Basin Scale Water Resources Assessment using Space Inputs

NRSC & CWC Joint Study

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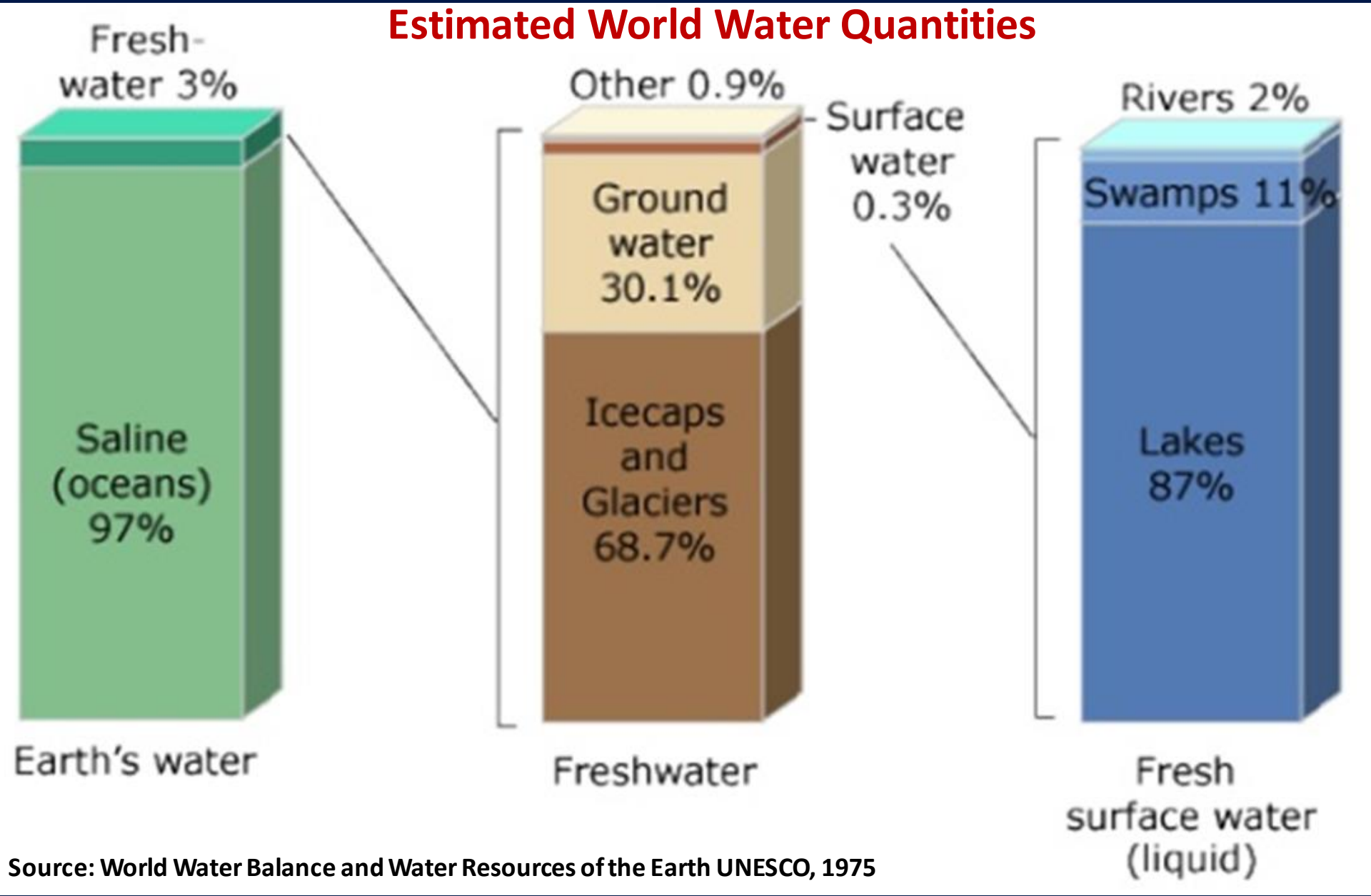
Basin Scale Water Resources Assessment using Space Inputs

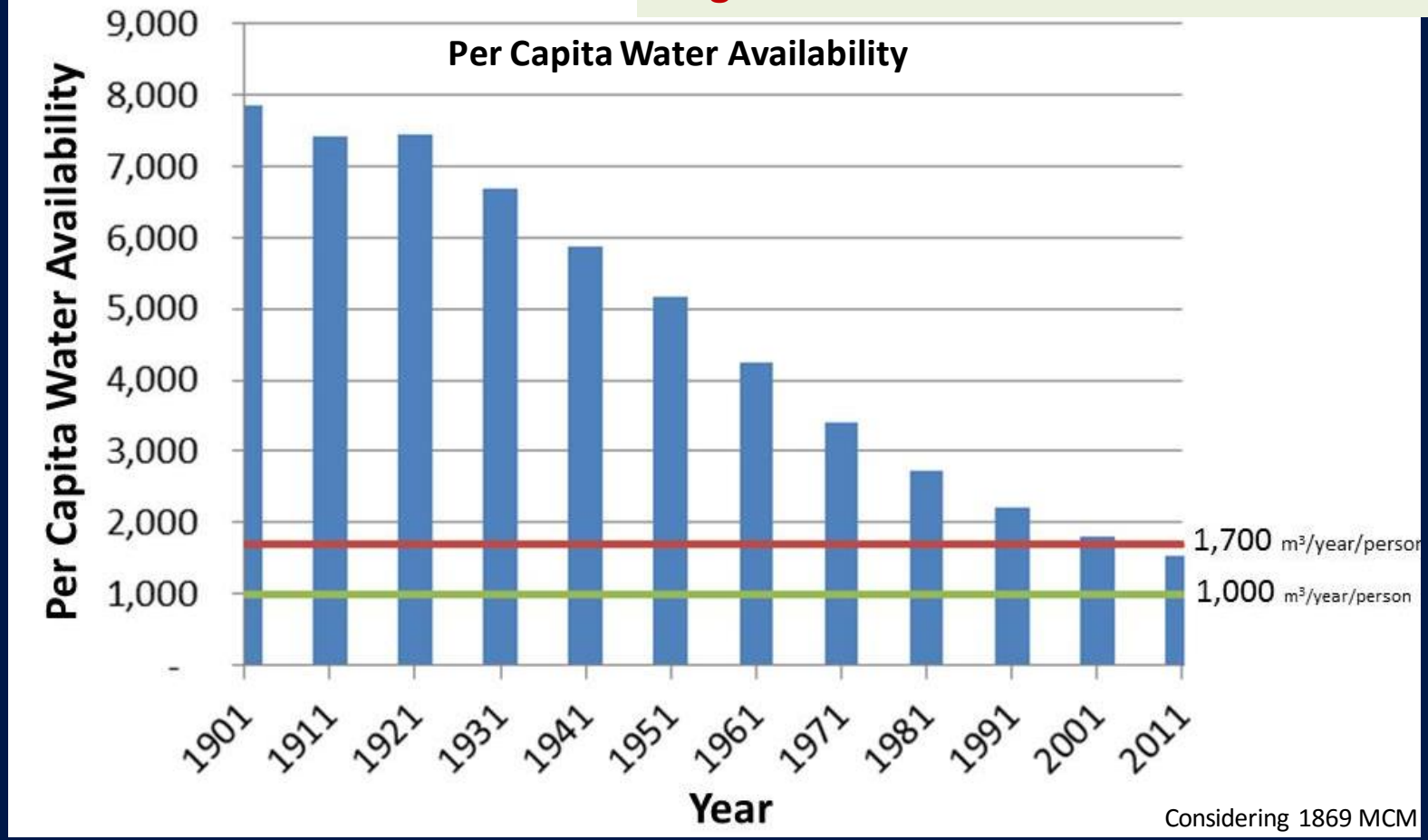


Source: World Water Balance and Water Resources of the Earth UNESCO, 1975

Basin Scale Water Resources Assessment using Space Inputs

Water Resources of India

Geographical Area = 329 Mha
Population (2018) = 1352.6 M
Total Cultivable Land = 182.2 Mha
Ultimate Irrigation Potential = 140 Mha
Irrigation Potential created (upto March 2012)=113.5 Mha



Considering 1869 MCM

Basin Scale Water Resources Assessment using Space Inputs

Natural flow in a river basin are considered as Water Resources Potential of a basin

$$R_N = R_O + R_{IR} + R_D + R_{GW} - R_{RI} - R_{RD} - R_{RG} \pm \Delta S + E$$

Where

R_N - natural flow

R_O - observed flow

R_{IR} - withdrawal for irrigation

R_D - withdrawal for domestic, livestock and industrial requirement

R_{GW} - withdrawal of ground water

R_{RI} - return flow from irrigated areas

R_{RD} - return flow from domestic, livestock and industrial withdrawal

R_{RG} - return flow from ground water withdrawal

ΔS - Change in storage of the reservoirs in the basin

E - net evaporation from the reservoirs

Basin Scale Water Resources Assessment using Space Inputs

Background

- The water resources potential in the river basins of the country has been assessed from time to time by various agencies
- 1901-03; 1946; 1954-60; 1976; 1988; 1993
- *These studies adopted - empirical formula, aggregation of observed basin terminal flow with upstream abstractions*
- NAPCC - Water Mission recommended Reassessment of basin wise water situation at *regular periodicity, water balance approach, using current data, and assessment of likely future situation*

Basin Scale Water Resources Assessment using Space Inputs

Previous Studies

Irrigation Commission (1901)

- First attempt to assess the average annual flow of all the river systems in India by Irrigation Commission of 1901-03.
- Rainfall records were available, river flows were not available for many of the most important river systems.
- Commission resorted to estimation of river flows by adopting coefficients of runoff

Water Resources Availability = 1,443.2 BCM

* Excluding Burma, Assam and East Bengal

Basin Scale Water Resources Assessment using Space Inputs

Previous Studies

Dr. A.N. Khosla (1946)

- Developed an empirical relationship between "mean temperature (as an expression for mean evaporation loss) and mean runoff, based on his studies of the flows of Sutlej, Mahanadi and other river systems.

On Monthly basis, $R_m = P_m - L_m$ $L_m = (T_m - 32)/9.5$

R_m = Monthly runoff, inches
P_m = Monthly rainfall, inches
L_m = Monthly evaporation loss, inches
T_m = Mean monthly temperature, ^0F

Areas where monthly data is not available

On Annual basis, $R_a = P_a - XT_a$

R_a = Annual runoff, inches
P_m = Annual rainfall, inches
L_m = Mean annual temperature, ^0F
X = Constant for a catchment for a given catchment which is to be determined from comparative catchments for which data are available

Water Resources Availability = 1,673 BCM

Basin Scale Water Resources Assessment using Space Inputs

Previous Studies

Central Water & Power Commission (1960)

- Based on the statistical analysis of the flow data wherever available.
- Rainfall runoff relationships wherever data were merge.
- Entire country was divided in to 23 basins.
- The Ganga was divided into 10 sub-basins.

Water Resources Availability = 1,881 BCM

Central Water Commission (1988)

- Observed river flows were corrected for groundwater abstractions.
- Observed river flows were corrected for additional ET due to use of groundwater.
- District-wise estimates of ground water drafts made by CGWB for the years 1983-84 and 1967-68 were used.

Water Resources Availability = 1,880 BCM

Basin Scale Water Resources Assessment using Space Inputs

Previous Studies

Water Resources Availability = 1,869 BCM

Central Water Commission (1993)

Basins - Reassessment not done

S. No	Basin	Previous Estimate
1	Indus	Irrigation commission of 1972
2	Ganga-Brahmaputra-Meghna	CWC 1988
3	Narmada	Narmada Water Disputes Tribunal, 1970
4	Mahanadi	CWC 1988
5	Cauvery	Cauvery Fact Finding Committee, 1972
6	WFR of Kutch and Saurashtra including Luni	
7	Area of Inland Drainage in Rajasthan Desert	
8	Minor Rivers draining into Myanmar and Bangladesh.	

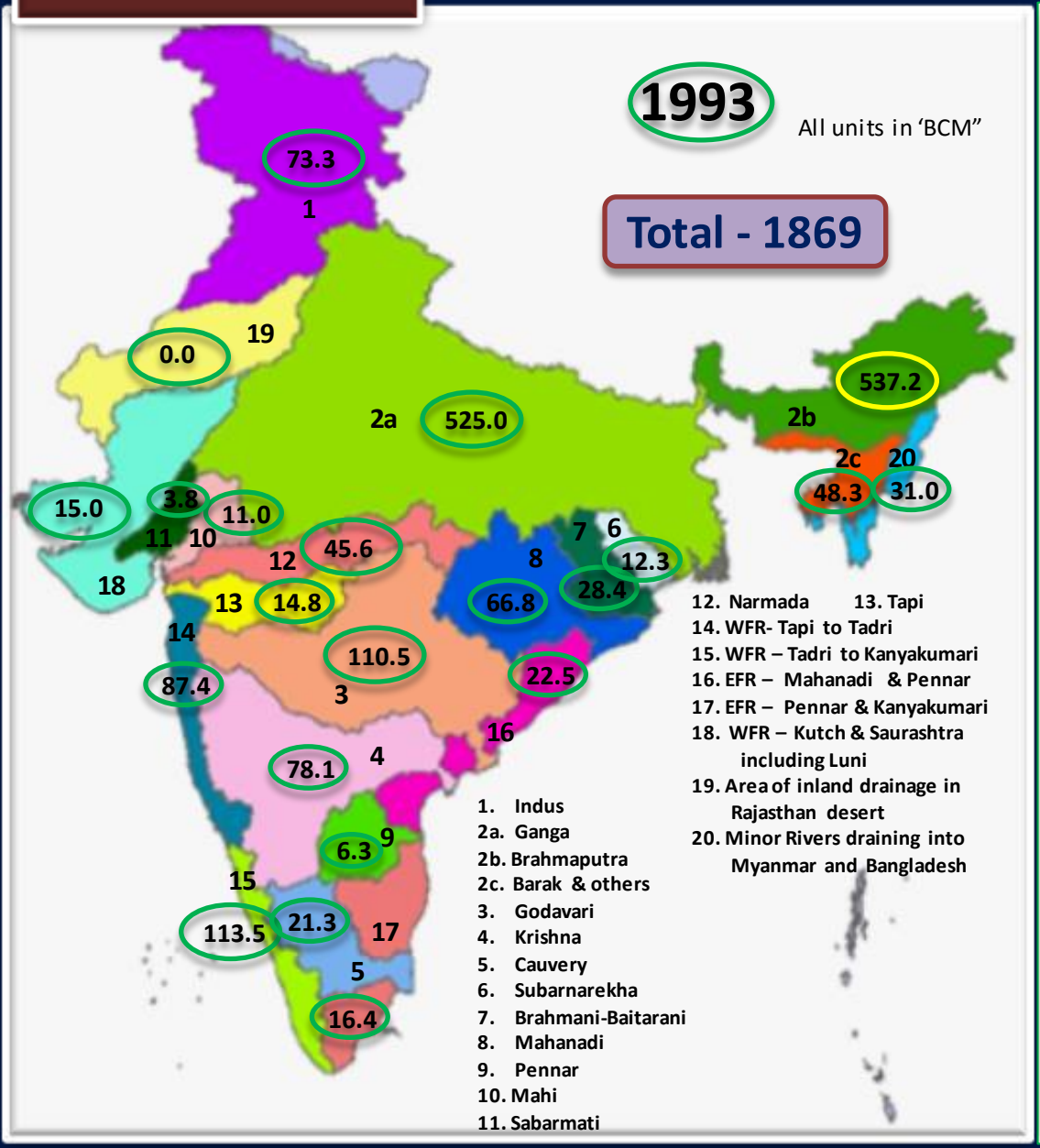
Basins - Reassessment done

S. No	Basin
1	Godavari
2	Krishna
3	Subernarekha
4	Brahmani-Baitarani
5	Pennar
6	Sabarmati
7	Mahi
8	Tapi
9	WFR from Tapi to Tadri
10	WFR from Tadri to Kanyakumari
11	EFR from Mahanadi and Pennar
12	EFR from Pennar and Kanyakumari

Basin Scale Water Resources Assessment using Space Inputs

Previous Studies

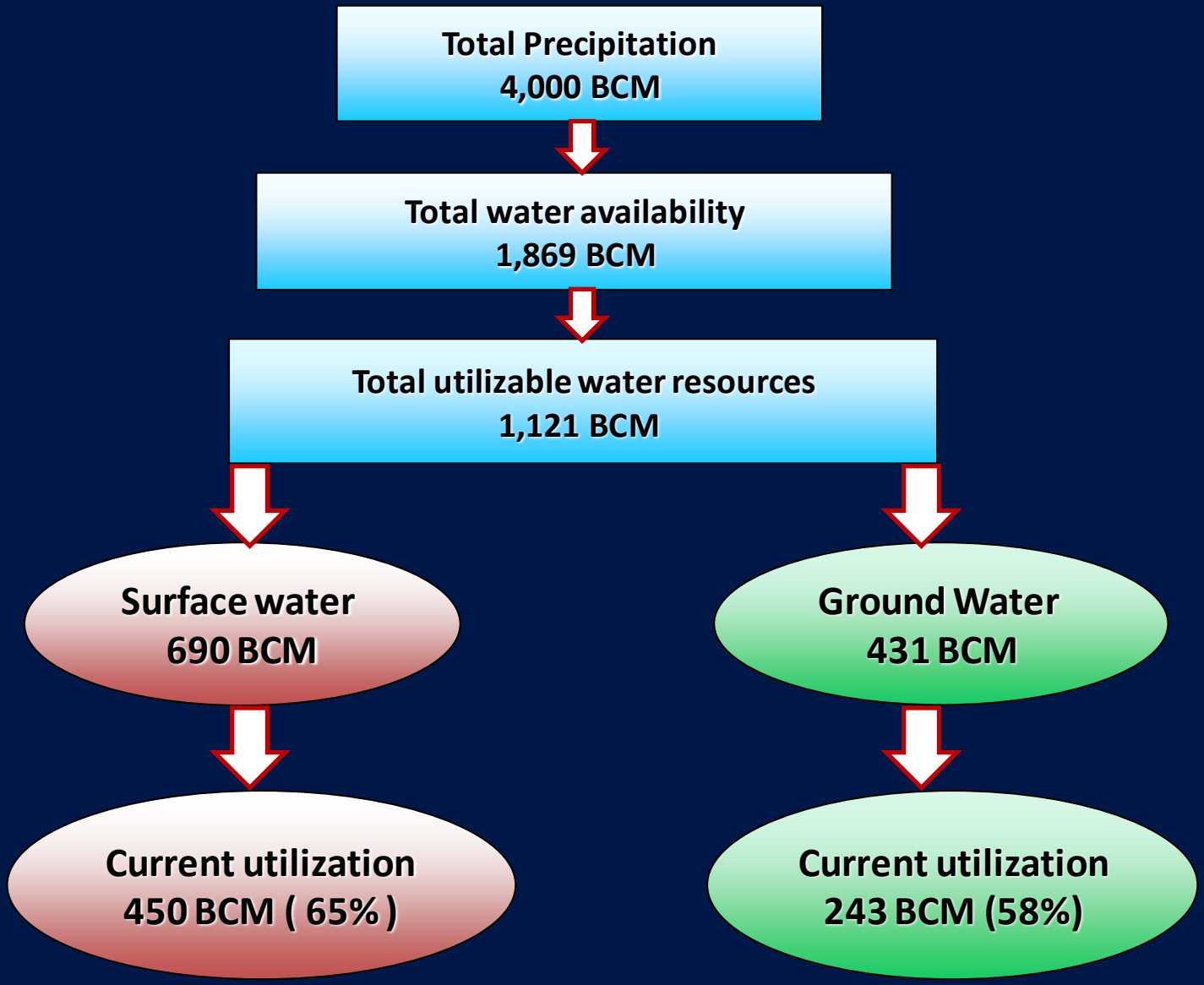
Central Water Commission (1993)



- The water resources potential was estimated by correcting for upstream abstractions to the observed flows
- Out of total area, assessment done for 35% of area (12 out of 20 basins)
- Average annual flow is computed on pro-rata basis from terminal site
- No uniform procedure for all the basins in computing the upstream abstractions
- Period of assessment varied for each basin based on data availability
- Ground water abstractions are considered for basins only where ground data was available
- Irrigation withdrawals was calculated based on year wise irrigation potential created assuming an average delta
- Irrigation withdrawals of Major and Medium projects were considered, those of minor schemes were not considered

Basin Scale Water Resources Assessment using Space Inputs

Water Availability In The Country



Basin Scale Water Resources Assessment using Space Inputs

need ...

