **India** | **BD** | **India** | **BD** | | |
| Agriculture | 32,555 | 42,241 | 32,875 | 42,311 | 320 | 70 |
| Hydropower | 5,817 | - | 1,761 | - | - 4,056 | - |
| Domestic | 688 | - | 688 | - | - | - |
| Fisheries | 97 | 1,630 | 414 | 1,989 | 317 | 359 |
| Navigation | 29 | 194 | 80 | 234 | 51 | 41 |
| Environment | - | 29,968 | - | 34,078 | - | 4,110 |
| Dredging | 2,385 | 2,970 | 3,889 | 3,833 | 1,504 | 862 |
| Total | 41,571 | 77,003 | 39,707 | 82,445 | - 1,864 | 5,442 |
| Basin-wide Gain ( if water is shared ) | | | | | | 3,578 |

# Comparison of benefit for two scenario



# Conclusion

- There is potential for a trade-off between hydropower use in India, and environmental use in Bangladesh.
- **There is no point of killing a river for 16.25 MW electricity**
- Bd may offer India -– installing solar energy power plant to minimize hydropower loss (22.5MW).



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# Thank You

Teesta Barrage India

Teesta Barrage Bangladesh