ASSESSMENT OF RIVER DIVERSION ON WATER ADEQUACY USING GOOGLE EARTH ENGINE – A TSANGPO BRAHMAPUTRA RIVER CASE STUDY

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ABSTRACT

Embracing the southern parts of China and northern parts of India, the mighty Tsangpo-Brahmaputra is bestowing the best of both worlds on both the countries. China, acknowledging its multifaceted benefits, is aiming to divert its water from its southern parts to northern parts to overcome the imbalance in water distribution in the country. The present study aims at understanding the effect of diversion on the water adequacy in downstream regions. To achieve this, different remotely sensed datasets like CHIRPS, JRC-GSW, GLDAS are analyzed using Google Earth Engine (GEE) Platform. GEE is a cloud-based platform specially designed to perform global scale geospatial studies related to water management, climate monitoring, land cover and many others. In the absence of comprehensive ground data, this study attempts to leverage the utility of remotely sensed data products by GEE.

1. INTRODUCTION

Mighty Tsangpo-Brahmaputra is worthy of its name (Tsangpo-“Purifier”, Brahmaputra-“Son of the Lord Brahma”) and lies at the heart of China and India (Figure 1). The river has proved to be an asset for both China and India. China’s proliferating water demands with the increasing population is majorly dependent on the river (Shanta, 2018). It endows the country with 11,389 million KW hydropower energy, hence, bagging the second position after Yangtze river (Peng, 2015). Similar to China, it lend wings to Indian economy. It commands 4.26 million hectares irrigation potential as well as 41 per cent of total hydropower potential. Thus, the basin region is blessed with the highest per capita and per hectare water availability of the country (Goswami, 2008).

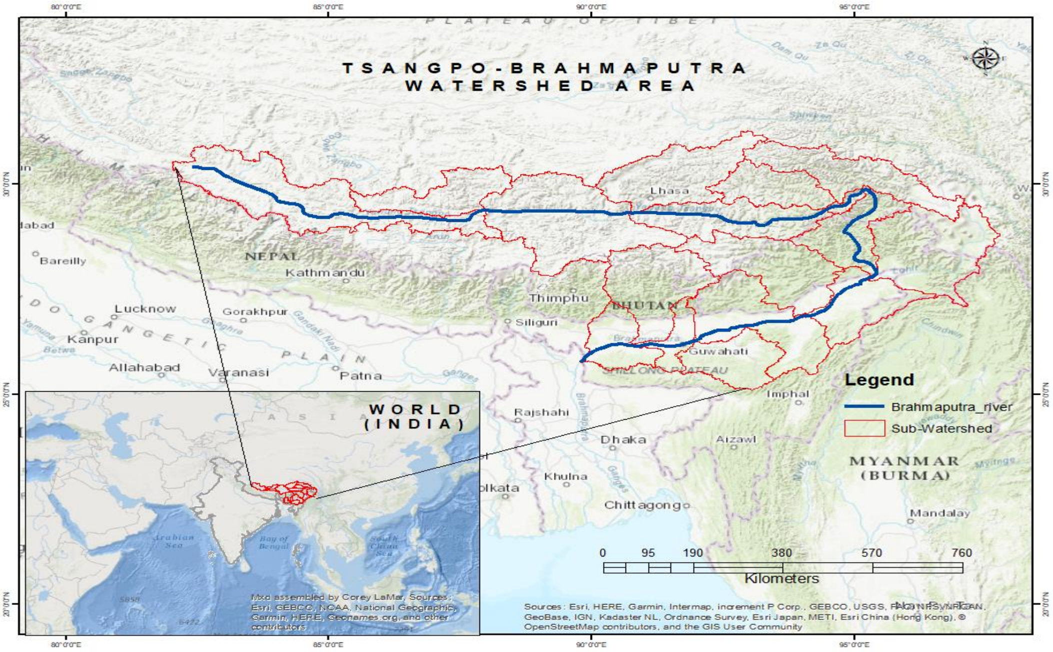

Figure 1. Tsangpo-Brahmaputra River Channel

China aims to divert 44.8 billion cubic meters of fresh water annually from southern parts to the northern parts of the country to overcome imbalance in water distribution. The socio-economic dependency of the North-Eastern parts of India on the river Brahmaputra motivates us to estimate the loss in flow of river Brahmaputra in India. The river is the agricultural lifeline of India's North-Eastern states and provides fertile marshy land, which is an ideal blend for single horned Rhinos also. With this diversion, there is a possibility of socio-ecological disruption in the downstream areas of the river. The main objective of the study is to assess the disturbances in water balance in the downstream areas of Brahmaputra. Some of the specific research questions are: a) whether the water is adequate in the downstream region, post diversion scenario? b) whether remotely sensed data is sufficient to carry out present hydrological study in absence of some of the detailed ground data? c) whether platform like GEE handles the data integration and analysis task seamlessly to provide effective solution?