- Currently used water resources potential estimates are old
  (CWC: 1988 & 1993 ; Lumped, Basin scale)
- Significant change in land use / land cover; demographic utilization
  (Sectoral water utilization and its temporal changes)
- Precipitation (or rainfall), as the primary resource for assessment
  (Precipitation (and not river flow/ aquifer recharge) constitutes the primary resource for assessment)
- Compute the runoff using process based models
  (Water balance approach, Hydrology Models)
- Take advantage of new technology tools
  (satellite derived spatial data bases, high density field observations, GIS,)
- Adopt distributed modelling approaches
  (Assessment of water resources at basin/sub-basin scale at required time-step and frequency)

Basin Scale Water Resources Assessment using Space Inputs

background …

- NRSC (ISRO) initiated internal effort to assess National level water resources at basin/sub-basin scale using geo-spatial approach (2009)
- NRSC conducted a brain storming session participated by IIT's, IISc, IITM, CWC, NIH (May 2009)
  (Data requirements, Scale, Methods & Models, Climate change)
- CWC approached NRSC for taking up a collaborative study (July, 2009)
- NRSC and CWC deliberated and evolved a joint activity to take up WRA (Oct, 2009; Jan, 2010)
  Requirements of CWC were incorporated.
  (Model, Methods, Framework, Database, Scale, Output were finalized)
- A pilot study is undertaken in two selected river basins (Godavari & Brahmani-Baitarani) (Feb - Oct, 2010)
- To be up scaled to National level

Basin Scale Water Resources Assessment using Space Inputs

Pilot Study – Godavari & Brahmani-Baitarani River basins

key aspects …

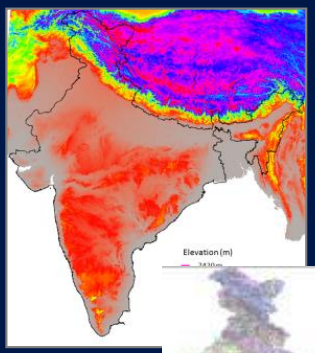
- Water balance approach
- Precipitation, the start point of water budgeting
- Integration of multi-variant terrain parameters in GIS
  (prevailing land use / land cover, elevation, soil, …)
- Spatial interpolation/extrapolation of meteorological data
  (rainfall, hydro-met data, groundwater data, …)
- Hydrological Response Unit (HRU) level water budgeting
- Monthly time-step, with carry over effect
- Calibration and validation with observed runoff
  (CWC recorded, …)
- Basin / sub-basin-wise water resources availability and sectoral utilization

Pilot Study on Godavari and Brahmani-Baitarani Basins

data used…

S. No.	Parameter	Data sources
1	Terrain	• SRTM DEM • CWC Basin maps • India-WRIS
2	Soil	• NBSS & LUP Soil Map of India • FAO Soil data series
3	Land Use / Land cover	• LULC (NRC-250k and India-WRIS)
4	Vegetation Coefficients	• Field data / Literature
5	Irrigation Command	• India-WRIS
6	Ground water	• CGWB ground water level observations, specific yield maps
7	River discharge	• CWC gauge-discharge data (India-WRIS)
8	Reservoir data	• Reservoir storage (India-WRIS)
9	Meteorological data	• IMD Gridded data • IMD Surface data • IMD AWS/ARG data • ISRO AWS data • Satellite RF Products (MOSDAC, CPC, TRMM)
10	Demographic Data	• Village Census (SOI) • Industrial & Domestic Consumption data/norms

Pilot Study on Godavari and Brahmani-Baitarani Basins

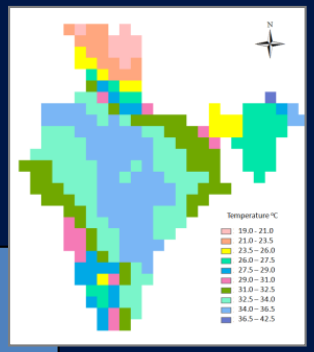


DEM

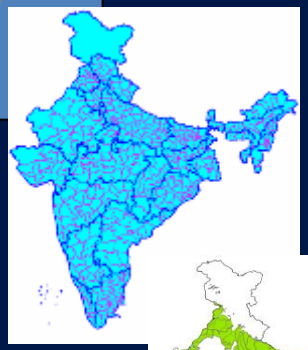
Soil

Geo-Spatial Data

Temperature

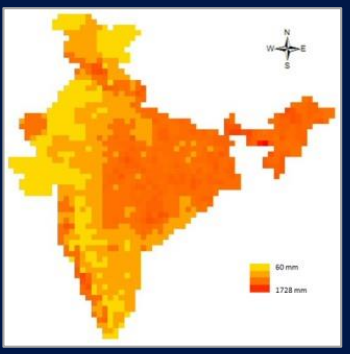


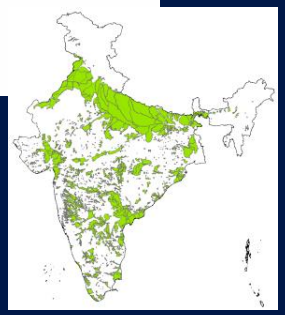
Land use / Land Cover



Administrative

Rainfall





Irrigation Command

data used…

Met Data

- 0.5 degree Rainfall Grids
- 1 degree Temperature Grids

Field Data

- Reservoir data
- Groundwater data
- River Discharge Data
- Demographic data
- Livestock census data

The study period was
1988-89 to 2007-08 (20 years)

Pilot Study on Godavari and Brahmani-Baitarani Basins

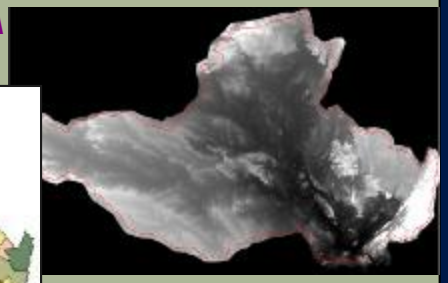
data preparation…

Data	Process
DEM	Basin/Sub-basin boundary and drainage delineation
0.5 degree daily Rainfall Grids	Conversion of daily rainfall to monthly rainfall for each water year wise (June – May)
1 degree daily Temperature Grids	Conversion of daily temperature to mean monthly temperature for each water year wise (June – May)
Mean Monthly Temperature	Monthly PET estimation for water year wise using TM method
Point ground water data	Spatial ground water draft for every year for each sub-basin
Demographic data	Estimation of domestic consumption for each year for all sub-basins
Livestock data	Estimation of Livestock consumption for each year for all sub-basins
Reservoir data	Estimation of carry over surface storage

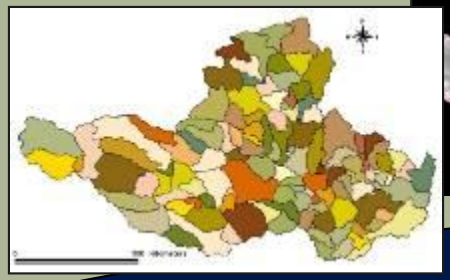
Pilot Study on Godavari and Brahmani-Baitarani Basins

approach...

DEM

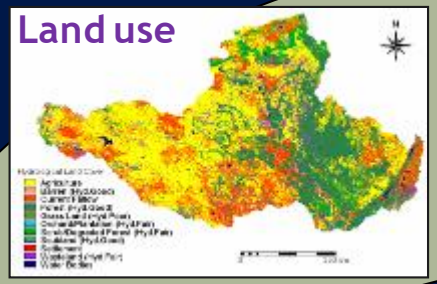


Basin / Sub-basin

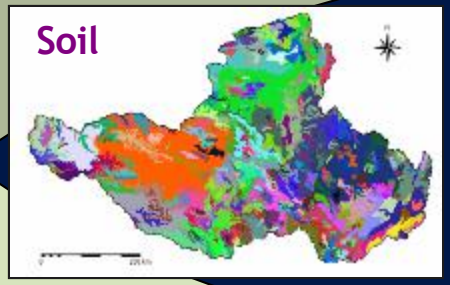


GIS Analysis

Land use

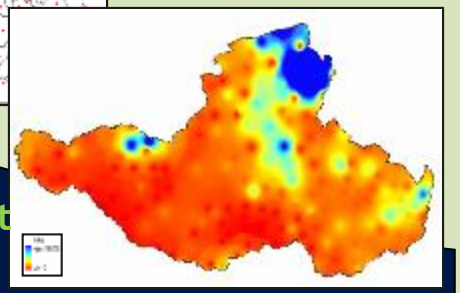


Soil



Point Hydro-Met data

Gridded Hydro-met Data



Hydrological Response Unit

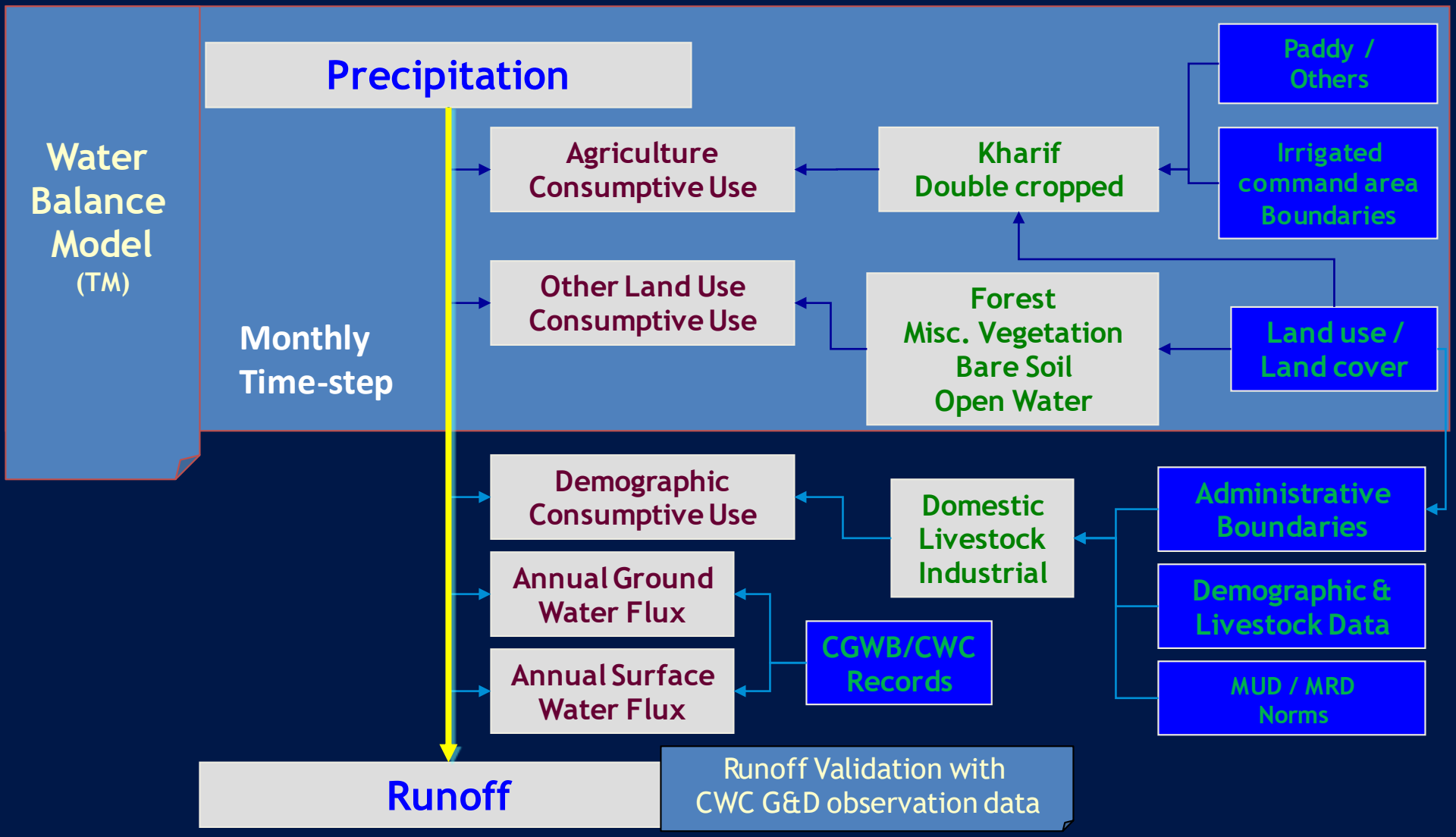
Water Balance Model (TM)

Water Balance Computation

Pilot Study on Godavari and Brahmani-Baitarani Basins

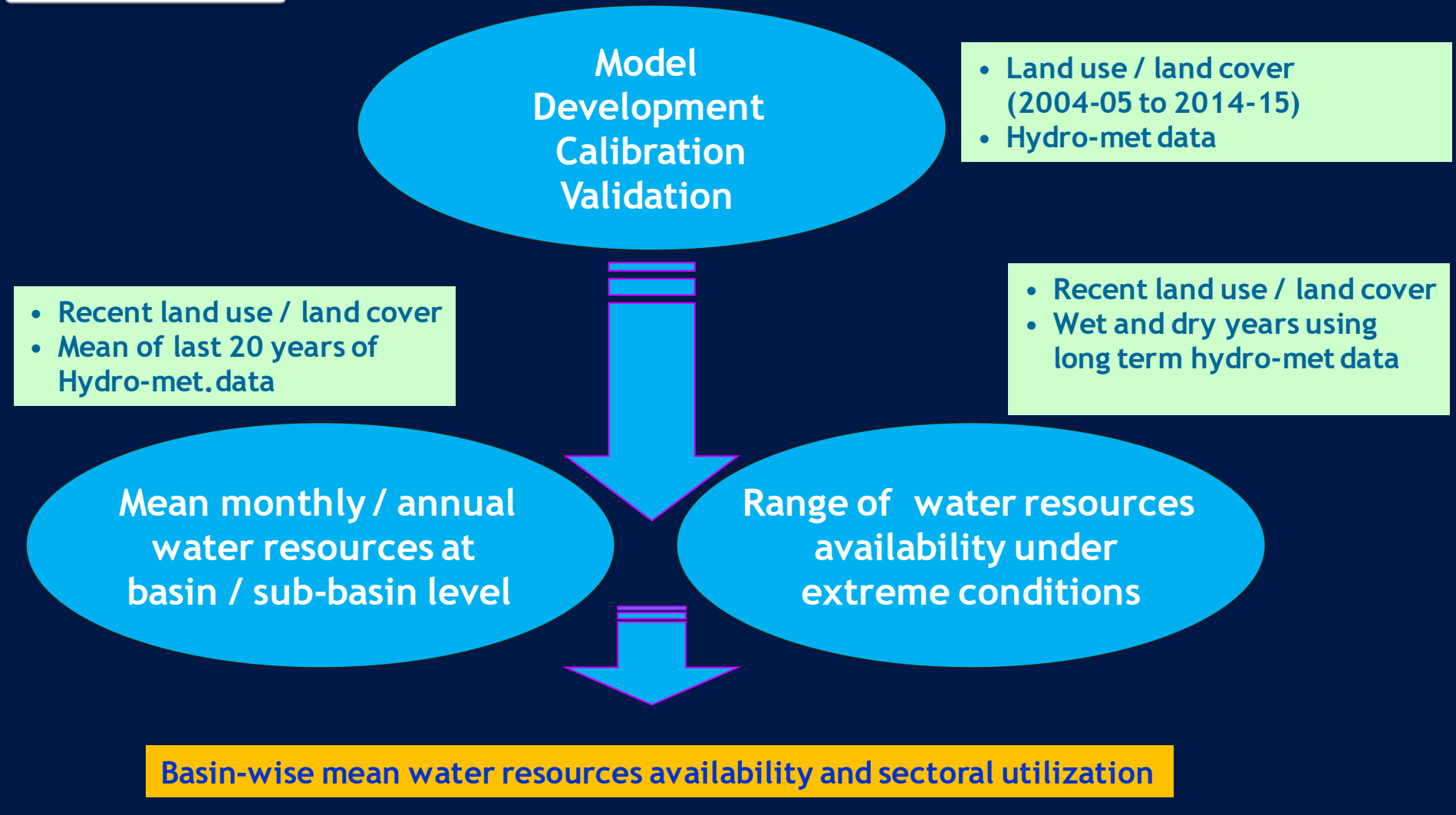
Methodology

Water balance computation at HRU Level



Pilot Study on Godavari and Brahmani-Baitarani Basins

Frame work



Pilot Study on Godavari and Brahmani-Baitarani Basins

ET Estimation Methods

Variety of empirical, semi-empirical, and physically-based equations/models generally categorized as:

- Temperature methods
  - Blaney-Criddle
  - Turc's formula
  - Thornthwaite's formula
  - Hargreaves method
- Radiation methods
  - FAO-Radiation
  - Priestly-Tayler method
  - Makkink method
  - Turc-Radation method
- Combination methods
  - FAO-Penmann method
  - P-M method
- Pan evaporation methods

Pilot Study on Godavari and Brahmani-Baitarani Basins

Methodology

Thornthwaite & Mather Method

- Computation of ET in this method is mainly based on temperature data only
- This method uses average monthly temperature, to compute monthly potential Evapo-Transpiration.
- TM method doesn't account for vegetative effect which is most useful parameter in water balance estimations

Monthly Heat Index (j) $j=(tn/5)^{1.514}$

where, j = monthly heat index
tn = monthly mean temperature, 0c
(where n= 1,2,3……12).

Annual Heat Index (J) $J = \sum_{1}^{12} j$

Monthly PET $PET=16f([\![10tn]\!]/J)^a$

where, a is the cubic function of J
$a = (675*10^{-9})J^3 - (771*10^{-7})J^2 + (179*10^{-4})J + 0.492$
f = factor, to correct for unequal day length between months

Methodology

Thornthwaite & Mather Method

Computation of Surface Runoff

PET revised = PET * Vegetation Coefficient

P revised = P + (PET revised – P) (only for areas where irrigation support is provided)

APWL = Σ(P revised – PET revised)

Soil Moisture = W*e^(((APWL)/W))

Where, SM = soil moisture, mm
APWL = accumulated potential water loss,
W = water holding capacity, which has been calculated for the different landuse class and soil texture, mm

AET = PET revised if P > PET revised

AET = P + |ΔSM| if P < PET revised

Deficit = PET revised - AET

Surplus = P – (AET+|ΔSM|)

Pilot Study on Godavari and Brahmani-Baitarani Basins

Methodology

Estimation of Runoff

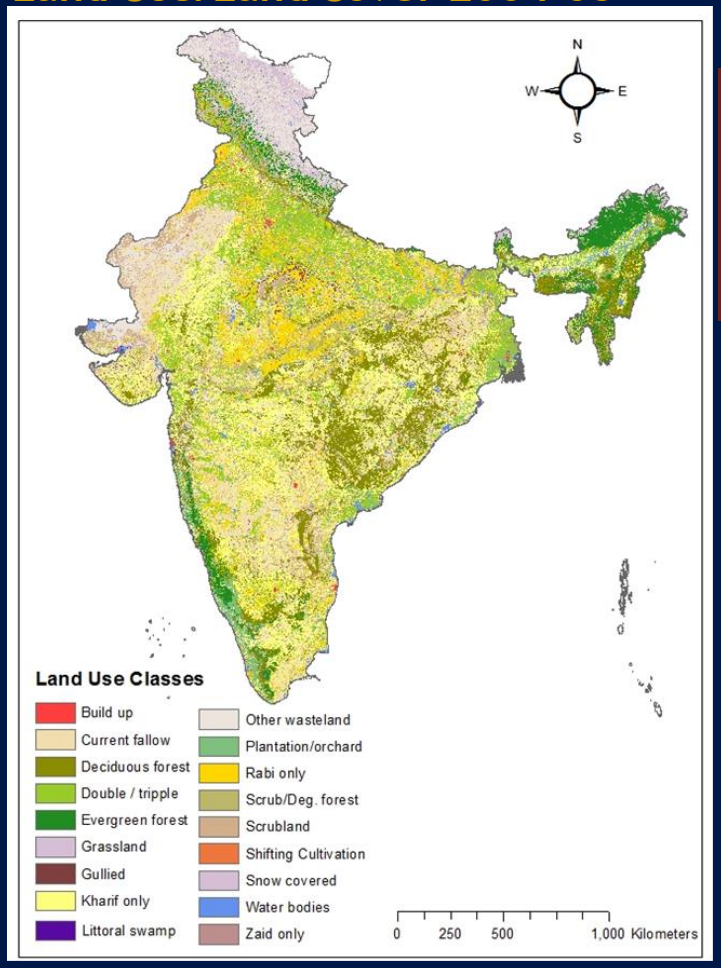
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	Total
Rainfall	75.7	459.7	520.1	146.0	10.0	1.3	0.1	0.0	20.3	1.8	0.0	3.7	1238.6
PET	294.7	156.9	138.8	166.9	134.0	87.0	53.4	46.4	76.3	142.6	285.5	373.6	1956.0
Vegetation Factor	1.1	1.2	1.1	0.9	1.1	1.2	1.1	0.9	0.5	0.8	1.1	0.7	
$PET_{revised}$	309.4	188.2	152.7	150.2	140.7	104.3	58.8	41.7	38.2	107.0	299.7	261.5	1852.5
$P_{revised}$	309.4	459.7	520.1	150.2	10.0	1.3	0.1	0.0	20.3	1.8	0.0	3.7	1476.5
$P_{revised} - PET_{revised}$	0.0	271.4	367.5	0.0	-130.8	-103.1	-58.6	-41.7	-17.9	-105.2	-299.7	-257.8	
APWL	0.0	0.0	0.0	0.0	-130.8	-233.8	-292.5	-334.2	-352.1	-457.3	-757.0	-1014.9	
Soil Moisture	0.0	90.0	90.0	90.0	21.0	6.7	3.5	2.2	1.8	0.6	0.0	0.0	
Change SM	0.0	90.0	0.0	0.0	-69.0	-14.4	-3.2	-1.3	-0.4	-1.2	-0.5	0.0	
AET	309.4	188.2	152.7	150.2	78.9	15.6	3.3	1.3	20.7	3.0	0.5	3.7	927.6
Deficit	0.0	0.0	0.0	0.0	61.8	88.7	55.4	40.4	17.5	103.9	299.2	257.8	
Surplus	0.0	181.4	367.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	548.9
Tot.avl.for Runoff	0.0	181.4	458.2	229.1	114.5	57.3	28.6	14.3	7.2	3.6	1.8	0.9	
RO (Runoff)	0.0	90.7	229.1	114.5	57.3	28.6	14.3	7.2	3.6	1.8	0.9	0.4	548.5
Detention	0.0	90.7	229.1	114.5	57.3	28.6	14.3	7.2	3.6	1.8	0.9	0.4	

Water Holding Capacity of the soil up to root depth = 90 mm

Pilot Study on Godavari and Brahmani-Baitarani Basins

Role of LU/LC

Land Use/Land Cover 2004-05



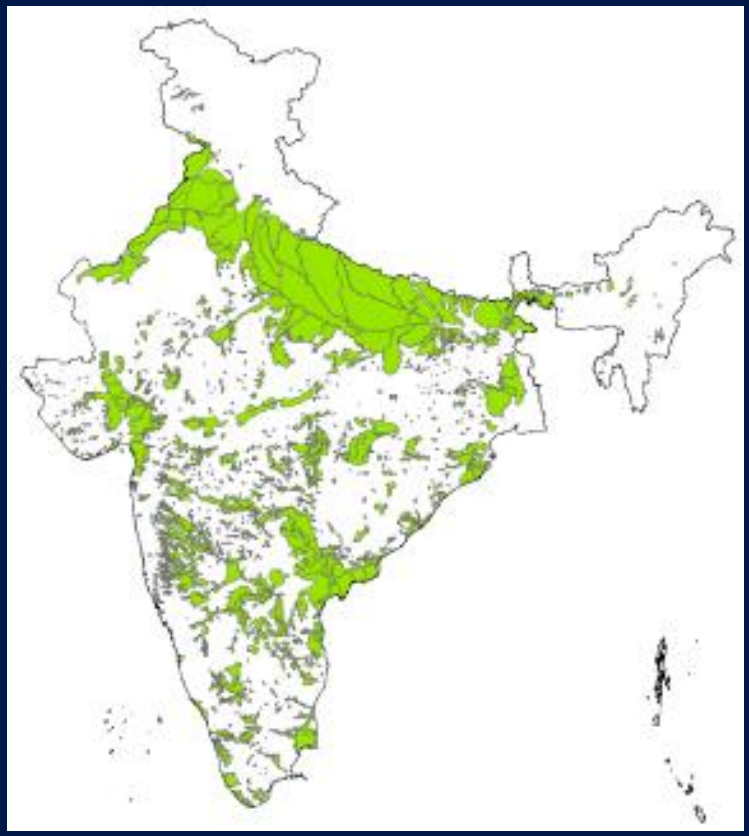
Agriculture

Kharif only
Double/Triple
Rabi only
Zaid only

- Region/District wise crop type variations
- Irrigation support

2004-05 to 2014-15 (11 years)

Irrigation Command Boundaries

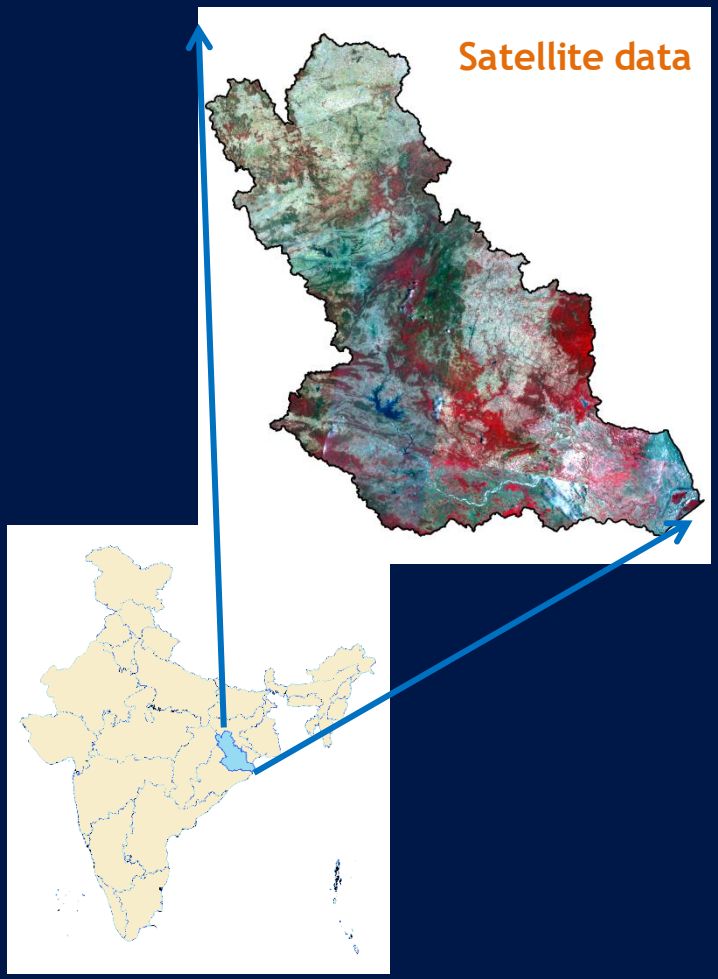


Command Area
Non-Command Area

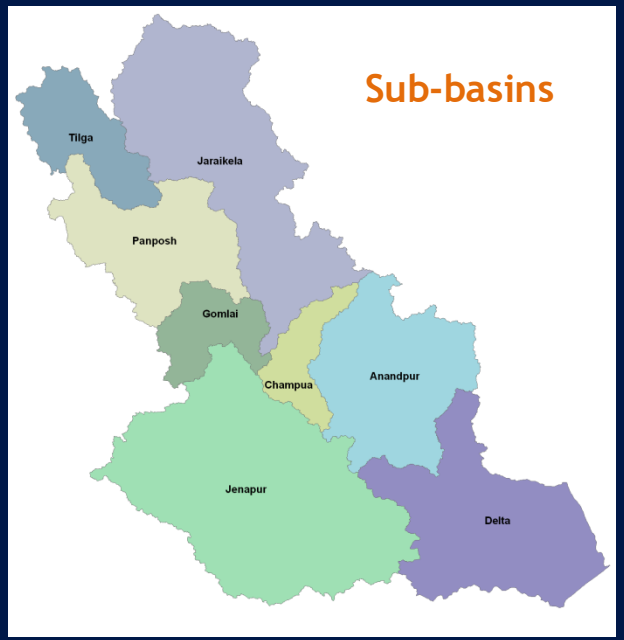
Pilot Study on Godavari and Brahmani-Baitarani Basins

Brahmani-Baitarani River Basin

Total Basin Area 50,768 sq.km



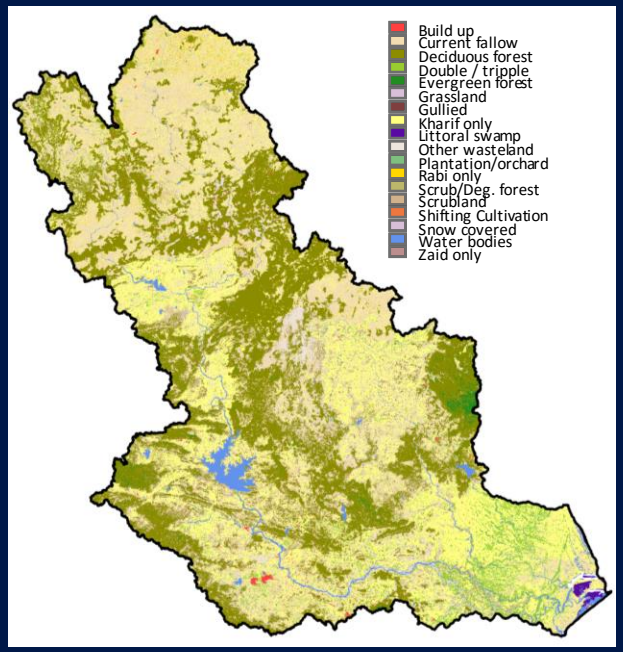
Brahmani independent Basin	34,574 sq.km
Baitarani independent Basin	8,307 sq.km
Combined Delta	7,887 sq. km

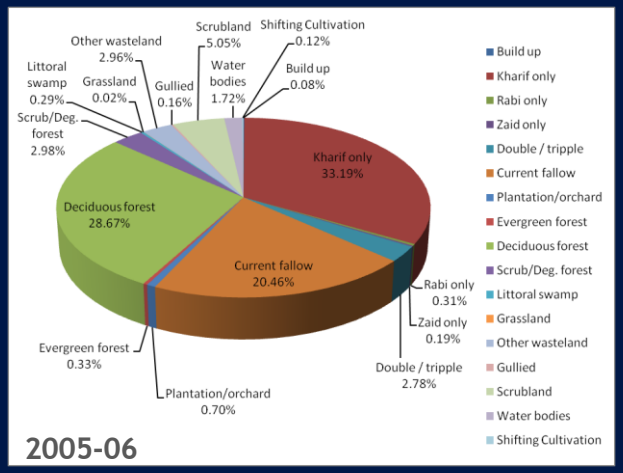


Pilot Study on Godavari and Brahmani-Baitarani Basins

Geo-Spatial Data Inputs

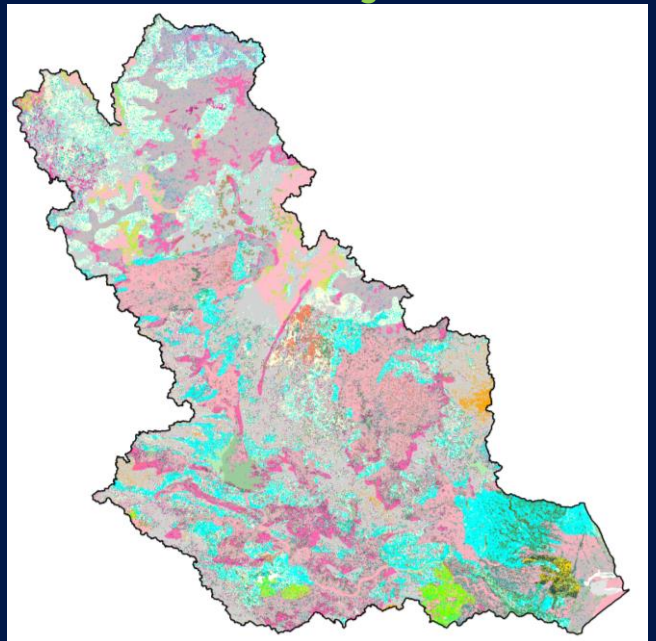
Land use / Land cover



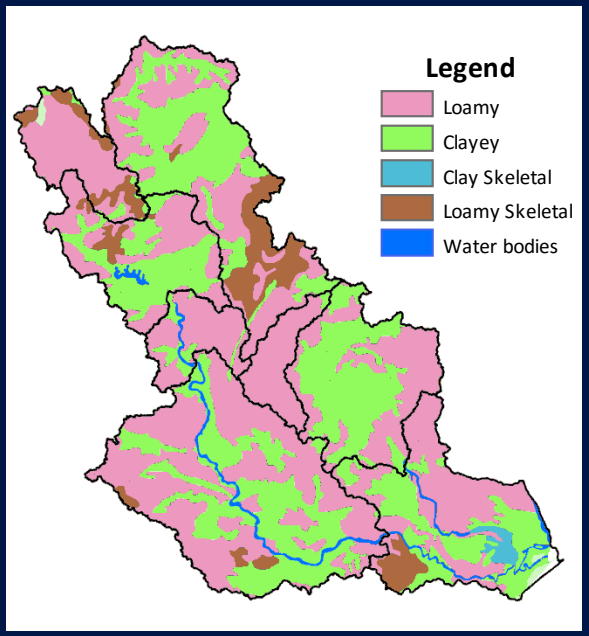


Hydrological Response Units

85 categories

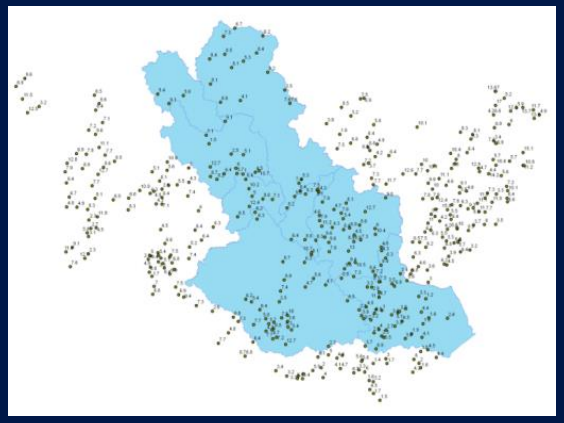


Soils

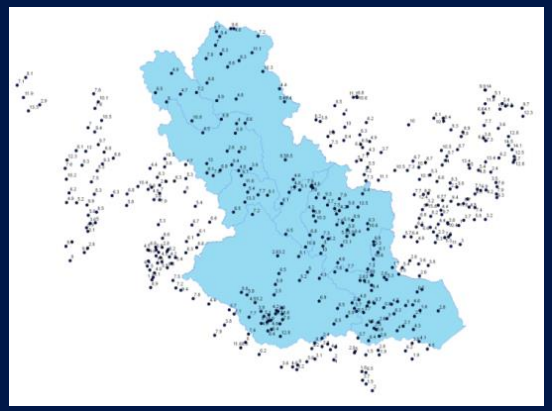


Pilot Study on Godavari and Brahmani-Baitarani Basins

DGWL May 2004



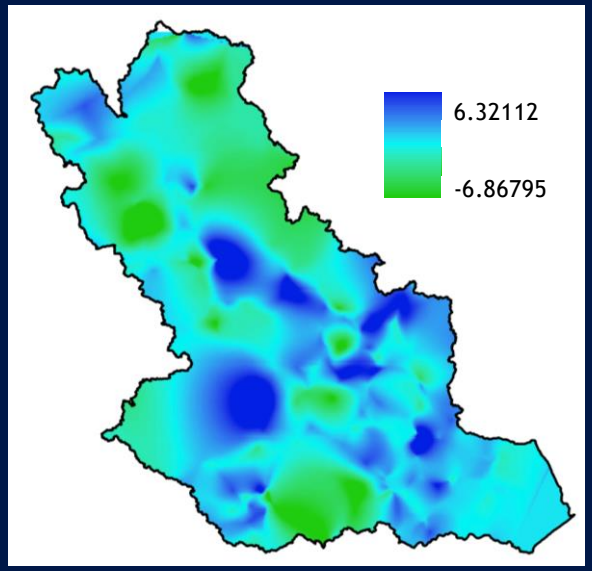
DGWL May 2005



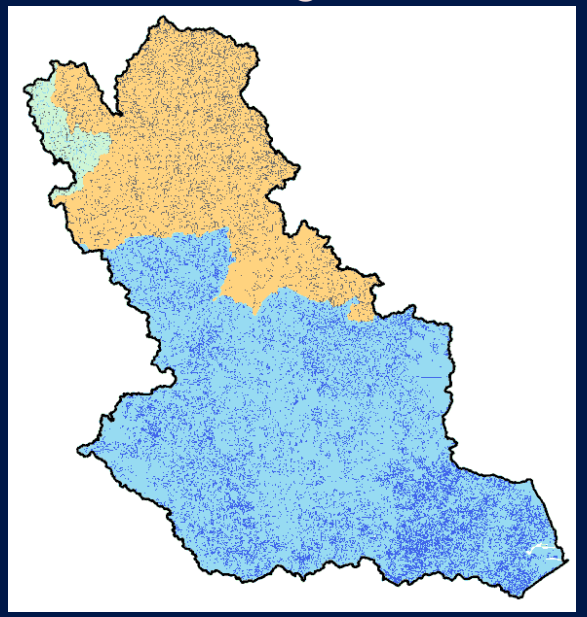
Computation of Fluxes

- Ground water abstractions
- Domestic Consumption
- Livestock Consumption
- Industrial Consumption
- Surface storage fluxes

DGWL Change 2004 to 2005

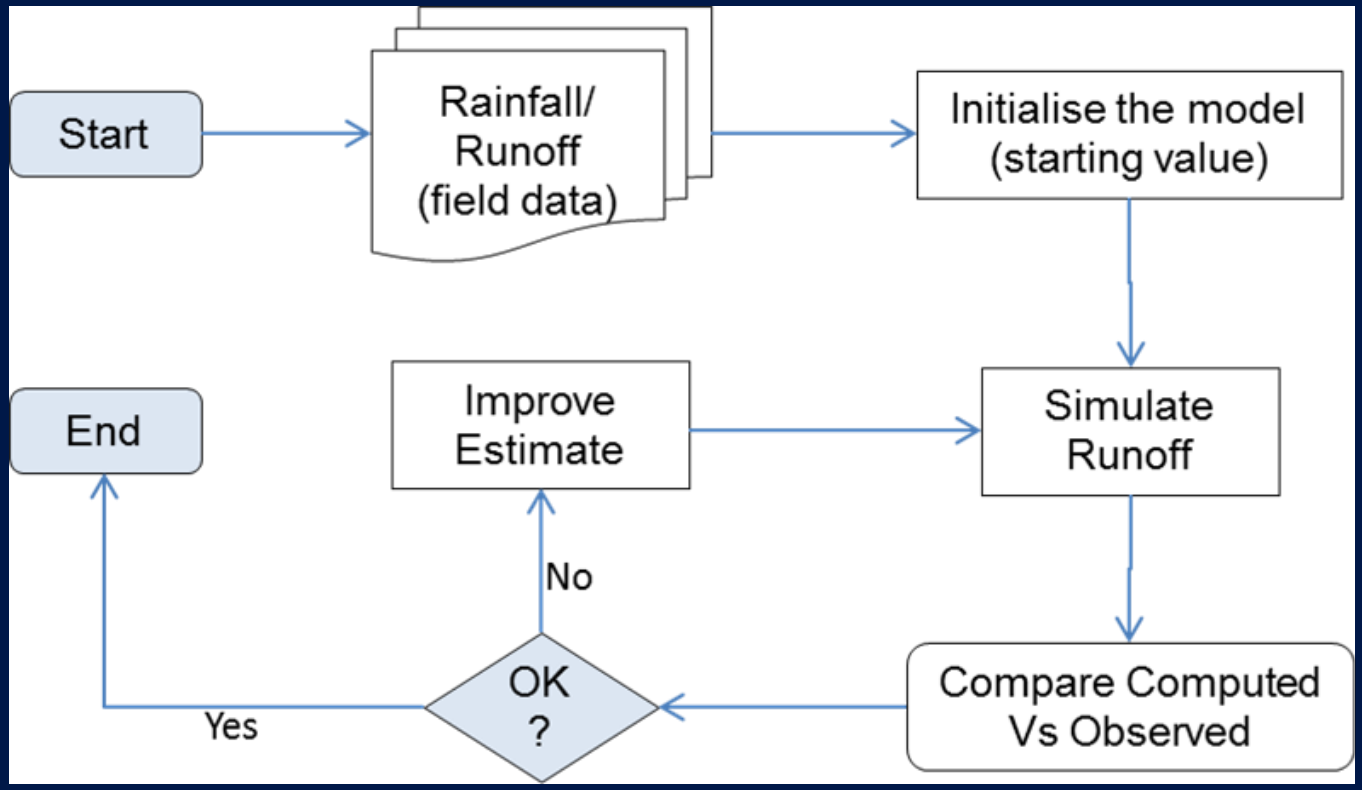


Village Census



Pilot Study on Godavari and Brahmani-Baitarani Basins

Calibration and Validation

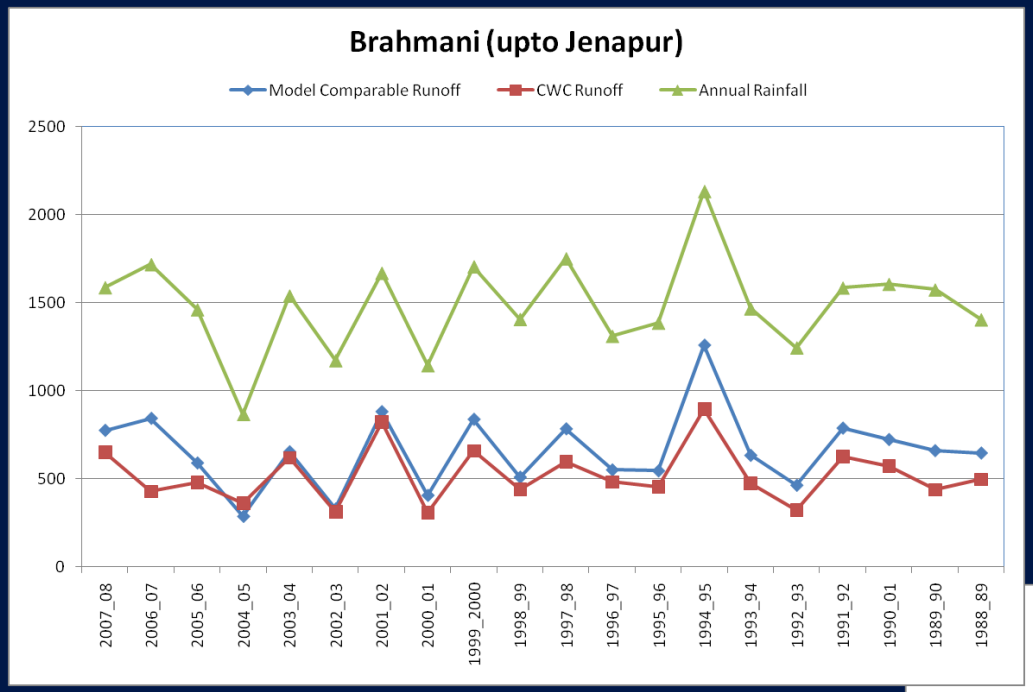


$$R_{Calibrated/computed} = (R_{Model} - F_{GW} - F_{R} - F_{DIL}) \approx R_{O}$$

$R_{Calibrated/computed}$ = Calibrated/computed runoff
R_{Model} = Model estimated runoff (output from Thornthwaite Mather Model)

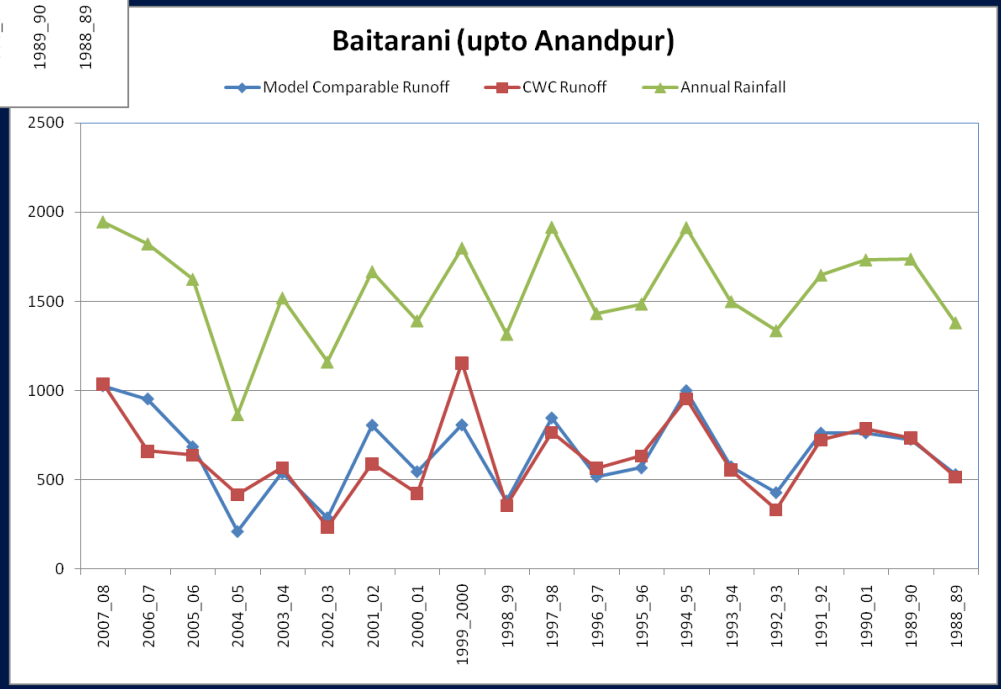
F_{R} = Reservoir Flux (- ve sign for drawdown)
F_{GW} = Ground water Flux (- ve sign for drawdown)
F_{DIL} = Domestic, Industrial and Livestock consumption
R_{0} = Observed runoff at gauge sites