As the study is for the trans-boundary Tsangpo-Brahmaputra river, the multi temporal ground level data collection is a challenging task. Synergetic usage of remotely sensed data and time series analysis provides ideal set of technologies to find an answer to the given problem. The study encompasses some global datasets like Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), Global Surface Water (JRC-GSW) etc., which are sensed remotely and have ground level information. Since our study area covers cross boundary regions with an area of more than 4,70,000 km^2 , which is quite challenging to monitor it in one go. To address this challenge, we have employed a cloud-based platform called Google Earth Engine (GEE). The GEE platform is well suited for global-scale geospatial studies and is equipped with multi-petabyte collection of Earth-observing remote sensing imagery such as Landsat and Sentinel collection and datasets related to water management, climate monitoring, land cover and many other studies (Gorelick et al., 2016). It provides high-performance computing resources for processing very large geospatial datasets, thus befitting for the study.

2. STUDY AREA

Securing the top position in the list of largest river systems in the world, Tsangpo-Brahmaputra river is geographically extended between 23^0 - 32^0 N latitude and 82^0 - 97^0 E longitude. It springs from Angsi glacier in northern Himalayas in Burang county of Tibet and travels around 1625 km east course where it is known as Tsangpo. Thereafter it enters India from the great bend and travels left course in India for around 918 km where it is known as Brahmaputra and finally enters in Bangladesh where it is named as Jamuna, travels 337 km and drains in the Bay of Bengal. The river boasts drainage area of around 580,000 km^2 having 50.5% share in China, 33.6% in India and rest in Bangladesh (8.1%) and Bhutan (7.8%) (Immerzeel, 2008). It has a very steep slope until it enters India wherein the average slope of 2.82 m/km get reduced to 0.1m/km in Assam. With an average width of 5.46 km it has 19,830 cumecs of average annual discharge and 100,000 cumecs of extreme discharge (Datta & Singh, 2004). With 1,128 metric tons per sq. km. per year sediment load at Bahadurabad in Bangladesh, the river stands second in the world in terms of sediments transported per unit drainage area (Goswami, 1985). According to Immerzeel et al. (2010), 27% of the total discharge produced in the Brahmaputra basin is comprised of snow and glacier melt in the basin. The basin receives heavy rainfall in the lower ranges which gradually decrease in higher ranges. Only the Chinese and Indian portion of the river system are within the purview of this study. Following the World Wild Fund for Nature (WWF) hydroSHEDS datasets, the whole catchment area (till Dhubri) is divided into seventeen sub catchment areas (Figure 3). Out of these seventeen, seven lie in Tibet, nine in Arunachal Pradesh-Assam and one lies in Bhutan-Assam.