Pilot Study on Godavari and Brahmani-Baitarani Basins



Comparison of Computed Vs Observed Runoff

Brahmani-Baitarani River Basin



Water Resources Availability

$$WRA = R_{Calibrated/computed} + IS + E + F_{DIL} + F_{GW} + F_{R}$$

$R_{Calibrated/computed}$ = Calibrated/computed runoff

F_R = Reservoir Flux

F_{GW} = Ground water Flux

F_{DIL} = Domestic, Industrial and Livestock consumption

R_0 = Observed runoff at gauge sites

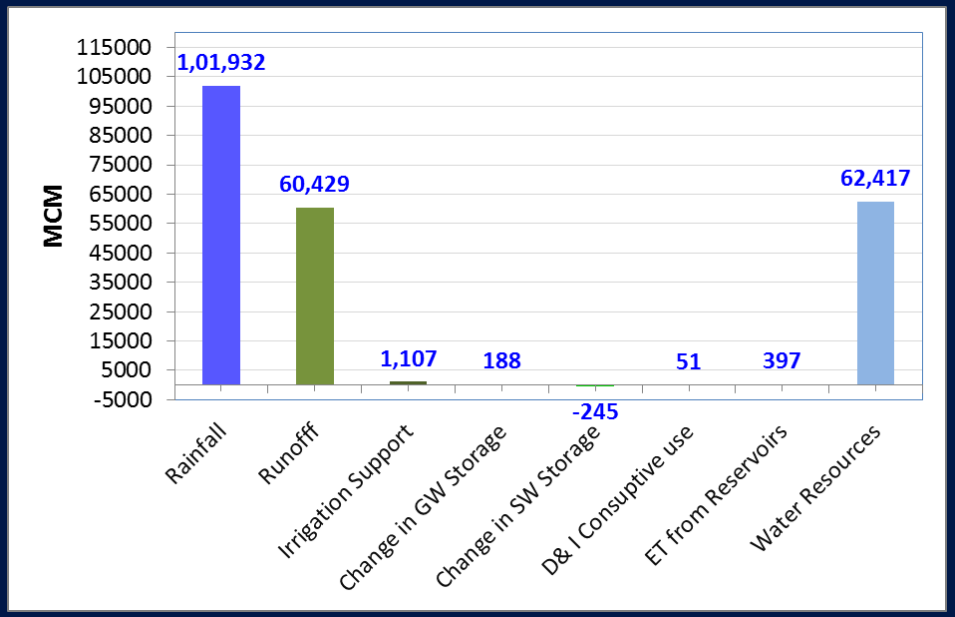
E = Evaporation losses from reservoirs

IS = Irrigation Support

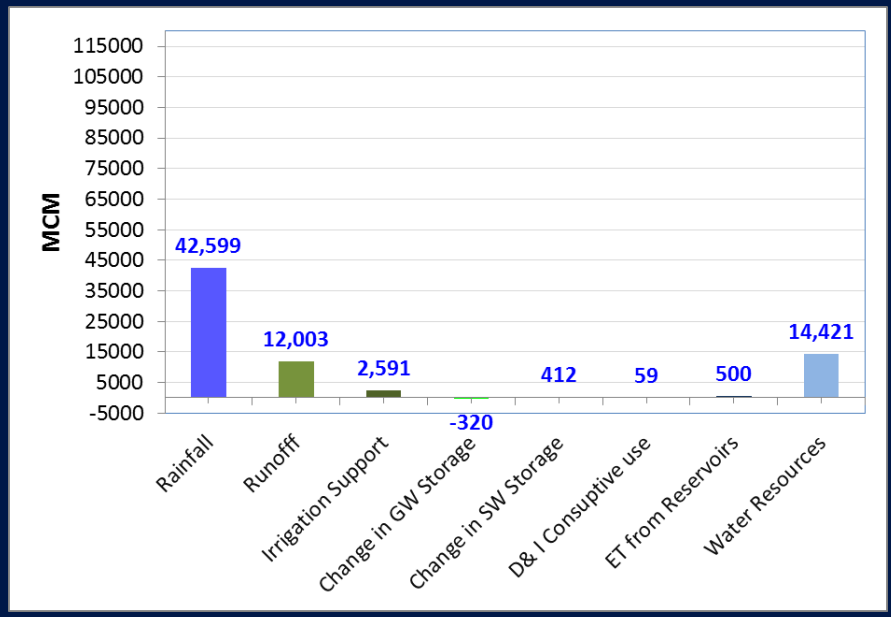
Water Resources Availability was estimated for a period of 20 years (1988-89 to 2007-08)

Pilot Study on Godavari and Brahmani-Baitarani Basins

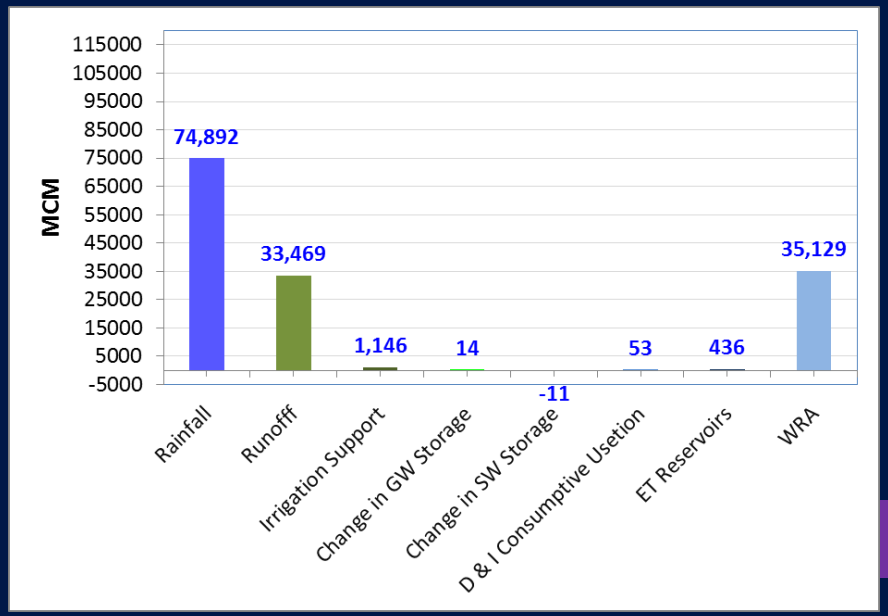
Water Balance components of Brahmani-Baitarani basin



High Rainfall



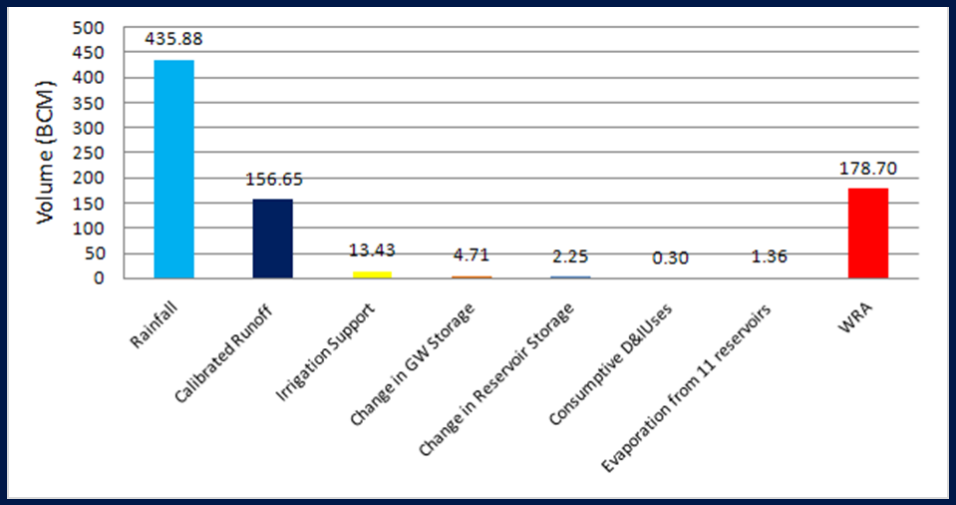
Low Rainfall



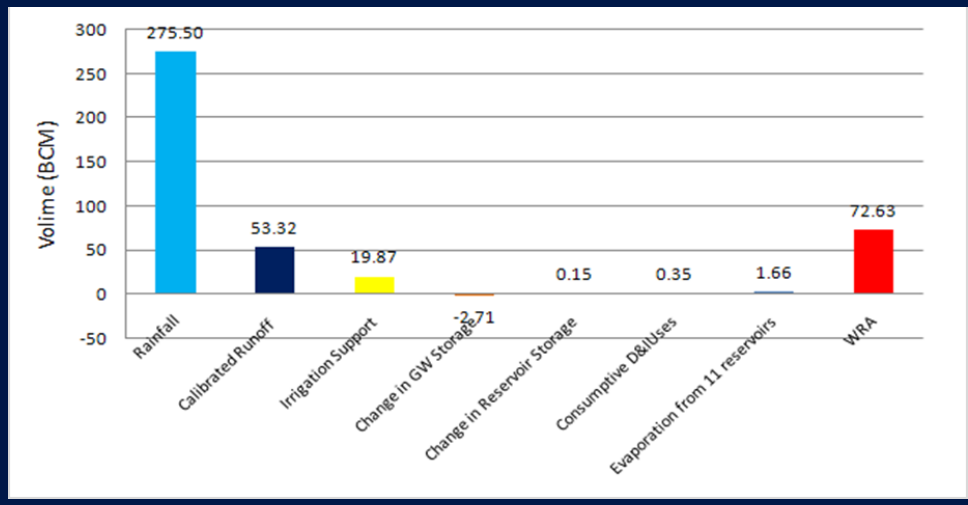
Mean of 20 years

Pilot Study on Godavari and Brahmani-Baitarani Basins

Water Balance components of Godavari basin

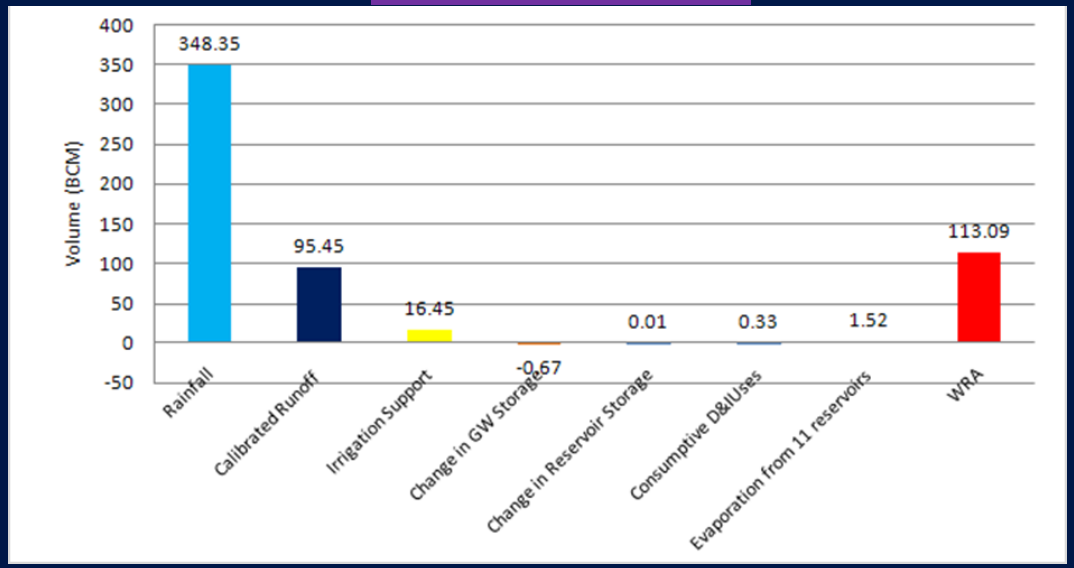


High Rainfall



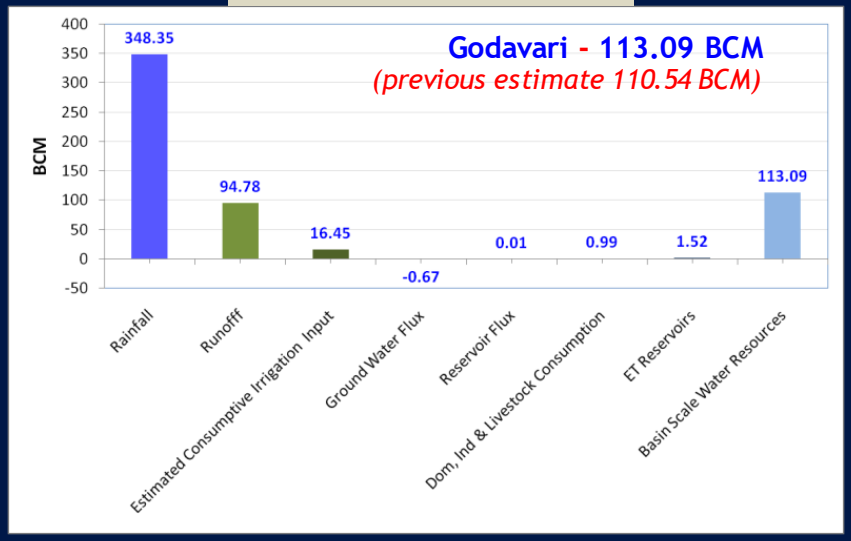
Low Rainfall

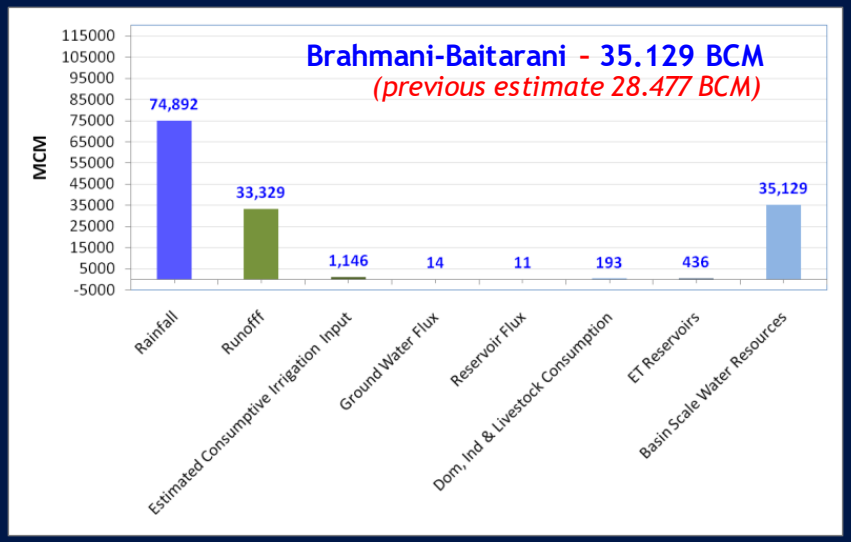
Mean of 20 years



Pilot Study on Godavari and Brahmani-Baitarani Basins

Pilot Study Results





- Pilot study demonstrated development of geo-spatial data based hydrological modeling approach (in Godavari and Brahmani & Baitarani river basins)
- Expert Committee constituted by MoWR reviewed Pilot Studies and Recommended for upscaling to entire Country to obtain latest update
- CWC through its 10 Regional Basin Organizations to carryout the study
- NRSC/ISRO to provide capacity building through Training and Hand holding
- The study to be carried out for a period of 30 years (1985-2015)

Reassessment of Water Availability in India using Space Inputs

Capacity Building and Technical Collaboration on Reassessment of WA

- NRSC and CWC Signed MoU during Jul, 2016 for Capacity Building and Technical Collaboration by NRSC on Reassessment of Water Availability in India using Satellite Based Inputs to Central Water Commission.
- CWC Procured requisite Computer Hardware and Geo-Spatial Analysis Software for executing the project activities
- The project was initiated from July 2016 with duration of one year.

Reassessment of Water Availability in India using Space Inputs

Capacity Building and Technical Collaboration on Reassessment of WA

- Before start of the Project activity,

- One week orientation course during May 25-29, 2015 on basics of remote sensing and theoretical aspects of WRA methodology of the project

Identified CWC Nodal officers are requested to collect the following data required for their respective basins and organize them for the next training programme.

- District-wise, year-wise agricultural crop statistics
- Region-specific crop coefficients, root depth, Soil AWC data

- Two-week capacity building programme during October 05-16, 2015 on WRA methodological steps with full-fledged hands on exercise
  - Using field discharge data collected by CWC Officers for identified one discharge location under each basin and corresponding sub-basin was chosen subsequent WRA methodology for hands on exercises.
  - End-to-end exercise of WRA assessment was carried by CWC Officers for a selected sub-basin/catchment in each basin

Reassessment of Water Availability in India using Space Inputs

Capacity Building and Technical Collaboration on Reassessment of WA

- NRSC provided the following Geo-Spatial data sets to CWC Engineers

1) Basin boundary shape file
2) Digital elevation model (Cartosat-1 & SRTM)
3) Land Use/Land Cover (56m resolution, 2004-05 to 2014-15; 11 years)
4) Soil map
5) Village boundary shape file
6) All India irrigation command boundary shape file
7) IMD 0.25 degree Gridded Rainfall images (1984-2015)
8) IMD 1 degree Gridded Mean Temperature images (1984-2015)
9) WRA Manual (version 2) in softcopy and hardcopy
10) Pilot study report in softcopy

Reassessment of Water Availability in India using Space Inputs

Capacity Building and Technical Collaboration on Reassessment of WA

- NRSC Developed customized Water Resources Assessment Tool (WRAT) for the benefit of CWC Officers.

- WRAT computes water resources at basin scale using geo-spatial data sets. The WRA tool is platform independent and does not need Image analysis/GIS software.

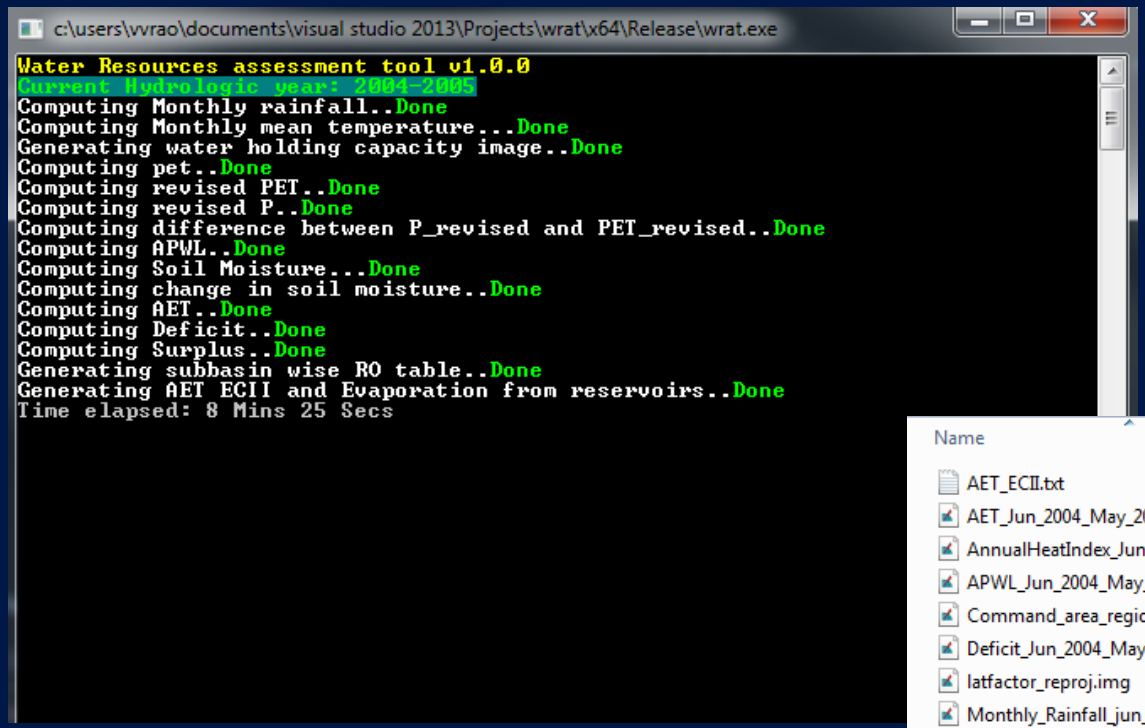
Input Files

- Daily Rainfall file (each containing 365/366 layers depending on whether the year is a leap year or not) for years; eg:2004,2005
- Daily temperature file (same format as used for rainfall).
- LULC file for the year; eg: 2004-2005 (for the basin which you want to assess).
- Command area file(each pixel should be either 1 or 0 depending on whether the pixel lies in the within boundary or outside boundary). This will be the same file for all the years
- Soils type file & sub-basin file(both in thematic raster format).
- Soil moisture & Reservoir mask if available (both in thematic raster format).

Reassessment of Water Availability in India using Space Inputs

Capacity Building and Technical Collaboration on Reassessment of WA

WRA Tool



Outputs – Images and Text files

Name	Date modified	Type	Size
AET_ECII.txt	9/30/2015 10:44 AM	Text Document	1 KB
AET_Jun_2004_May_2005.img	9/30/2015 11:48 AM	IMG File	264,641 KB
AnnualHeatIndex_Jun_2004_May_2005.img	9/30/2015 10:36 AM	IMG File	9 KB
APWL_Jun_2004_May_2005.img	9/30/2015 11:35 AM	IMG File	151,210 KB
Command_area_regions_reproj.img	9/30/2015 10:57 AM	IMG File	330 KB
Deficit_Jun_2004_May_2005.img	9/30/2015 11:52 AM	IMG File	149,181 KB
latfactor_reproj.img	9/30/2015 10:36 AM	IMG File	35 KB
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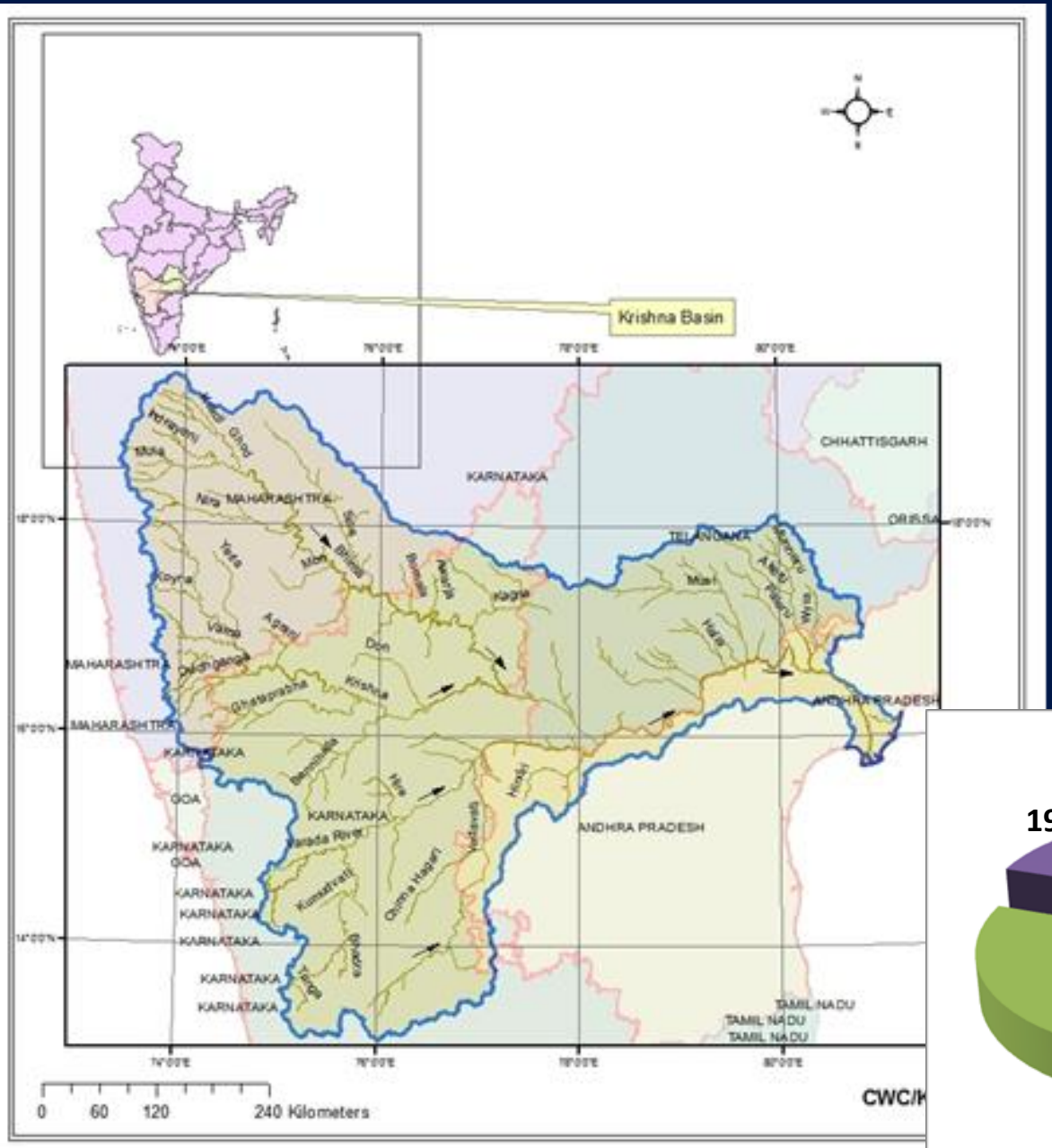
subbasin_wise.txt	9/30/2015 10:44 AM	Text Document	1 KB
Surplus_Jun_2004_May_2005.img	9/30/2015 11:53 AM	IMG File	125,311 KB
WHC_Jun_2004_May_2005.img	9/30/2015 10:36 AM	IMG File	19,958 KB

Reassessment of Water Availability in India using Space Inputs

Handholding

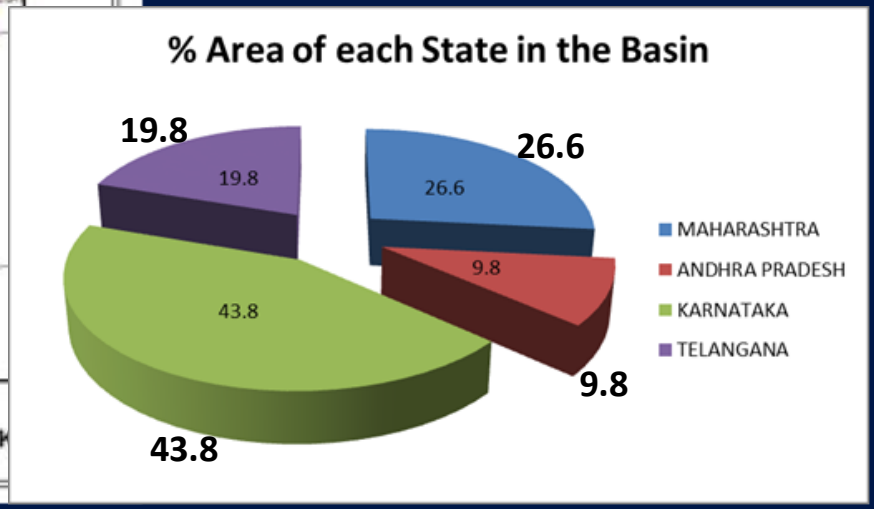
- Mid-term review workshop was conducted at NRSC for CWC officers during 05-09, Dec 2016 to review the status of the project work and clarify the methodological aspects with full-fledged hands on exercise.
- Basin-Specific issues and Complexities are being addressed through CWC and NRSC interaction meetings
- Hand holding and technical guidance continued till the completion of the project
- The Study was completed by Aug, 2017
- Individual basin-wise reports were prepared
- Final summary report was prepared

Reassessment of Water Availability in India using Space Inputs-Krishna

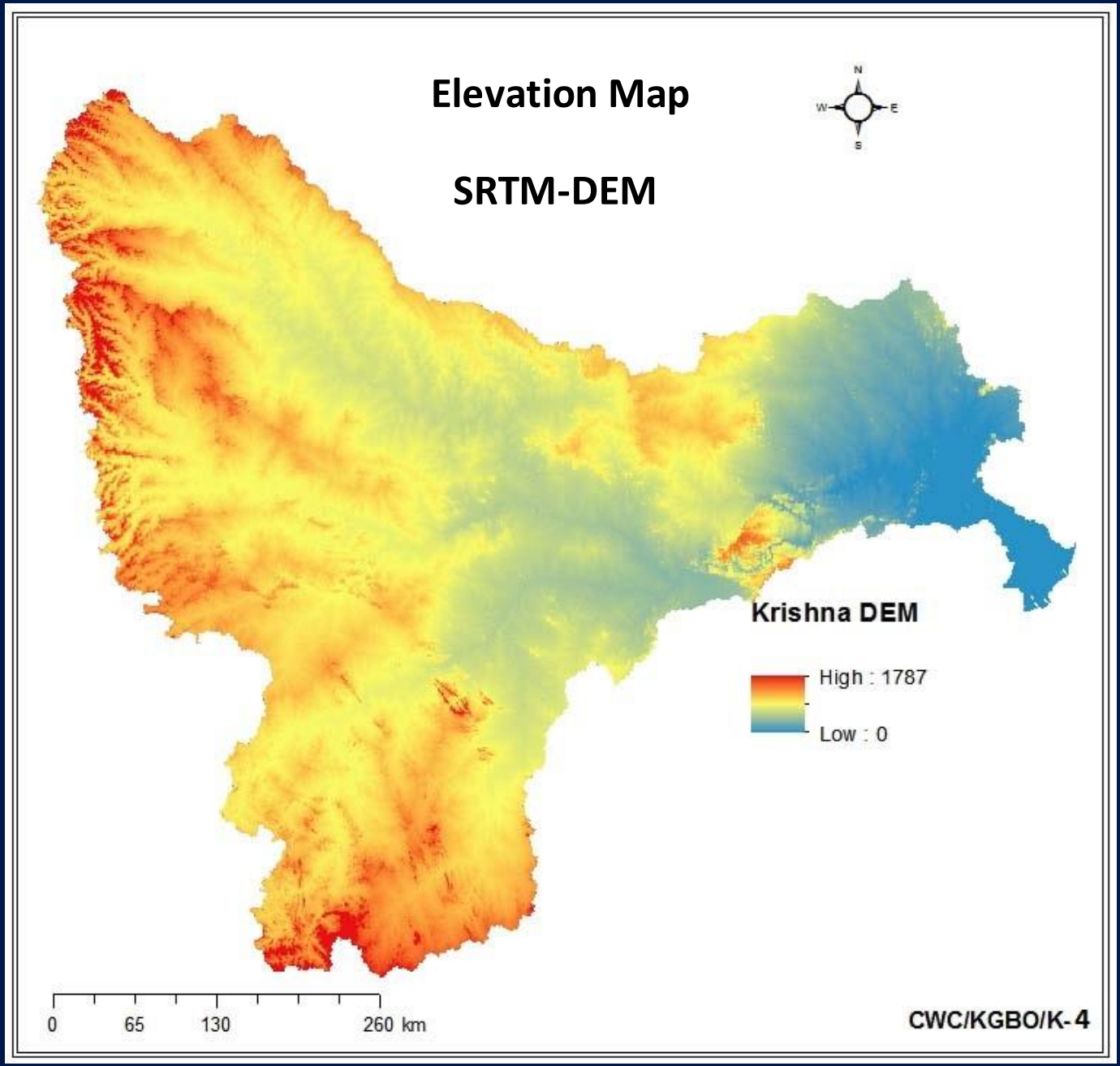


Krishna Catchment Area = 2,59,439 Km^2

Study Period: 30 years (1985-2015)



Reassessment of Water Availability in India using Space Inputs-Krishna



Input Data

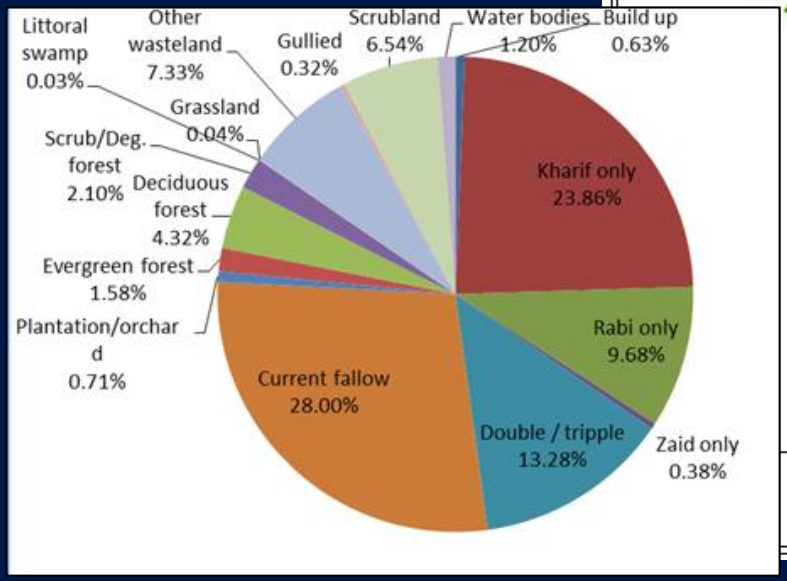
Maximum Elevation - 1,787 m

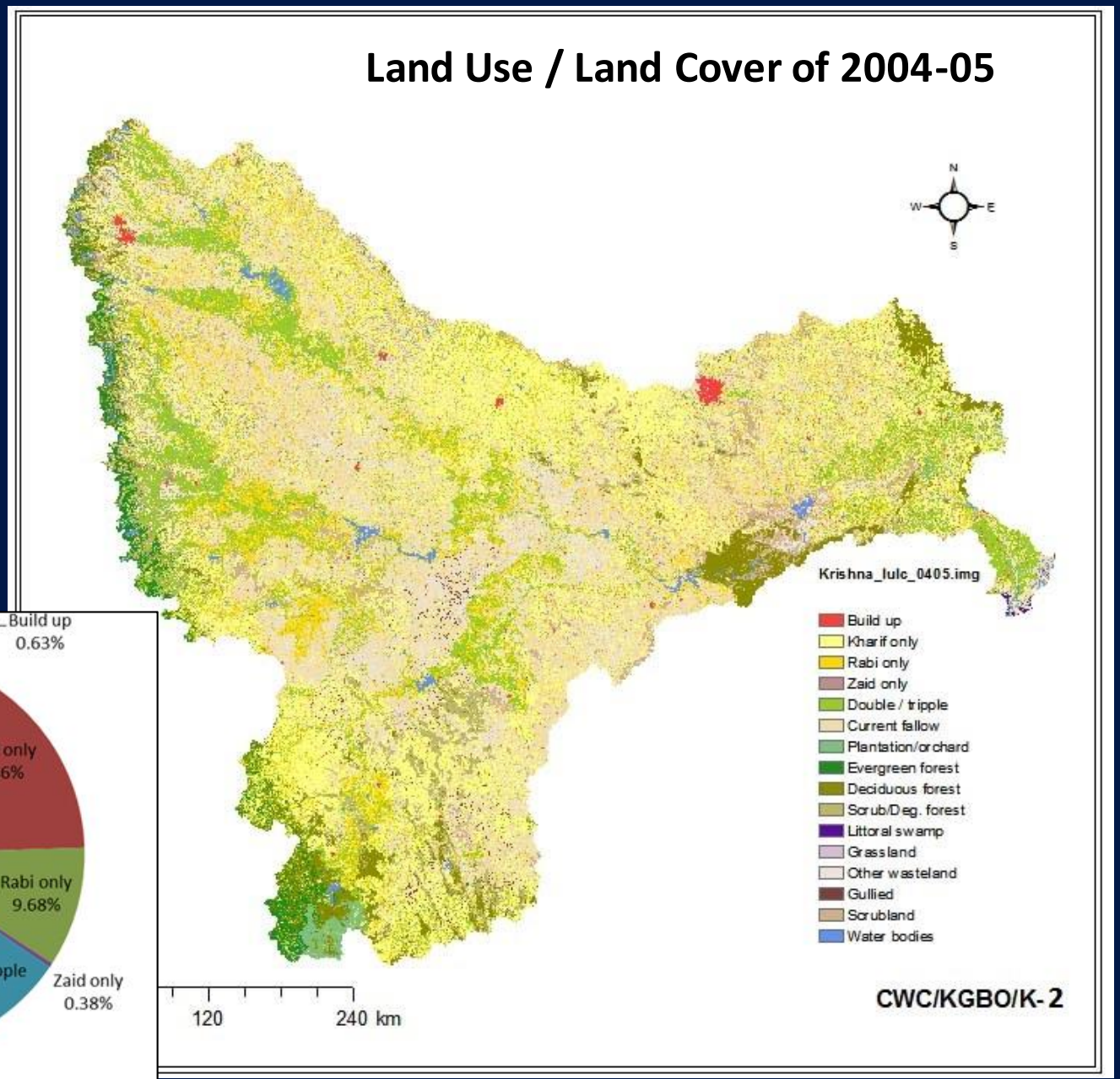
Mean Elevation - 444 m

Reassessment of Water Availability in India using Space Inputs-Krishna

Input Data

Spatial distribution of Land cover types

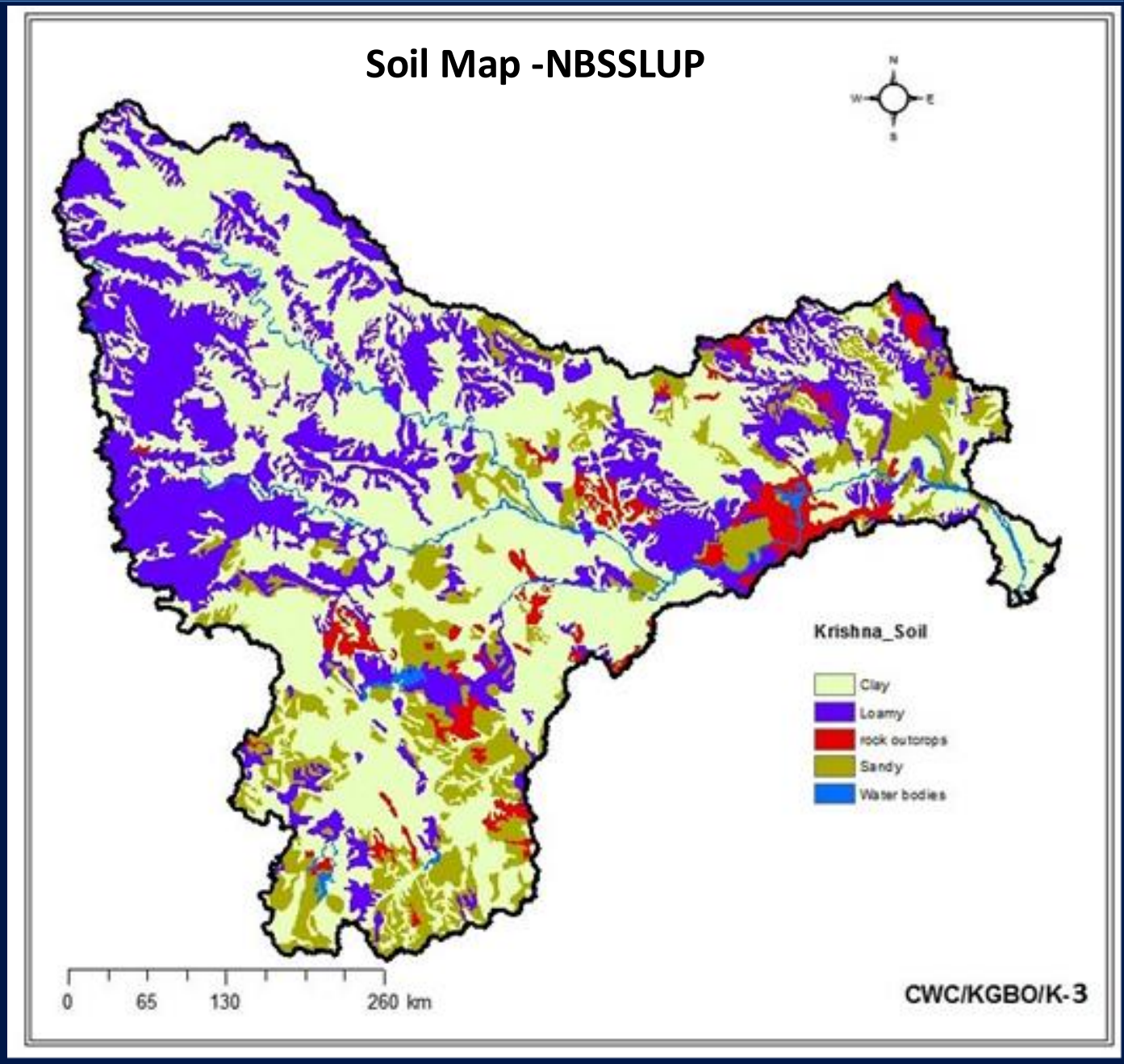




Reassessment of Water Availability in India using Space Inputs-Krishna

Input Data

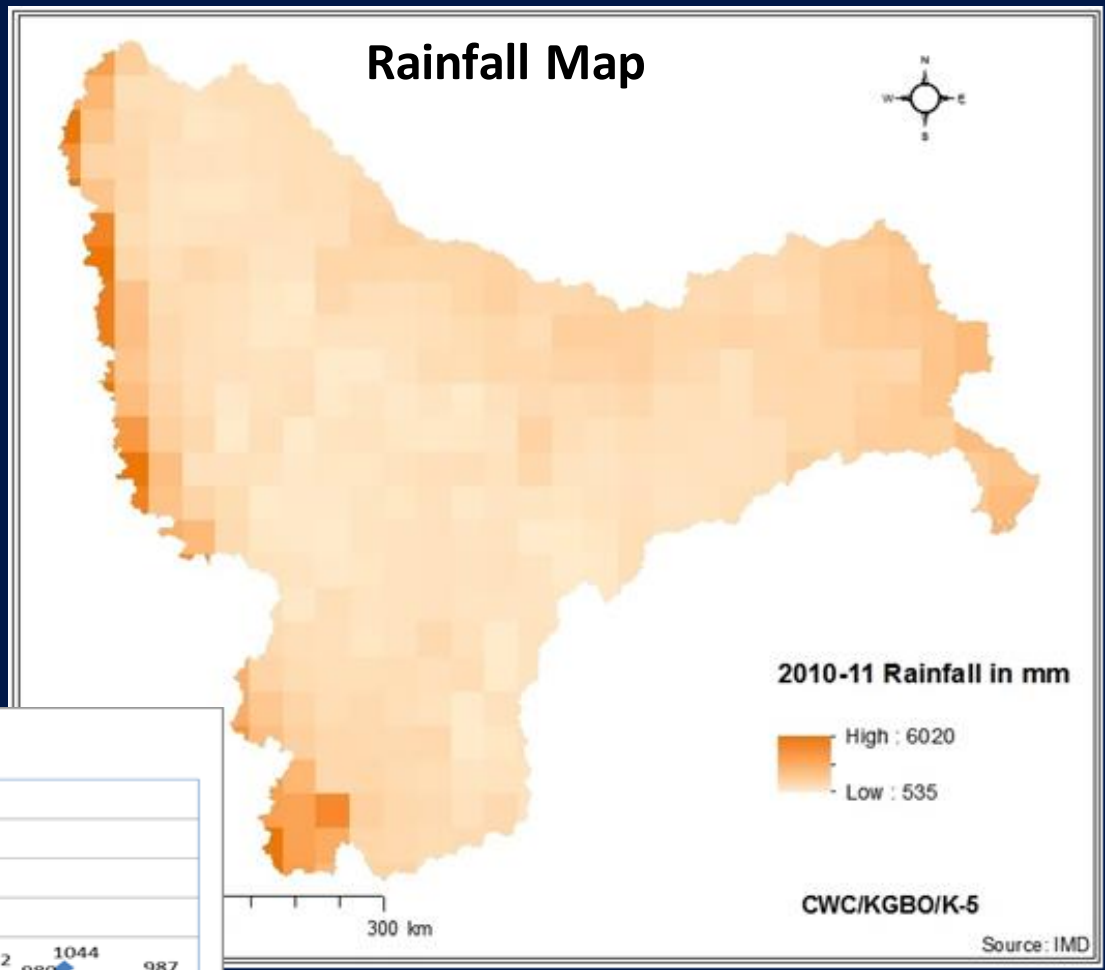
Spatial distribution of Soil types

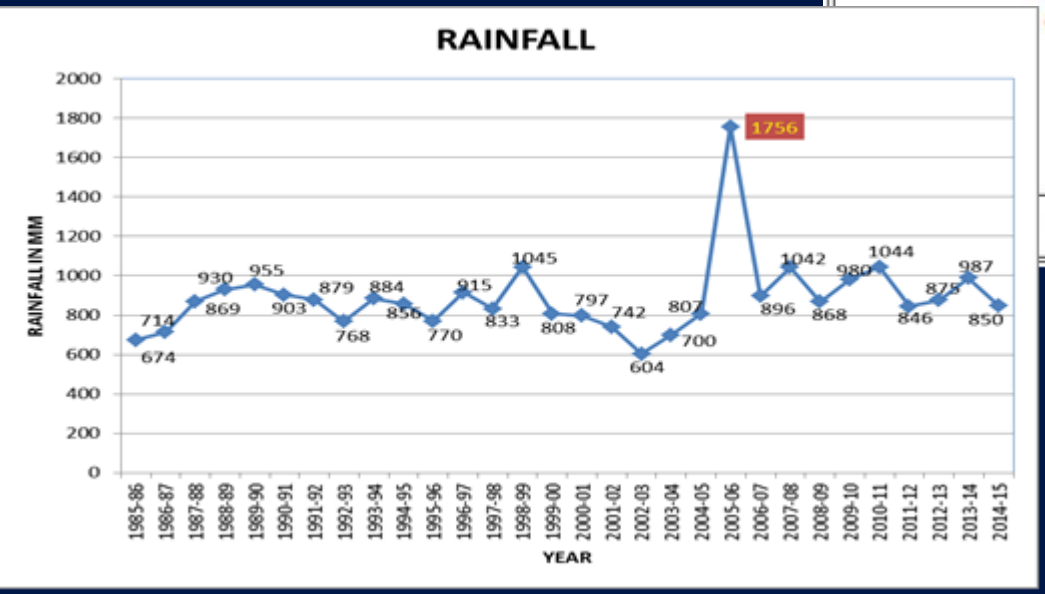


Reassessment of Water Availability in India using Space Inputs-Krishna

Input Data

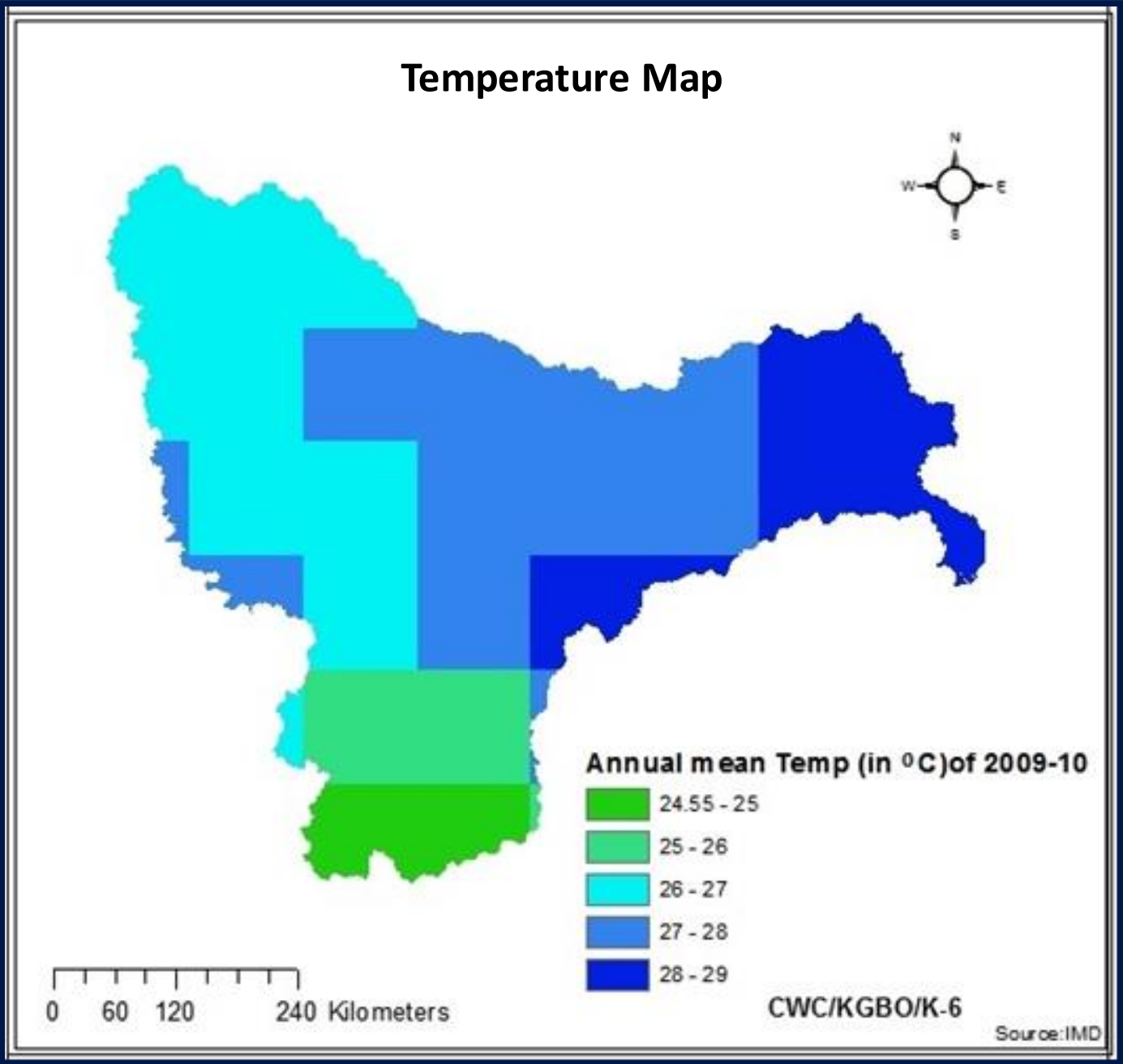
	Rainfall (mm)
Maximum	1,045
Minimum	604
Mean	857