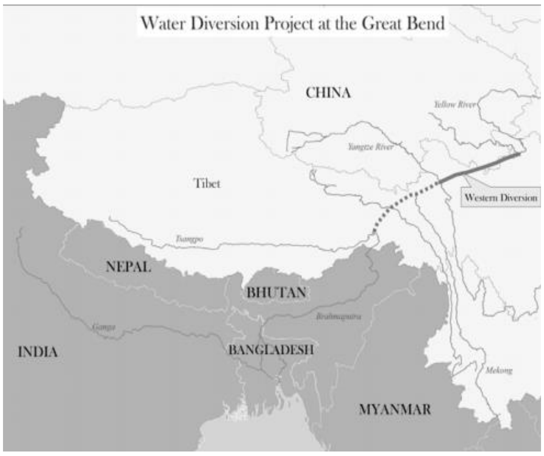

Figure 2. The "Great Western Route", Source: Svensson, 2012

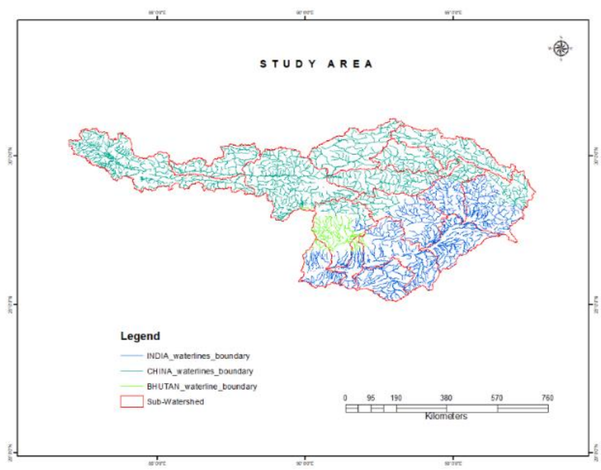

Figure 3. Study area

China is the largest industrial water consumer with the yearly water consumption of 120 billion cubic meters, out of which coal mining, and power generating industries consumes a fifth of national water consumption (Svensson, 2012). China's dependence on coal is projected to grow by 30 % by 2020 (Svensson, 2012). These industries in China are concentrated in northern province whereas the water required for it is concentrated in the south. Moreover most of the big cities in China including the capital Beijing is in the eastern province, where the water demands are huge because of the high population. In order to incorporate this imbalance China has started multiple projects like SNWTP (South-North Water Transfer Project) and the new Twelfth Five-year plan which mostly deals with water transfer and hydropower generation respectively (Svensson, 2012). The Yarlung-Tsangpo river basin has 114 GW hydropower potential, considering this fact some of China's main hydropower projects have already been started (Zangmu hydropower station) or are under process (Lengda, Zhongda, Langzhen and Jaicha) (Svensson, 2012). Also the Great Bend of the Yarlung-Tsangpo/Brahmaputra river has a great potential of hydropower generation and is proposed as the starting point of major water diversion project namely "Great Western Route" (Figure 2). There is a possibility of channeling around 200 billion m^3 of water annually and linking it with central and eastern routes of South-North Water Transfer Project which can be a major concern for India (Svensson, 2012).

3. DATA SOURCES

The study employs multitude of datasets in the attempt to find answers to the research questions raised in the study. The catchments are extracted from Hydro Engine, which is a service and a command-line tool to query static and dynamic hydrographic Earth Observation data built over Google Earth Engine. For precipitation related enquiries, we have sourced Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) across the seventeen catchment areas. Other datasets include Joint Research Center: Global Surface Water (JRC-GSW) to study water transition states, Global Land Data Assimilation System version 2.1 (GLDAS 2.1) for snow melt and evapotranspiration, Global Land Data Assimilation System version-1 (GLDAS-1) for surface runoff and Global Water System Project (GWSP) to study river discharge. All these datasets are analyzed temporally using Google Earth Engine Platform. These datasets have satellite and ground-based observational data at global scale and are available in GEE platform, thus, fits best for our study. The further details are available in the Table 1.

Table 1. Data sources

S. No	Dataset Name	Source	Acquisition Period	Resolution
1	Catchments	WWF hydroSHEDS dataset	-	15 arc seconds
2	CHIRPS	Climate Hazards Group	2000-2015 (Yearly Average composites)	0.05 arc degrees
3	JRC_GSW	Joint Research Center	1985-2015	30 meters
4	GLDAS 2.1	NASA	2000-2014 (Monthly Average composites)	0.25 arc degrees
5	GLDAS-1	NASA	2000-2015 (Yearly Average composites)	0.25 arc degrees
6	GWSP	Center for Development Research, University of Bonn	-	-

4. METHODOLOGY

4.1 Water Balance Calculations

The methodology for achieving the objective of the study is summarized in Figure 4. Firstly, we considered the parameters namely, Water Transition States, Precipitation, Snow melt, Runoff and Discharge in order to estimate an average water availability in those seventeen catchment areas. In order to get the water adequacy in the downstream areas (North-Eastern states of India), we formulated an equation (Figure 4). It states that there will be water adequacy in the regions after the diversion point, if the total water requirement in those regions is less than the water available there (post diversion scenario). If this is not the case, then the downstream regions after the diversion point will suffer from water inadequacy in the near future. As the catchment areas lie in Himalayan range, the main source of water in the catchment areas is precipitation and snow melt. Thus, a combined study of precipitation, snow melt and discharge for each of the catchment area is a valuable source to calculate the total water in the catchments before and after the proposed diversion point. Studying the water transition states is useful to understand the seasonality factor of the water available in each of the catchment areas, which will help us derive the seasonal water contribution of each catchment to the river.

In order to calculate A and B (Total water before and after the proposed diversion point respectively), we have added the total annual average precipitation and snow melt for the catchment areas lying before and after the proposed diversion point respectively. To get C (Total water requirement in eastern states of India), a World Bank Group report (Mahanta, 2006) which has the details about the water withdrawal and the potential utilizable water from the Brahmaputra basin in India is taken into consideration. The difference of A and B is compared to C, in order to get the water adequacy status in the downstream regions of the river.