IMD Rainfall grid of 0.25^0 X 0.25^0

Reassessment of Water Availability in India using Space Inputs-Krishna



Input Data

IMD Temperature grid of 1^0 X 1^0

Mean Temperature - 27^0 C

Reassessment of Water Availability in India using Space Inputs-Krishna

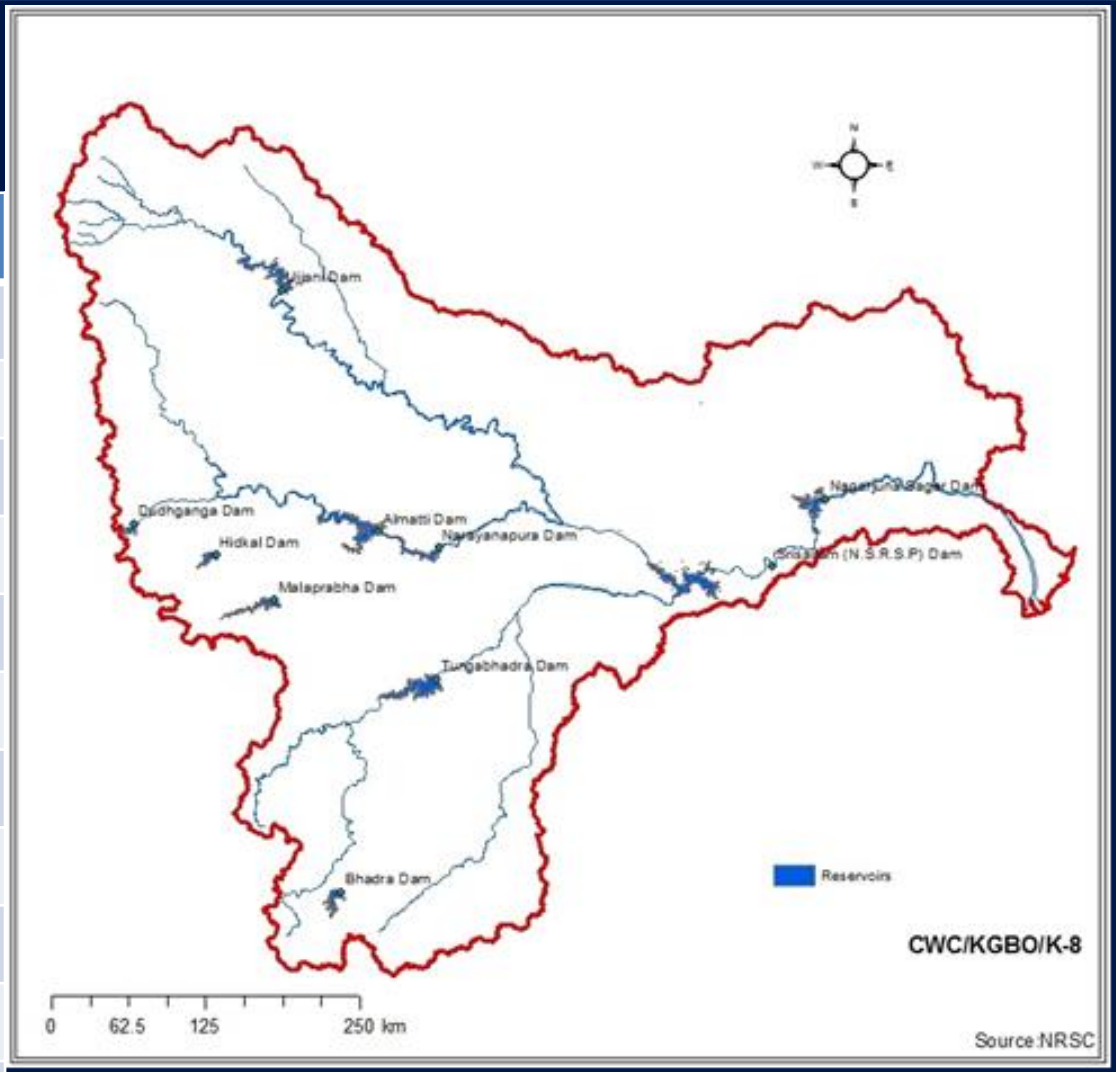
Sub-basins

S. No.	Sub-basin	River	Catchment Area (sq.km)
1	Kurundwad	Krishna	15,352
2	Huvinhedgi	Krishna	38,951
3	Takli	Bhima	33,398
4	Yadgir	Bhima	36,135
5	Bawapuram	Tungabhadra	66,653
6	Wadinepalli	Krishna	52,663
7	Vijayawada	Krishna	13,240
8	Delta	Krishna	3,047
TOTAL			2,59,439

Reassessment of Water Availability in India using Space Inputs-Krishna

Surface Water Flux

S. No.	Reservoir	River	Year
1	Khadakwasla	Mutha	1879
2	Tungabhadra	Tungabhadra	1953
3	Koyna	Koyna	1964
4	Linganamakki	Sharavathi	1964
5	Bhadra	Bhadra	1965
6	Nagarjuna sagar	Krishna	1967
7	Ghataprabha	Ghataprabha	1977
8	Ujjani	Krishna	1980
9	Srisailam	Krishna	1981
10	Narayanpur	Krishna	1982
11	Supa	Kali	1987
12	Jurala	Krishna	1995
13	Almatti	Krishna	1999

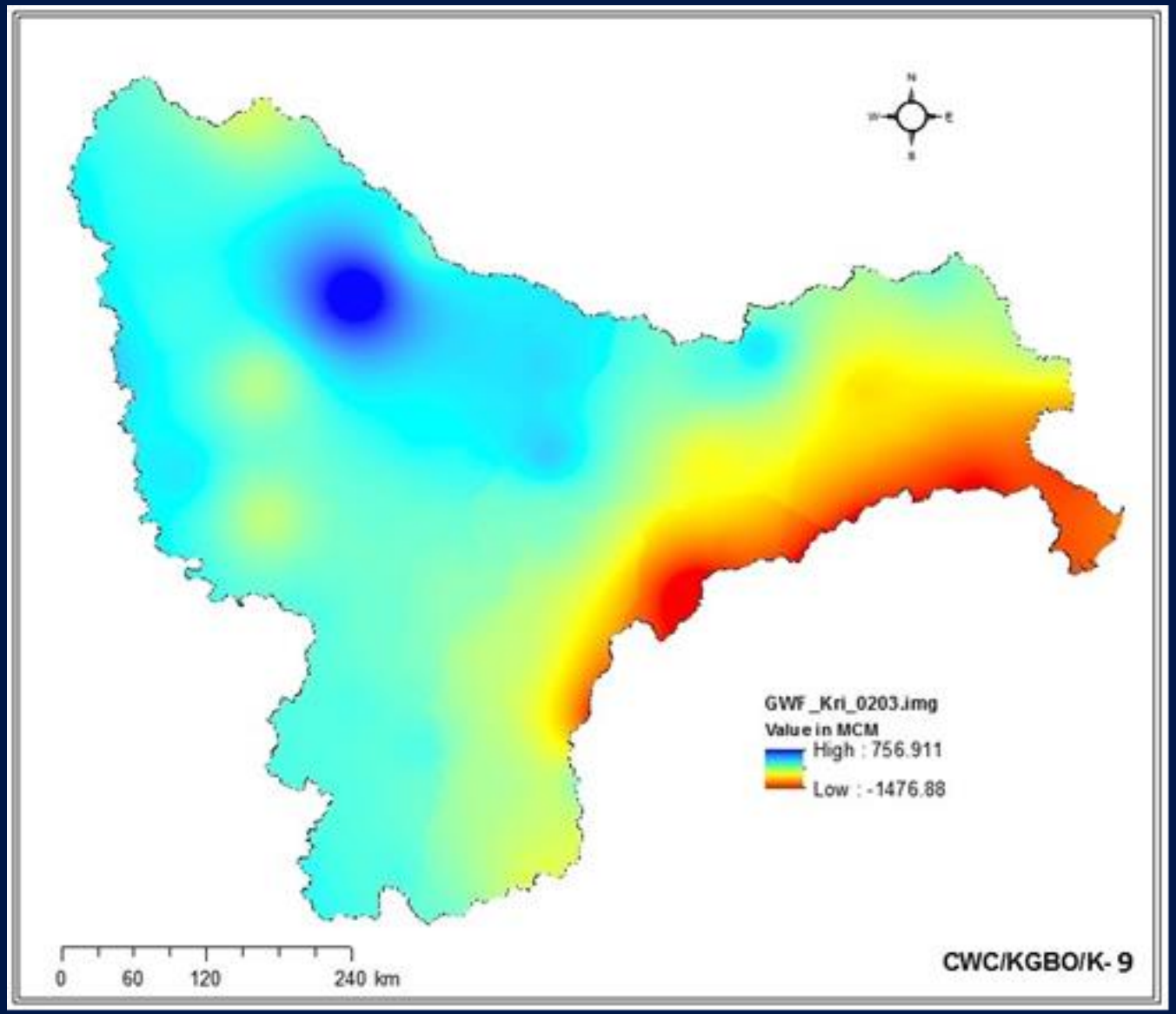


Major Reservoirs

Reassessment of Water Availability in India using Space Inputs-Krishna

Ground Water Flux

Ground water abstractions for 2002-2003



Reassessment of Water Availability in India using Space Inputs-Krishna

DIL Flux

Census data:
1991, 2001, 2011

Industrial demand = 50% of domestic demand

Live stock Census data 1982, 1990, 2003, 2012

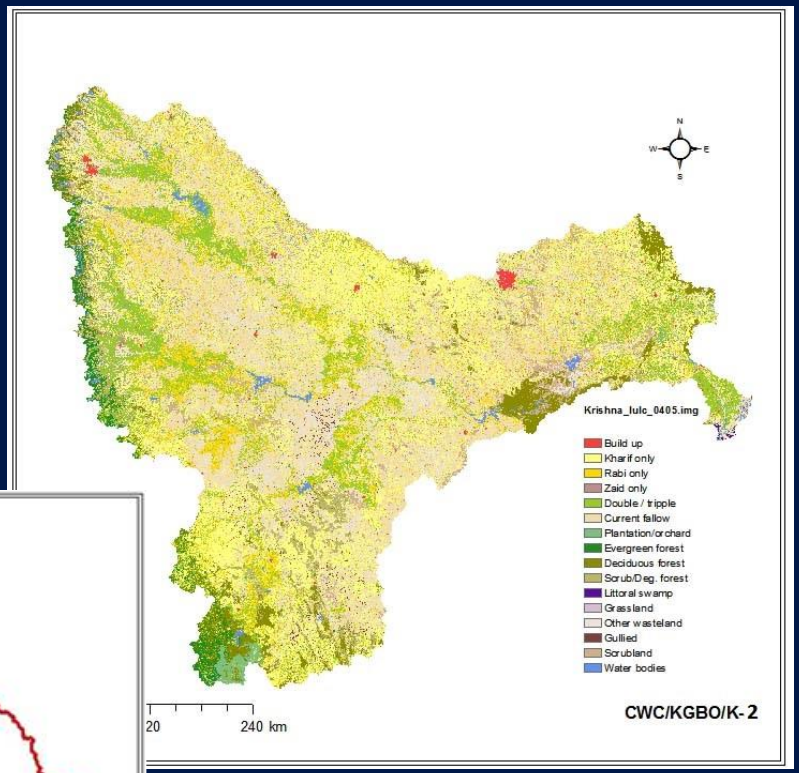
Type	Quantity (lpcd)
Urban	140
Rural	70
Livestock	30

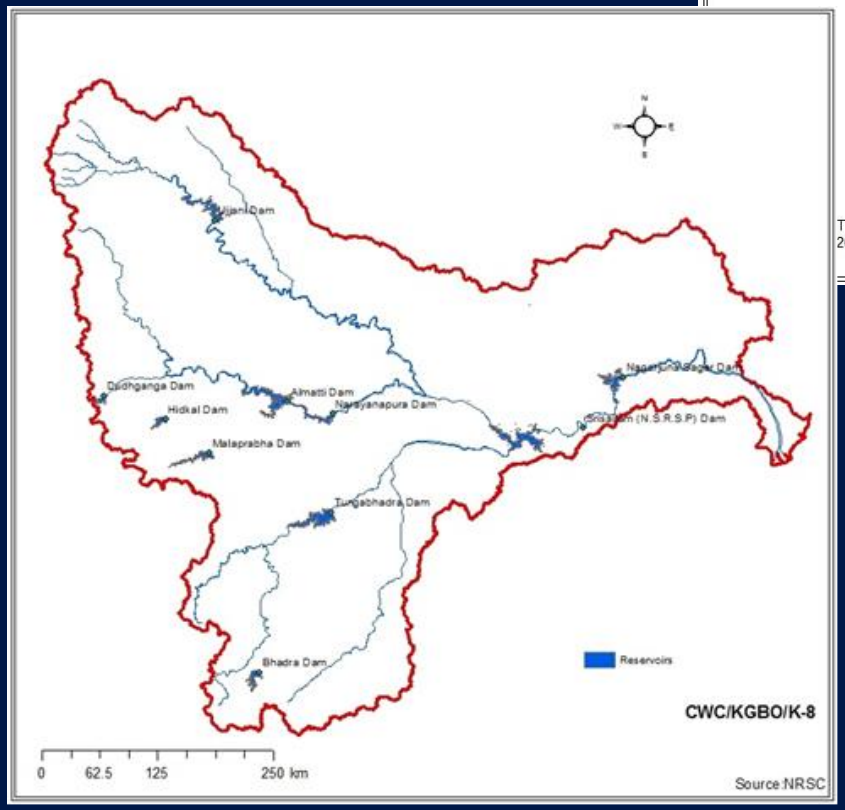
Consumption=15%

Reassessment of Water Availability in India using Space Inputs-Krishna

Evaporation Losses

- Water bodies > 1 hectare
- water bodies area of respective dams was removed based on the year of completion of the dam





Reassessment of Water Availability in India using Space Inputs-Krishna

Vegetation Coefficients

	Region No. 1 (Ahmednagar)				Region No. 4 (Belgaum)			
	Kharif only	Rabi only	Double/ Triple	Zaid only	Kharif only	Rabi only	Double/ Triple	Zaid only
	Bajra	Jowar	Sugarcane		Maize	Jowar	Sugarcane	
June	0.50	0.50	0.74	0.50	0.50	0.50	0.74	0.50
July	0.50	0.50	0.50	0.50	0.55	0.50	0.50	0.50
August	1.00	0.50	0.55	0.50	0.75	0.50	0.55	0.50
September	1.10	0.50	0.80	0.50	1.25	0.50	0.80	0.50
October	0.55	0.50	0.90	0.50	0.80	0.50	0.90	0.50
November	0.50	0.50	1.10	0.50	0.55	0.50	1.10	0.50
December	0.50	0.52	1.20	0.50	0.50	0.52	1.20	0.50
January	0.50	0.71	1.20	0.50	0.50	0.71	1.20	0.50
February	0.50	0.62	1.20	0.50	0.50	0.62	1.20	0.50
March	0.50	0.55	1.20	0.75	0.50	0.55	1.20	0.75
April	0.50	0.50	0.90	1.05	0.50	0.50	0.90	1.05

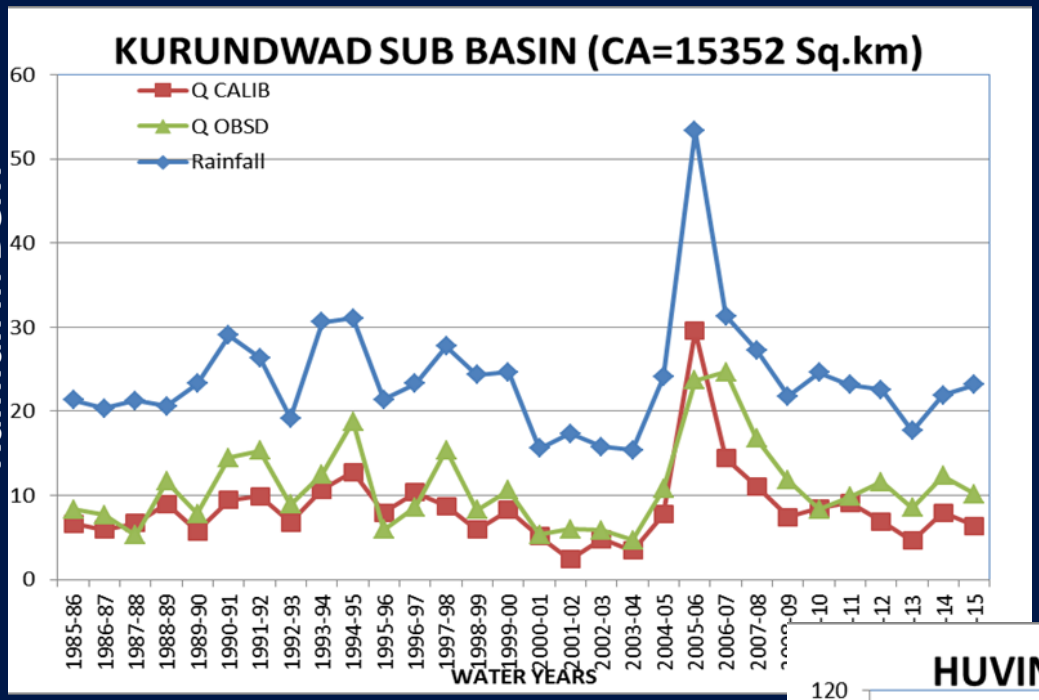
Reassessment of Water Availability in India using Space Inputs-Krishna

Calibrated runoff along with observed discharge at Kurundwad on Krishna River

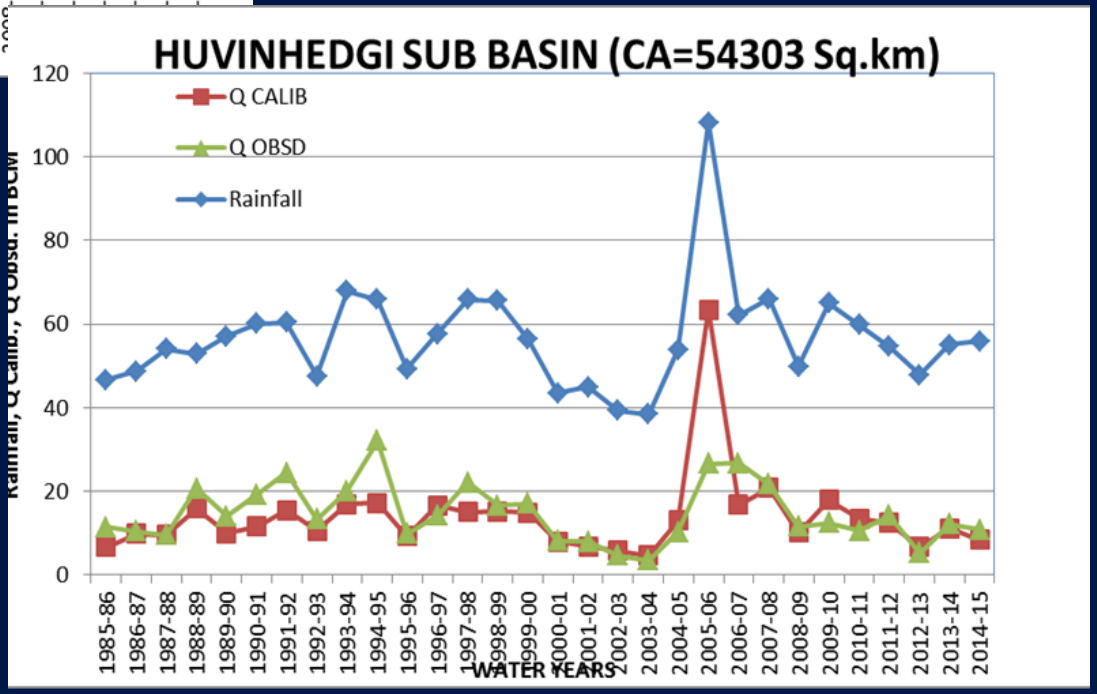
BASIN/SUB-BASIN NAME : Kurundwad Catchment Area = 15,352 Sq.Km

YEAR	RAINFALL		AET (from irrigated area) Irrigation Support (ECII)	DLI	GW Flux	Reservoir Flux Export from the Basin Q-Calibrated	Q-Observed	Reservoir Evap.	Water Availability
	mm	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)
1	2(a)	2(b)	3	4	5	6	7	8	9	10	11	12= 4+5+6+7 +8+9+11
1985-86	1391	21.36	4.20	1.30	0.08	-0.11	0.26	2.46	6.62	8.37	0.11	10.72
1986-87	1327	20.37	4.34	1.08	0.08	0.19	-0.40	2.46	5.90	7.68	0.13	9.44
1987-88	1386	21.27	5.13	1.14	0.08	0.04	0.16	1.85	6.72	5.25	0.15	10.14
1988-89	1343	20.62	4.27	1.38	0.09	0.18	0.14	2.46	9.01	11.70	0.11	13.37
1989-90	1517	23.28	7.18	4.21	0.09	0.14	-0.19	2.21	5.76	7.83	0.13	12.34
1990-91	1889	29.00	7.51	3.96	0.09	0.04	0.21	2.21	9.43	14.47	0.13	16.07
1991-92	1719	26.39	7.34	4.47	0.09	-0.06	-0.30	2.21	9.90	15.35	0.11	16.43
1992-93	1251	19.20	5.24	1.75	0.09	-0.18	0.07	2.21	6.76	8.97	0.12	10.81
1993-94	1992	30.57	7.66	3.55	0.09	0.56	0.03	2.34	10.70	12.53	0.15	17.43
1994-95	2021	31.03	7.30	3.63	0.09	-0.14	-0.26	2.50	12.78	18.79	0.14	18.74
1995-96	1394	21.39	4.69	1.70	0.10	-0.14	0.08	1.91	7.93	5.92	0.12	11.69
1996-97	1518	23.30	4.94	1.20	0.10	0.23	0.62	1.91	10.38	8.61	0.17	14.60
1997-98	1805	27.72	9.00	5.16	0.10	-0.18	-0.27	1.91	8.76	15.38	0.16	15.64
1998-99	1583	24.30	7.80	4.28	0.10	0.35	0.33	1.91	5.93	8.27	0.19	13.09
1999-00	1608	24.68	7.25	4.10	0.10	-0.23	-0.17	1.91	8.28	10.62	0.16	14.17
2000-01	1015	15.58	5.34	1.70	0.10	-0.19	-0.13	1.92	5.15	5.35	0.16	8.72
2001-02	1129	17.34	8.49	4.96	0.11	0.08	-0.02	1.91	2.44	6.03	0.16	9.64
2002-03	1027	15.77	5.05	1.96	0.11	-0.29	0.06	1.91	4.81	5.89	0.14	8.70
2003-04	1001	15.37	5.15	2.00	0.11	-0.26	-0.10	1.98	3.47	4.71	0.15	7.36
2004-05	1568	24.07	7.57	3.82	0.11	0.32	0.14	2.13	7.76	10.80	0.16	14.44
2005-06	3473	53.31	7.48	3.38	0.11	0.17	0.06	2.56	29.53	23.67	0.18	36.00
2006-07	2041	31.33	7.47	4.08	0.12	0.20	0.07	2.40	14.40	24.68	0.15	21.41
2007-08	1777	27.28	8.13	4.65	0.12	-0.27	0.20	2.17	11.11	16.76	0.15	18.13
2008-09	1420	21.80	6.09	2.75	0.12	0.36	0.05	1.93	7.46	11.81	0.17	12.84
2009-10	1603	24.61	7.84	4.32	0.13	-0.03	-0.17	2.29	8.45	8.35	0.19	15.19
2010-11	1510	23.18	6.30	2.82	0.13	0.05	-0.06	2.12	9.13	9.83	0.19	14.38
2011-12	1470	22.56	7.63	4.87	0.14	-0.15	0.01	2.02	6.90	11.58	0.18	13.97
2012-13	1152	17.69	6.13	2.80	0.14	-0.24	-0.19	1.98	4.66	8.57	0.20	9.36
2013-14	1429	21.94	7.78	4.15	0.15	0.31	-0.47	2.53	7.94	12.35	0.23	14.83
2014-15	1508	23.16	8.77	4.59	0.16	-0.08	0.44	2.03	6.39	10.15	0.27	13.79
Avg	**1562**	**23.98**	**6.64**	**3.19**	**0.11**	**0.02**	**0.01**	**2.15**	**8.48**	**11.01**	**0.16**	**14.11**
excluding 2005-06	1496	22.97	6.61	3.18	0.11	0.02	0.00	2.13	7.76	10.57	0.16	13.36

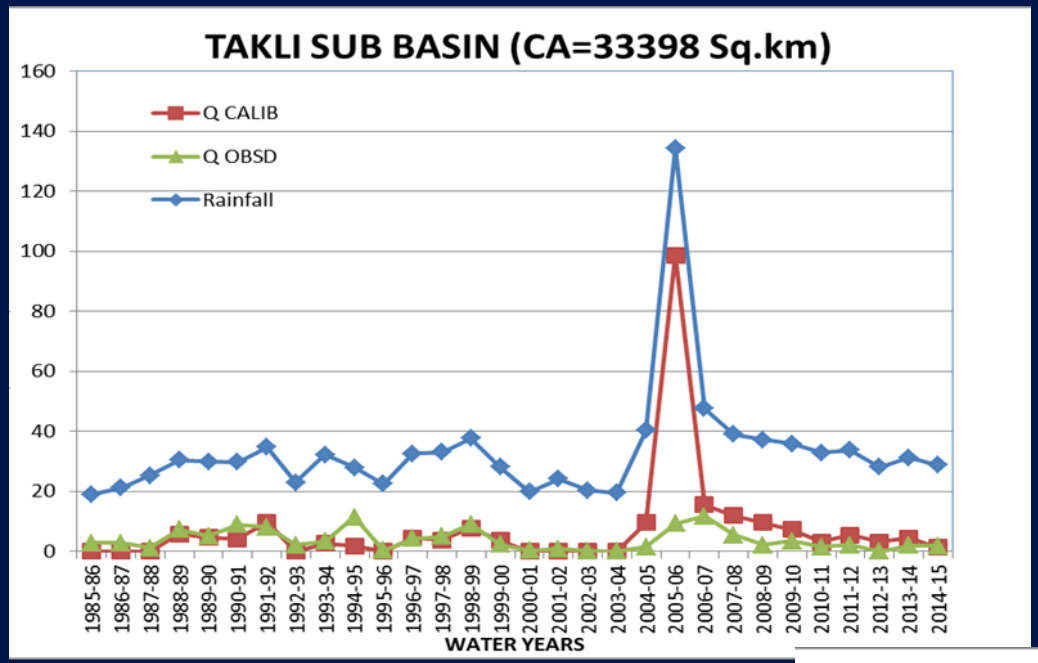
Reassessment of Water Availability in India using Space Inputs-Krishna



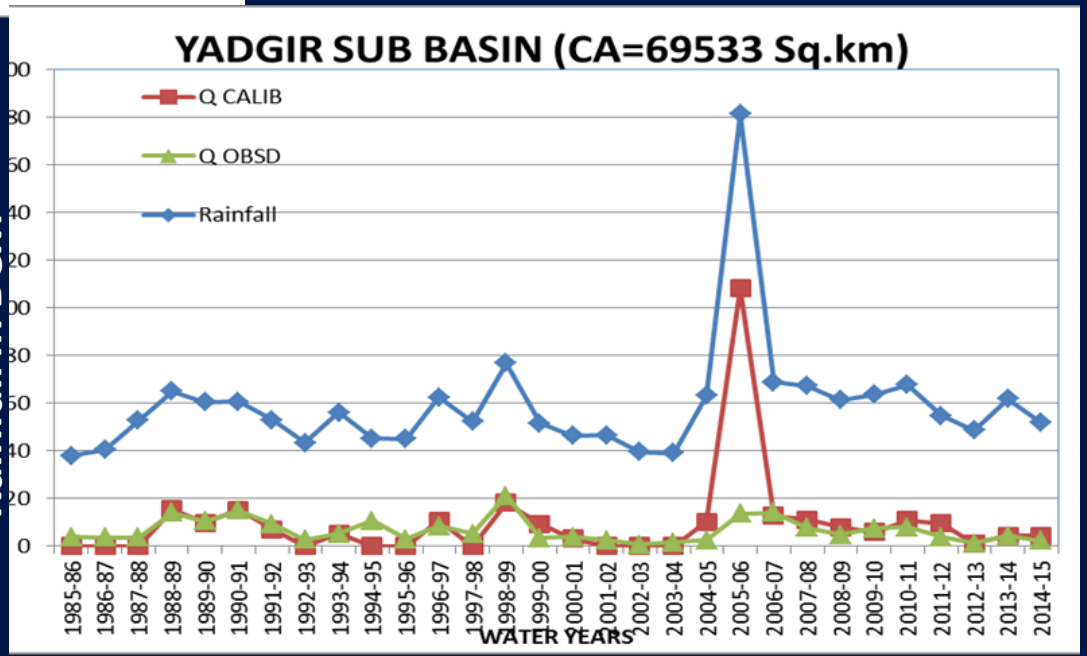
Krishna river



Reassessment of Water Availability in India using Space Inputs-Krishna

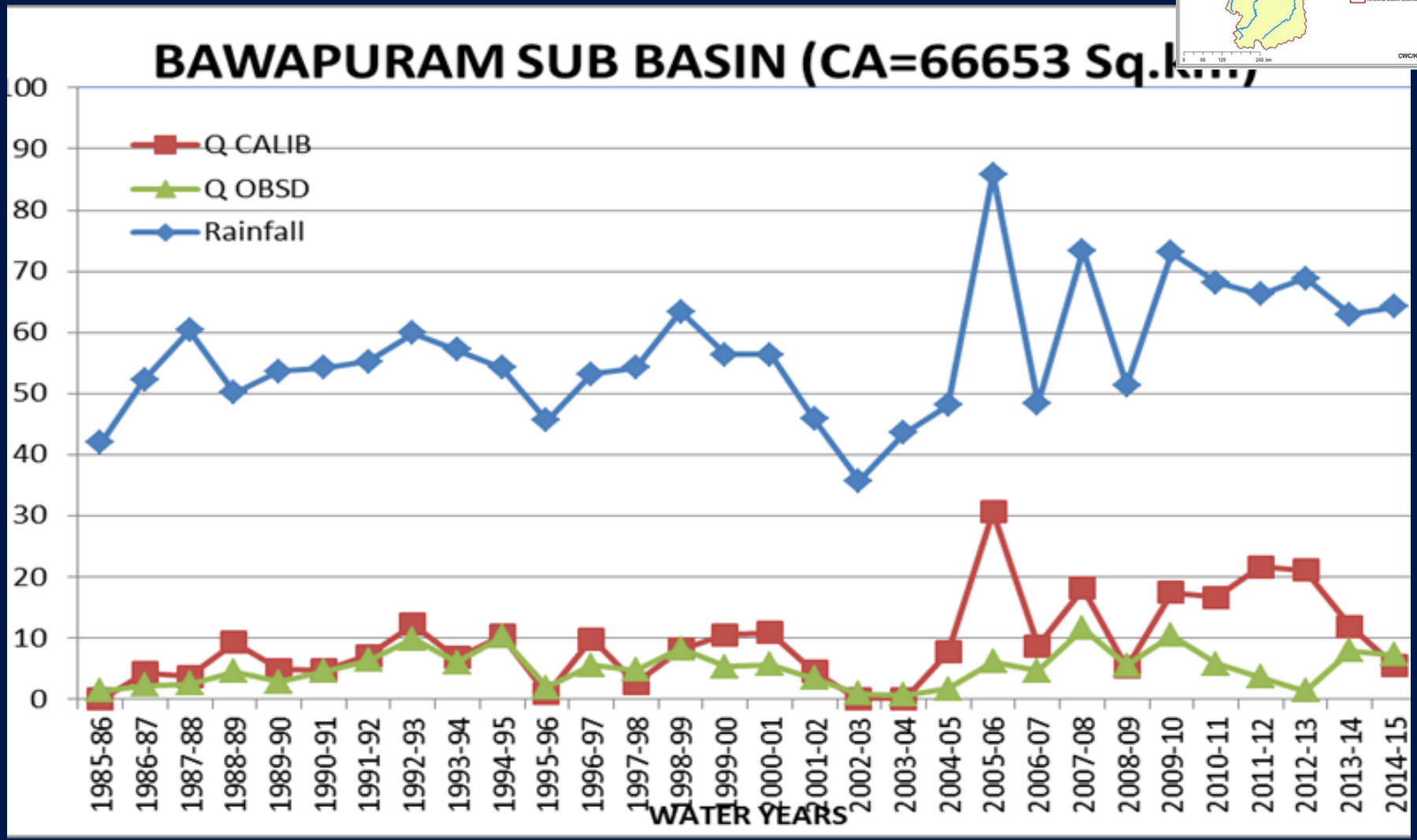


Bhima river

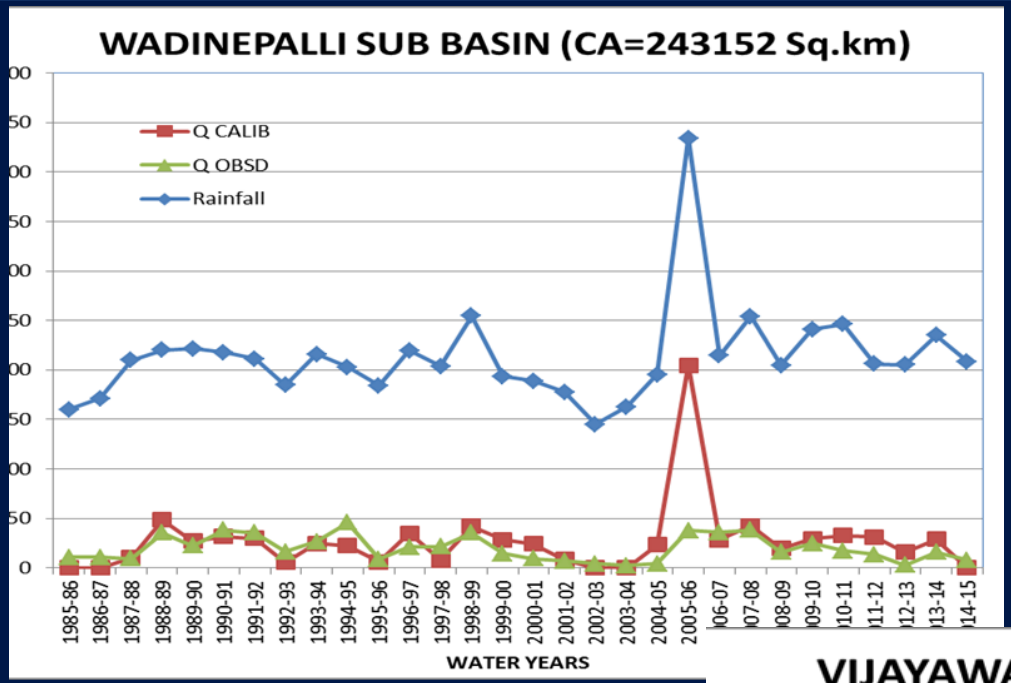


Reassessment of Water Availability in India using Space Inputs-Krishna

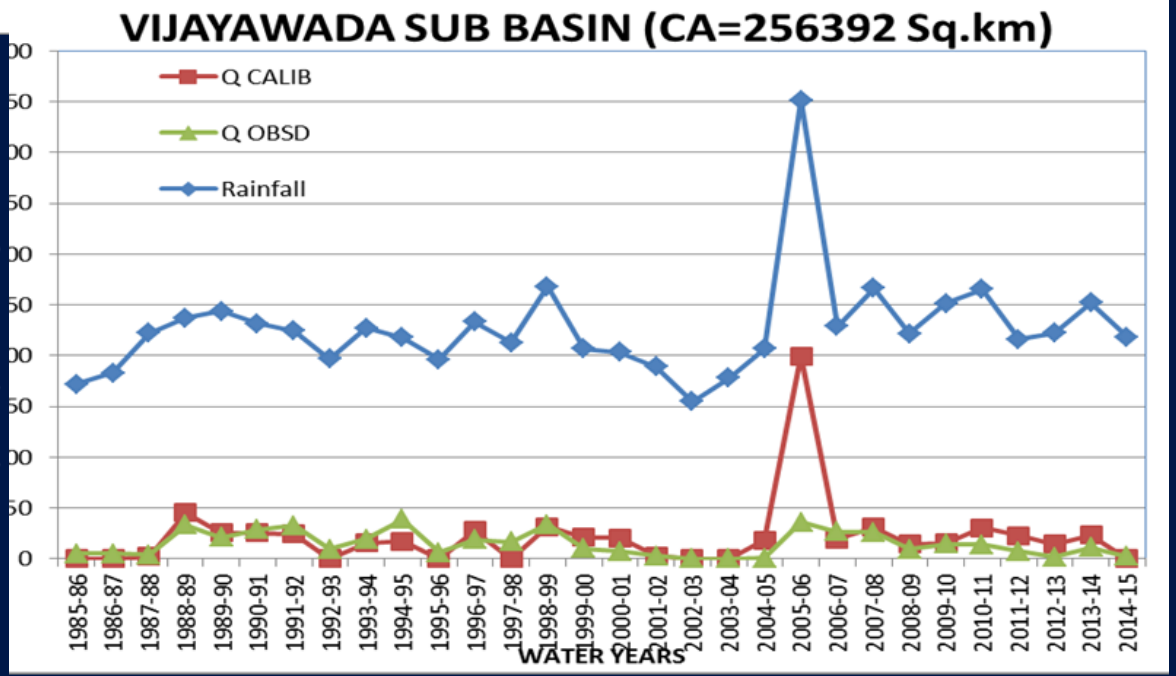
Tungabhadra river



Reassessment of Water Availability in India using Space Inputs-Krishna



Krishna river



Reassessment of Water Availability in India using Space Inputs-Krishna

Calibrated Runoff

$$R_{Calibrated/computed} = (R_{Model} - F_{GW} - F_{R} - F_{DIL}) \approx R_{O}$$

WRA

$$WRA = R_{Calibrated/computed} + IS + E + F_{DIL} + F_{GW} + F_{R}$$

Mean WRA of Krishna basin = 102 BCM

Reassessment of Water Availability in India using Space Inputs-Krishna

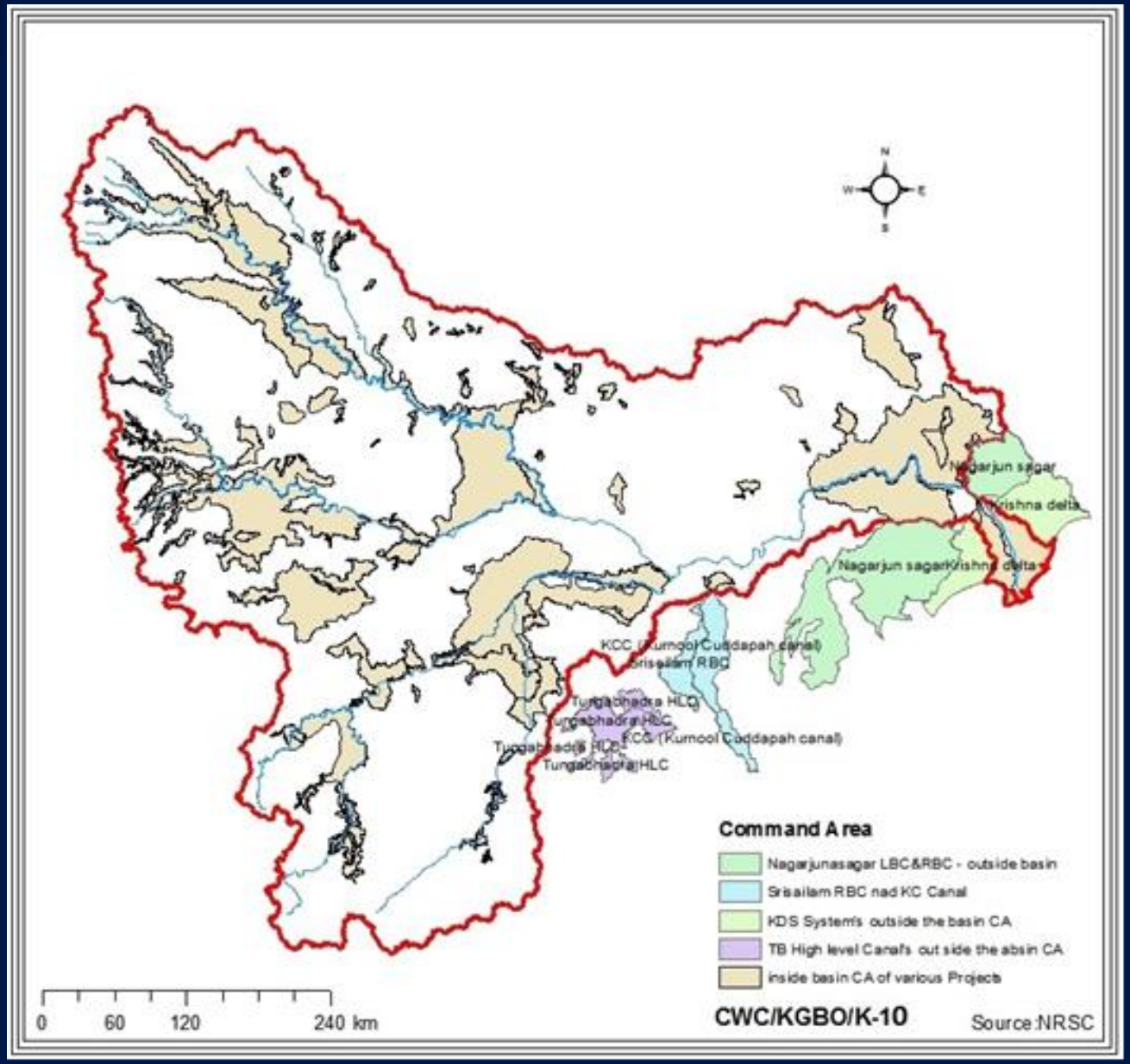
Previous Estimates

S.No.	Year	Authority/Method of estimation	Quantity (BCM)
1	1901	First Irrigation Commission/using records of the surplus flow of Krishna from the greater part of its catchment extending back for a sufficient number of years to estimate the average flow as accurately as possible	84.863
2	1949	CW&PC/Khosla's empirical formula	44.923
3	1953	The technical committee for the optimum utilisation of Krishna and Godavari waters	46.872
4	1960	CW&PC /Statistical analysis of flow data wherever available and rainfall-runoff relationships wherever data were meagre.	57.764
5	1962	The Krishna Godavari Commission-aggregation of average annual yields of all sub basins	62.784
6	1973	The KWDT	67.790
7	1993	CWC	78.124