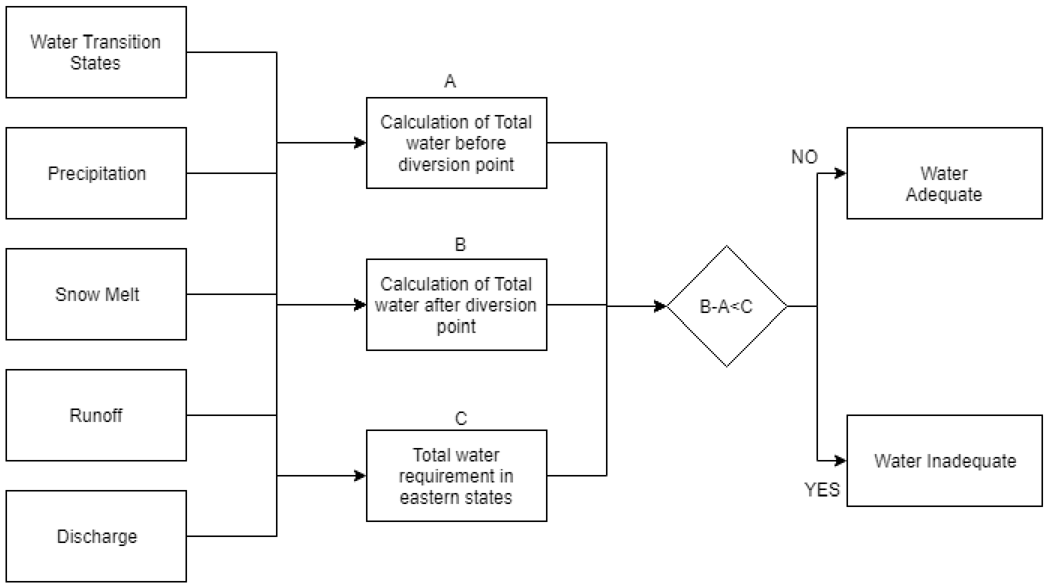

Figure 4. Methodology for the study

4.2 Working with GEE

The water transition states are identified using JRC-GSW available in GEE. This dataset contains maps of the location and temporal distribution of surface water from 1984 to 2015 and provides statistics on the extent and change of those water surfaces (Pekel, Jean-François, et al., 2016). Transition maps captures changes between the first year of observation to the last year of observation for the three conditions of water namely no water, seasonal water and permanent water. The water transition states across all the 17 catchment areas is analyzed using Transitions map of JRC-Global Surface Water product. For the study only 6 classes are considered which are mainly Permanent, New Permanent, Lost Permanent, Seasonal, New Seasonal and Lost Seasonal. The Seasonal to Permanent class is considered in Permanent, similarly Permanent to Seasonal is considered as Seasonal for the study.

To get an estimate of precipitation across all the catchment areas, CHIRPS dataset for a pentad (5 day average composite) available in GEE is used. This data is converted into yearly average mosaics over a period of 15 years (2000-2015) using the *temporalAverage* function explained in Figure 5, so as to retrieve the yearly average precipitation value for all the 17 catchment areas. The *temporalAverage(collection, unit)* function makes a new image collection with temporal averages of images in input.

Further, to study the snowmelt GLDAS dataset in GEE is used. For this, monthly temporal average of snow melt for all the 17 catchment areas over a period of 15 years (2000-2014) is calculated using the *temporalAverage* (Figure 5). For studying the surface runoff, GLDAS dataset and the runoff monitored under Trans-Boundary Waters Assessment Programme (TWAP) of United Nations Environment Program is used. Yearly average of surface runoff is calculated using the *temporalAverage* (Figure 5).

```
var temporalAverage = function(collection, unit) {

  var startDate = ee.Date(ee.Image(collection.sort('system:time_start').first().get('system:time_start')));
  startDate = startDate.advance(ee.Number(0).subtract(startDate.getRelative('month',unit)),'month')
    .update(null,null,null,0,0,0);

  var endDate = ee.Date(ee.Image(collection.sort('system:time_start',false).first()).get('system:time_start'));
  endDate = endDate.advance(ee.Number(0).subtract(endDate.getRelative('month',unit)),'month')
    .advance(1,unit).advance(-1,'month')
    .update(null,null,null,23,59,59);

  var dateRanges = ee.List.sequence(0, endDate.difference(startDate,unit).round().subtract(1));

  function makeTimeslice(num) {
    var start = startDate.advance(num, unit);
    var startDateNum = ee.Number.parse(start.format("YYYYMMdd"));
    var end = start.advance(1, unit).advance(-1, 'second');
    // Filter to the date range
    var filtered = collection.filterDate(start, end);
    // Get the mean
    var unitMeans = filtered.mean()
      .set('system:time_start',start,'system:time_end',end,'date',startDateNum);
    return unitMeans;
  }
  // Aggregate to each timeslice
  var new_collection = ee.ImageCollection(dateRanges.map(makeTimeslice));

  return new_collection;
};
```

Figure 5. Function to perform temporal average of a collection

The *temporalAverage* is custom function that takes the filtered collection as input, processes it and produces the average for the temporal extent specified ('year', 'month', 'week' or 'day').

Lastly, the discharge data under Global Water System (GWS) Project - Center for Development Research (ZEF), University of Bonn is used as input as acquiring ground data was not feasible. This dataset captures river discharge across the globe. Out of that we have limited our interest to the Tsangpo-Brahmaputra river. In the dataset the whole Tsangpo-Brahmaputra river channel is divided into 33 tiles, discharge from which we have analyzed.

5. RESULTS AND DISCUSSION

Results obtained for the taken parameters of different catchment areas (Figure 6) are as follows:

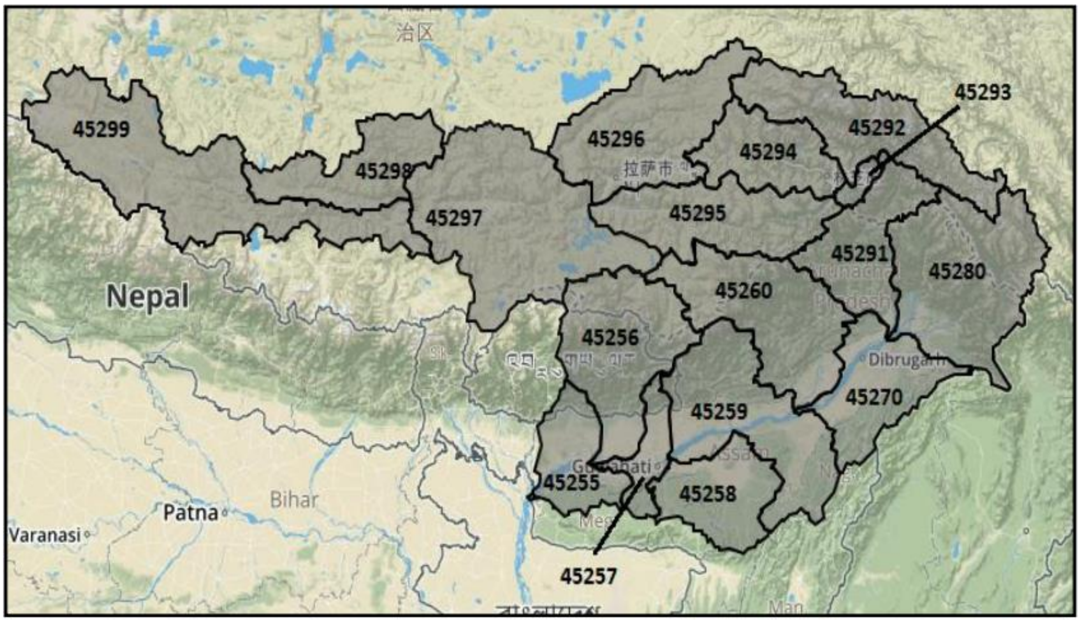

Figure 6. Seventeen Catchment areas with their unique id

5.1 Water Transition States

A chart illustration (Figure 7) shows how water availability in these 17 catchment areas varies over the mentioned classes. The study determines that catchment areas 45259, 45255, 45260 and 45270 receives highest seasonal water with 69.7%, 69.2%, 65.2% and 64.2% of the total water availability respectively as compared to other catchment areas. These catchment areas lies in Assam and Arunachal Pradesh. This high percent of seasonal water in the catchments is one of the reasons that Assam experiences floods every year.

5.2 Precipitation (mm)

Figure 8 illustrates how precipitation varies across the 17 catchment areas yearly.
It can be inferred from the chart that the catchment areas 45255, 45270, 45258 and 45257 lying in Assam and Arunachal Pradesh receives maximum average precipitation of 482mm, 429mm, 375mm and 363mm yearly respectively which subsequently contributes to the Brahmaputra river in India.

5.3 Snow Melt (kg/m^2)

Figure 9 illustrates the yearly distribution of snowmelt across seventeen catchment areas. The catchment areas numbering 45292, 45294 and 45293 shares highest annual snow-melt contribution with $233* 10^7$ liters, $185*10^7$ liters and $173*10^7$ liters respectively to the river.

5.4 Surface Runoff (kg/m^2/s)

Figure 10 illustrates yearly average surface runoff across all the 17 catchment areas. The Surface Runoff study showed that the catchment areas 45292 and 45293 have highest average runoff of 11.05 and 16.7 kg/m^2/sec respectively, which directly contributes to the river Tsangpo and the downstream regions in India.
The other study taken into consideration for Runoff is that monitored under Trans-Boundary Waters Assessment Programme (TWAP) of United Nations Environment Program (hosted by DHI group). The assessment is done across all the basins of the world. We have considered Ganga-Brahmaputra-Meghna basin data for our study.
The study performed by UNEP-DHI (Figure 11) clearly claims Arunachal Pradesh with an average 3580 mm/year runoff shares the maximum run off contribution to the river as compared to any other state.

5.5 River Discharge

Figure 12 shows a graphical representation of discharge information for the Tsangpo-Brahmaputra river in Tibet, India and Bangladesh. Tile number 1-14 lies in Tibet, 15-25 in India and 26-33 lies in Bangladesh.
The representation shows that the discharge in the river till tile 14 is negligible with maximum 56 km^3 where the river is in Tibet as compared to discharge in any other tile. After tile 15 there is a steady increase from 98 km^3 to 632 km^3 till tile 21 respectively which lies in Arunachal Pradesh and maintain the discharge of around 573 km^3 to 630 km^3 from 21 to 25 in Assam. After tile 26 it enters Bangladesh where with the Ganga, the river experience sharp increase in the discharge from 700 km^3 in tile 28 to 1260 km^3 in tile 33.

5.6 Summary of the findings

The diversion is proposed to take place from the Great bend (Svensson, 2012) which collects the water from eight catchment areas namely 45292, 45293, 45294, 45295, 45296, 45297, 45298 and 45299. We began with the methodology where the total water before the diversion point is A, water after diversion point in the downstream regions is B and the water requirement in the North-Eastern states of India is C. From the results it is clearly inferred that the catchment areas before diversion point have an average of $11.4*10^9$ liters snow melt and $1.8*10^{14}$ liters precipitation (precipitation in mm X area in mm^2) annually which is $1.8001*10^{14}$ liters (which is A in our context). The catchment areas after the diversion point have an average of $3.4*10^9$ liters snow melt and $6.6*10^{14}$ liters precipitation (precipitation in mm X area in mm^2) annually which is $6.6003*10^{14}$ liters (which is B in our context). Overall, A contributes 79.6 % of total snow melt and 21.7 % of total precipitation among all catchment areas. According to the World Bank Group report (Mahanta, 2006), the water withdrawal from the Brahmaputra basin in India is $9.9*10^{12}$ liters (which is C in our context) out the potential utilizable water which is $5*10^{13}$ liters. Post diversion, A i.e. $1.8001*10^{14}$ liters of water will be lost and only $4.8002*10^{14}$ liters (B-A) of water will be there in downstream region which is greater than the requirement of $9.9*10^{12}$ liters (C). So, the total requirement of the downstream regions would meet if the proposed diversion happens from the same point even after the direct loss of the water coming from the upstream regions in the form of the Tsangpo river, precipitation and Snow melt.

Even after high seasonal water in Assam in the past, Assam has a risk of hydrological and agricultural drought because of uneven rains and high temperature (Das et al., 2009). Also with the increase in global temperatures, glaciers are retreating at an average rate of 15 meter per year (Das et al., 2009). The catchment areas with high water contribution to the river in terms of snow melt, lie in the Himalayan belt and are prone to loss in the glacial ice over a period of time. Considering the increasing global warming and high retreating rate of the Himalayas, we can say that the river may experience high water equivalent in the form of snow melt for a duration but will definitely suffer no or very little contribution to the river in the long run with diversion.

Though the availability of ground data in the context would have raised the accuracy of the parameters, then also working on this much big area would be a challenging task. GEE with remotely sensed datasets have proved to be a great asset in accomplishing such big scale analysis.

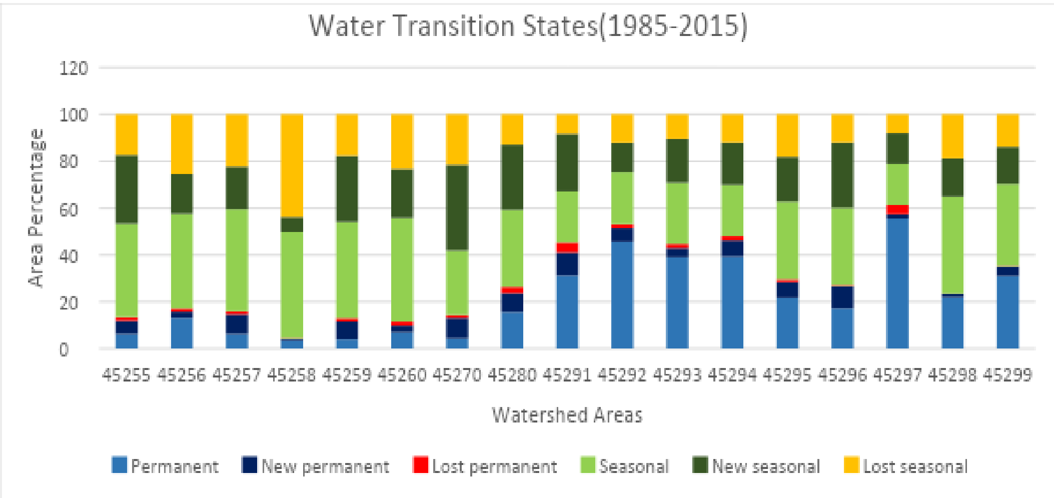

Figure 7. Water Transition states for 17 catchment areas

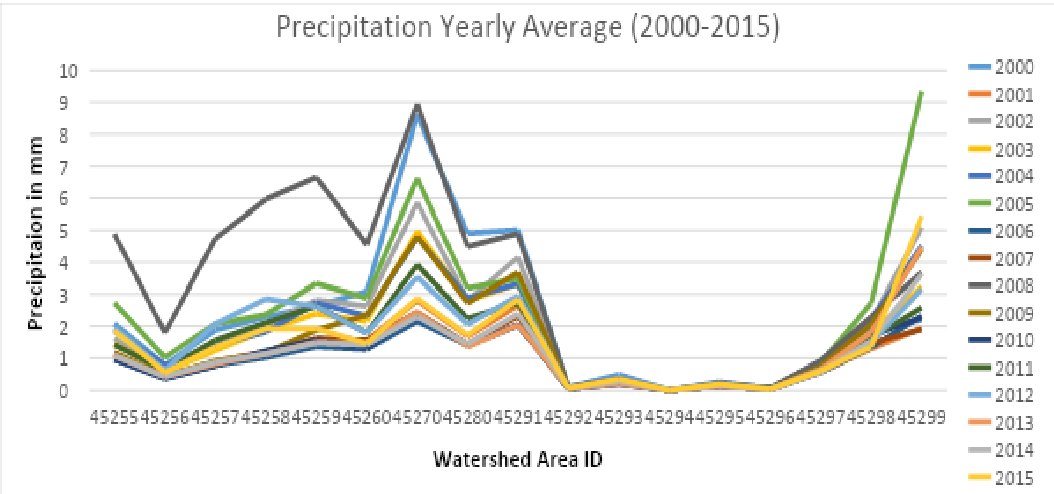

Figure 8. Precipitation for 17 watershed areas

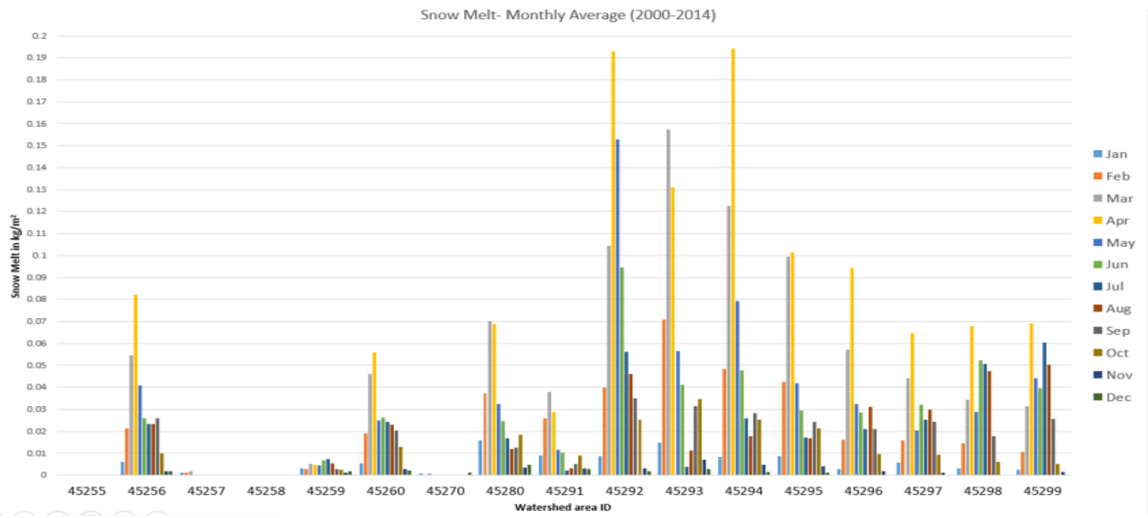

Figure 9. Average monthly Snow Melt across 17 catchment areas

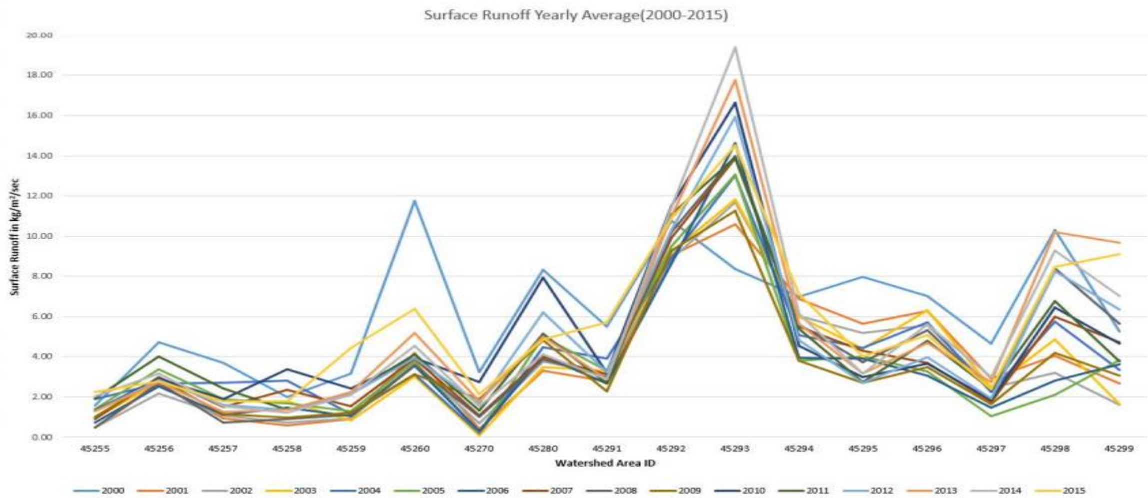

Figure 10. Average yearly surface runoff across 17 catchment areas

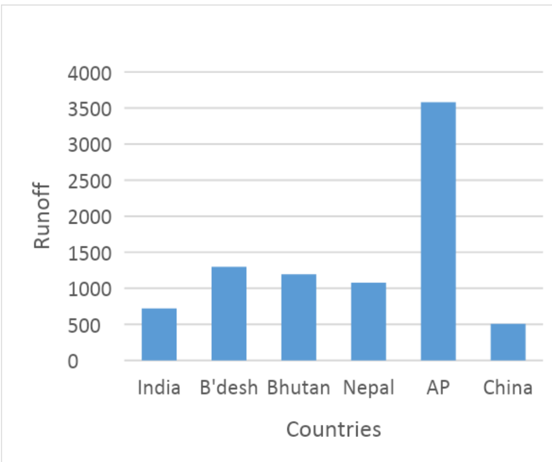

Figure 11. Runoff, Source: DHI group

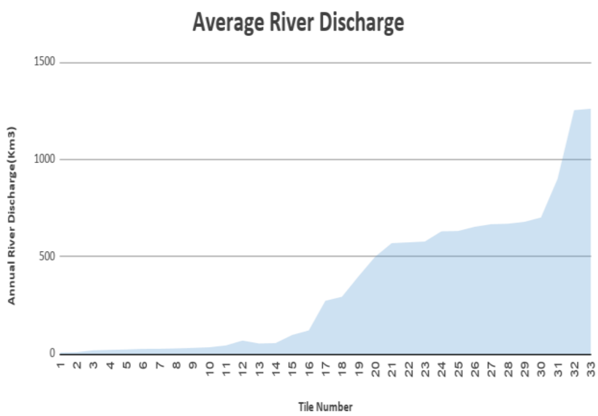

Figure 12. River discharge for Tsangpo-Brahmaputra river, Source: GWSP

6. CONCLUSION

The preliminary assessment of catchments manifested that if the execution of proposed diversion by China will happen, then also there will be adequate water in downstream regions of Assam to fulfill the requirements. However, the qualitative and quantitative assessment of the severity would require ground data from the hydrological sites in India and Tibet. Assessing the total water requirements of the downstream area is another challenge. We are in the process of collecting the ground data as required. We plan to perform quantitative analysis for the water balance before and after the planned diversion. This would provide an objective assessment of the downstream impact of the planned diversion. Furthermore, Google Earth Engine (GEE) provides adequate computational power and the data required for the assessment. The GEE along with the supporting ground data as required shows the potential for single platform for the impact assessment analysis of similar nature.

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GWSP, Global Water System Project: River Discharge data, from http://www.gwsp.org/about/organization.html