Reassessment of Water Availability in India using Space Inputs-Krishna

Irrigation Command

- THLC
- Srisailam
- NSP



Reassessment of Water Availability in India using Space Inputs-Krishna

Outward Diversions from Krishna Basin

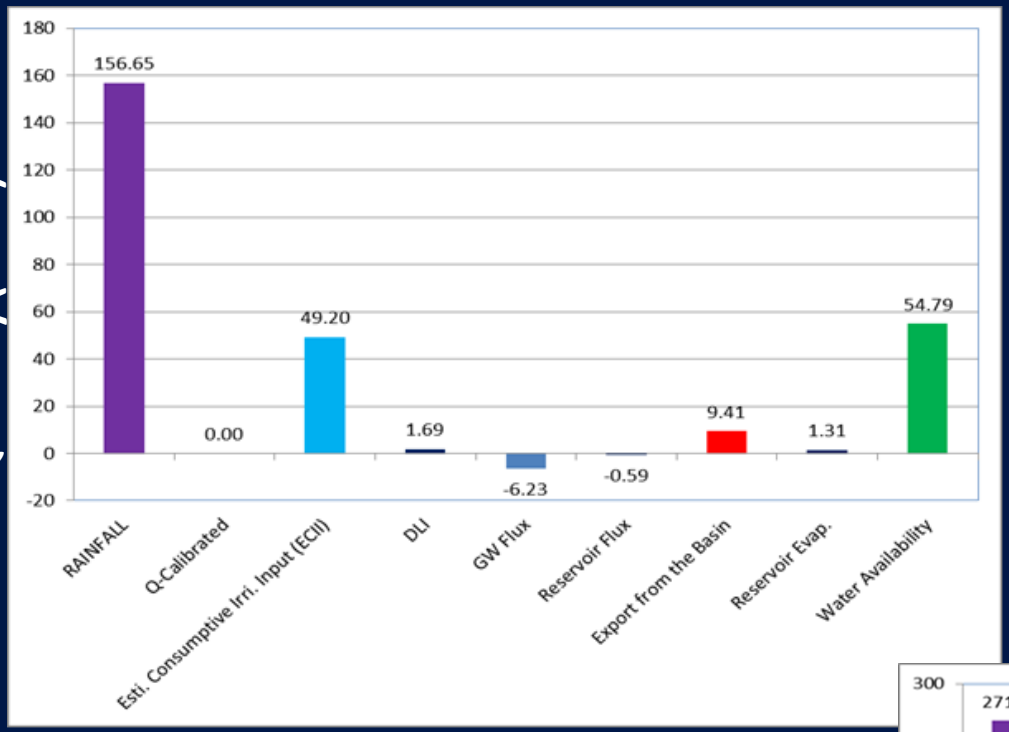
S.No.	Name of Projects	Quantity of Diversion Water		Remarks
		(BCM)	(TMC)	
1	Koyna Dam	2.15	76	The diversions takes place for Power generation and it eventually flow out of the basin (Westward) data obtained from Govt. of Maharashtra.
2	Tata Dams	1.16	41	
3	Prakasham Barrage	3.54	125	Data for 1985-86 to 2006-07 was taken from the data submitted by Govt. of AP to KWDT II and later data has been downloaded from http://cadarsms.cgg.g ov.in which contains for entire KDS system. Hence 3.54 BCM is considered for outside the basin component and remaining was assumed to be utilised in delta area within basin
4	TGP	0.42	15	Chennai water supply
5	ECII component for TB-HLC	0.29	10	
6	ECII component for NSP/Srisailam	4.35	154	Calculated based on project command area outside the basin
	Total	**11.91**	**420**	

Reassessment of Water Availability in India using Space Inputs-Krishna

Water balance components of Krishna basin

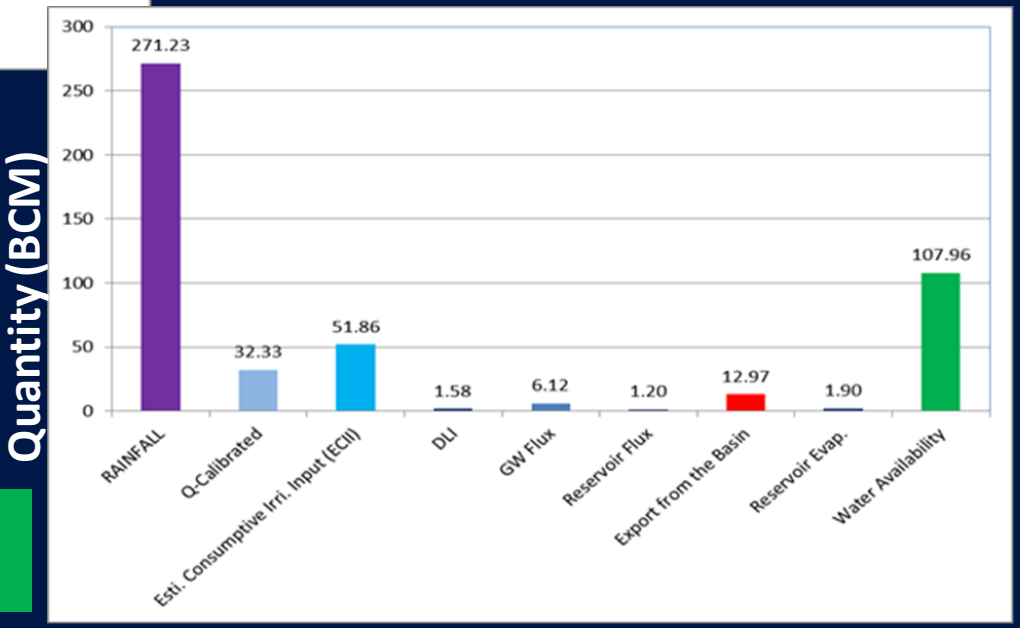
YEAR	Model Runoff	Irrigation Support (ECII)	DLI	GW Flux	Reservoir Flux	Export from the Basin	Q-Calibrated
	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)	(BCM)
1985-86	49.48	52.55	1.24	-5.52	-0.14	12.69	0.00
1986-87	54.16	47.85	1.26	1.19	-1.51	13.66	0.00
1987-88	72.76	51.33	1.28	3.90	0.89	11.95	3.41
1988-89	115.09	51.77	1.31	2.51	-0.68	13.40	46.79
1989-90	96.33	52.05	1.33	2.51	0.50	13.32	26.63
1990-91	89.98	51.41	1.35	-2.29	0.52	12.65	26.34
1991-92	92.27	57.14	1.38	-2.54	-0.53	11.09	25.74
1992-93	68.65	56.91	1.40	-0.09	0.00	11.31	0.00
1993-94	82.87	51.99	1.43	1.80	-1.08	12.70	16.02
1994-95	86.63	55.16	1.46	-1.54	-1.12	13.63	19.04
1995-96	65.37	53.04	1.49	0.01	-0.18	10.57	0.45
1996-97	93.76	45.48	1.52	3.78	2.85	10.70	29.44
1997-98	75.53	65.41	1.54	-1.09	0.46	13.31	0.00
1998-99	106.06	51.86	1.58	6.12	1.20	12.97	32.33
1999-00	80.32	50.84	1.61	-4.34	-2.43	12.86	21.78
2000-01	80.62	**43.95**	1.64	1.37	0.04	11.81	21.82
2001-02	66.79	53.82	1.67	-1.72	-0.83	10.25	3.59
2002-03	42.37	49.20	1.69	-6.23	-0.59	9.41	0.00
2003-04	44.71	46.52	1.72	1.71	-1.16	8.35	0.00
2004-05	81.21	49.72	1.75	-1.12	1.96	10.00	18.89
2005-06	291.76	60.67	1.79	12.29	4.37	11.98	200.66
2006-07	105.41	74.92	1.82	-4.96	-1.94	14.62	20.95
2007-08	122.51	67.73	1.86	6.92	2.70	11.81	31.49
2008-09	92.25	69.37	1.90	-2.50	-3.77	12.09	15.15
2009-10	104.19	67.49	1.94	2.43	2.26	13.77	16.30
2010-11	113.90	63.75	1.99	2.81	2.82	9.87	32.66
2011-12	104.67	78.40	2.05	-7.84	-4.94	13.22	23.78
2012-13	89.95	67.01	2.11	-3.09	-0.82	8.64	16.11
2013-14	106.23	60.94	2.17	6.63	-1.07	12.66	24.90
2014-15	79.65	**79.47**	2.25	-2.67	-0.47	11.85	0.00
Avg	**91.85**	**57.59**	**1.65**	**0.28**	**-0.09**	**11.90**	**22.48**

Reassessment of Water Availability in India using Space Inputs-Krishna



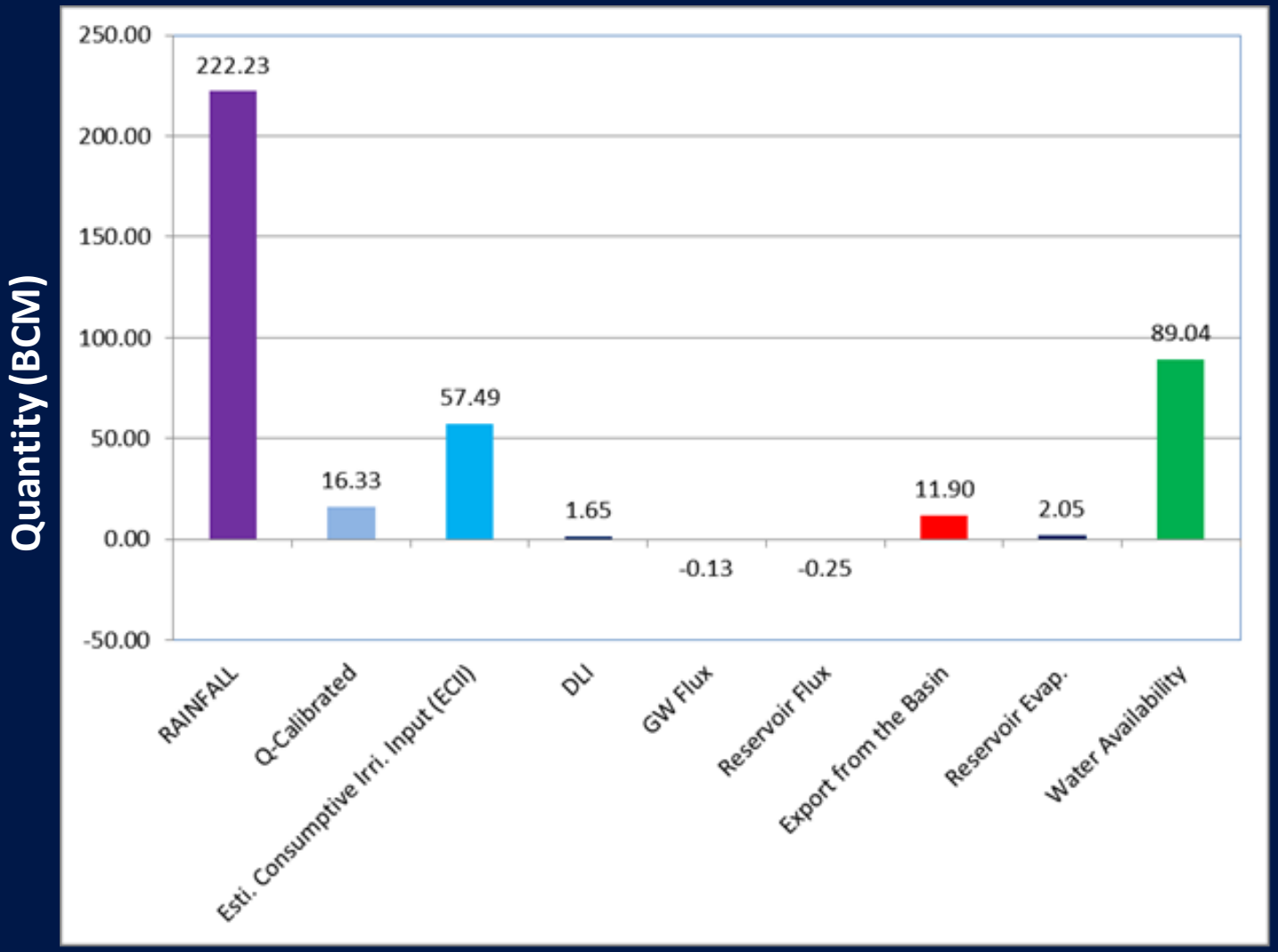
Condition	Year of Occurrence	Rainfall (BCM)	Water Resources Availability (BCM)
Minimum Rainfall	2002-03	156.65	54.79
Maximum Rainfall	1998-99	271.23	107.96

Water Balance components of Krishna basin during extreme low rainfall (2002-03) year



Water Balance components of Krishna basin during extreme high rainfall (1998-99) year

Water Balance components of Krishna basin (mean of 29 years)

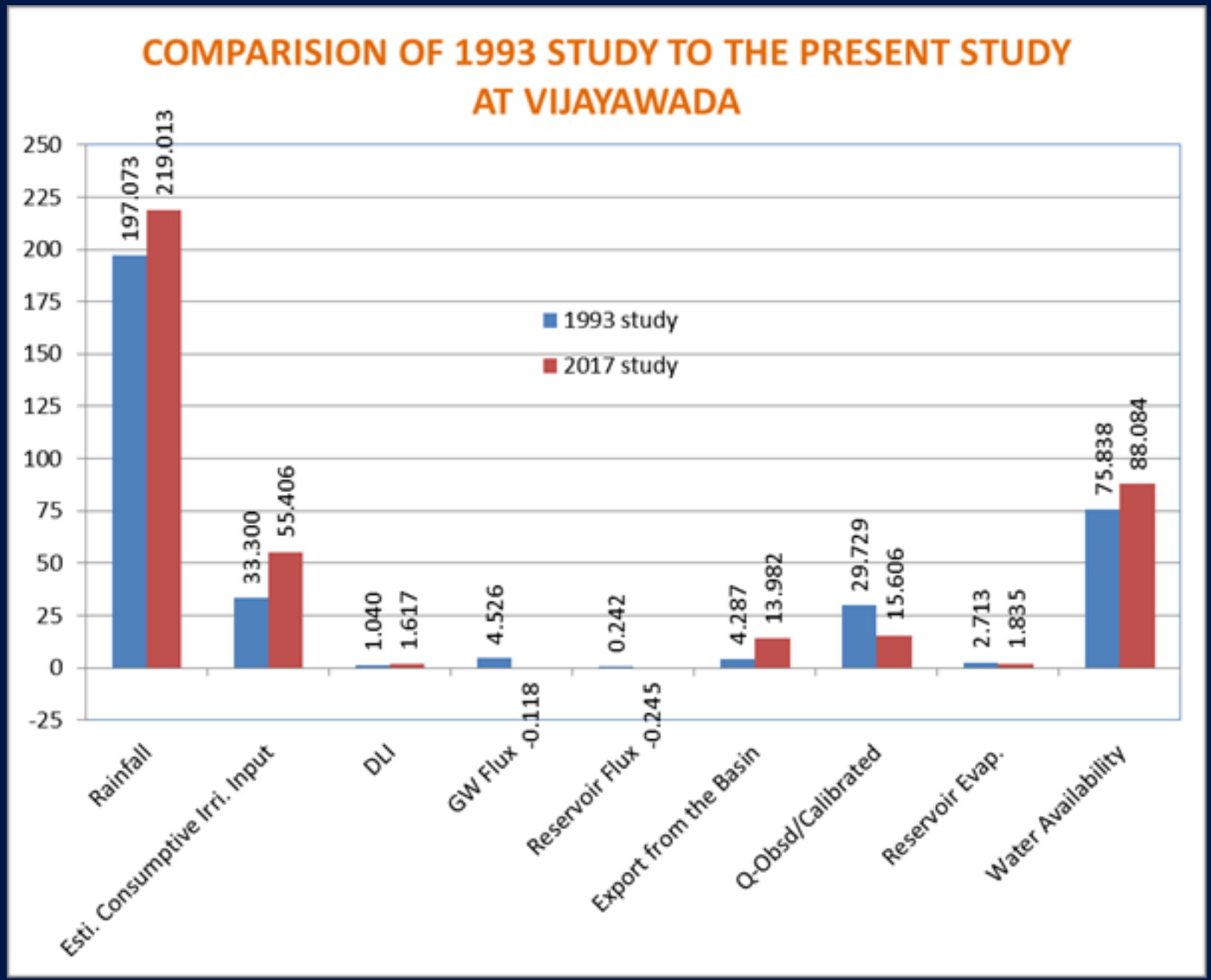


Reassessment of Water Availability in India using Space Inputs-Krishna

1993 CWC Study

- The observed flows were corrected for the upstream abstractions to arrive at the natural flows
- Observed flows at Vijayawada for 1971-72 to 1984-85 (14 Years) with catchment area of 2,51,369 sq.km
- Irrigation (R_{IR}) abstraction was obtained from records maintained by the irrigation project authorities wherever available.
- Withdrawals for domestic taken as 70 lpcd rural and 200 lpcd urban and 50 lpcd for livestock.
- Industrial water requirements is taken as domestic water requirement.
- Ground water abstractions are computed by considering linear variation from the withdrawal (CGWB) for the year 1984 and 1967-68.
- 10% of the abstractions for irrigation and 80% of the abstractions for domestic and industrial purposes have been considered as return flows.
- The data on evaporation losses are available for almost all the major projects in the basins. For medium and miner projects suitable assumptions have been made in this respect.

Reassessment of Water Availability in India using Space Inputs-Krishna



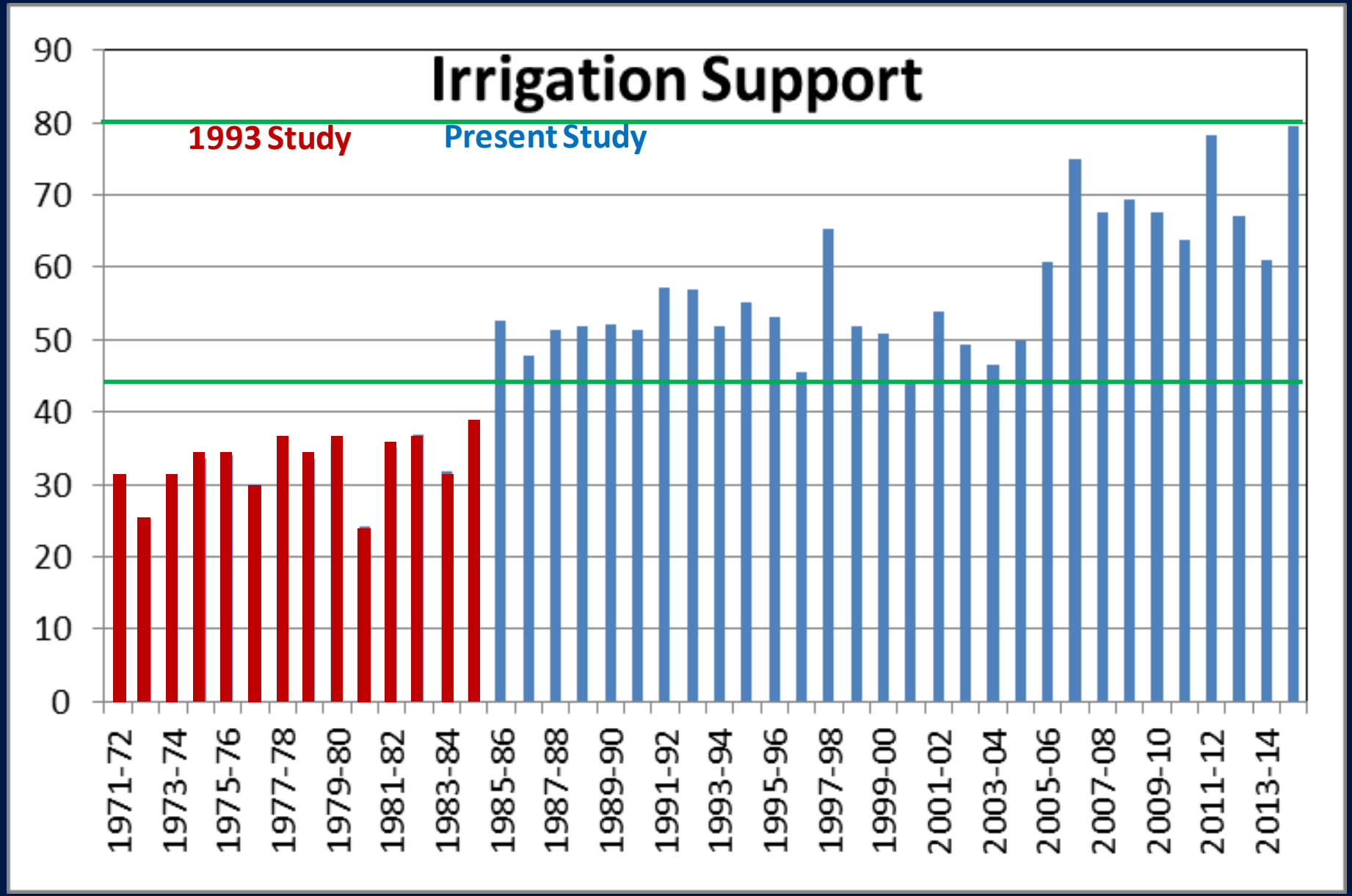
Reassessment of Water Availability in India using Space Inputs-Krishna

Comparison of 1993 and Present study

	1993	2017
Catchment Area	2,58,950 sq.km	2,59,439 sq.km
Mean annual rainfall	197 BCM	222 BCM (11% higher)
WRA in Delta	In 1993 estimate, area proportionate approach was adopted to estimate delta area water resources. The delta area was estimated at 7,581 sq.km.	The delta area was estimated is 3,047 sq.km
Outward diversions	1993 CWC estimate considered the westward diversions from Krishna Basin from Koyna Dam and TATA dams (Private Dams) in Krishna Upper catchment and Bhima Upper catchments.	The diversions taking place from Tungabhadra Dam on Tungabhadra river, from Nagarjunasagar Dam/Srisailam Dam, for Chennai water supply, and for Krishna Delta System for various purposes were also considered in the present study

Reassessment of Water Availability in India using Space Inputs-Krishna

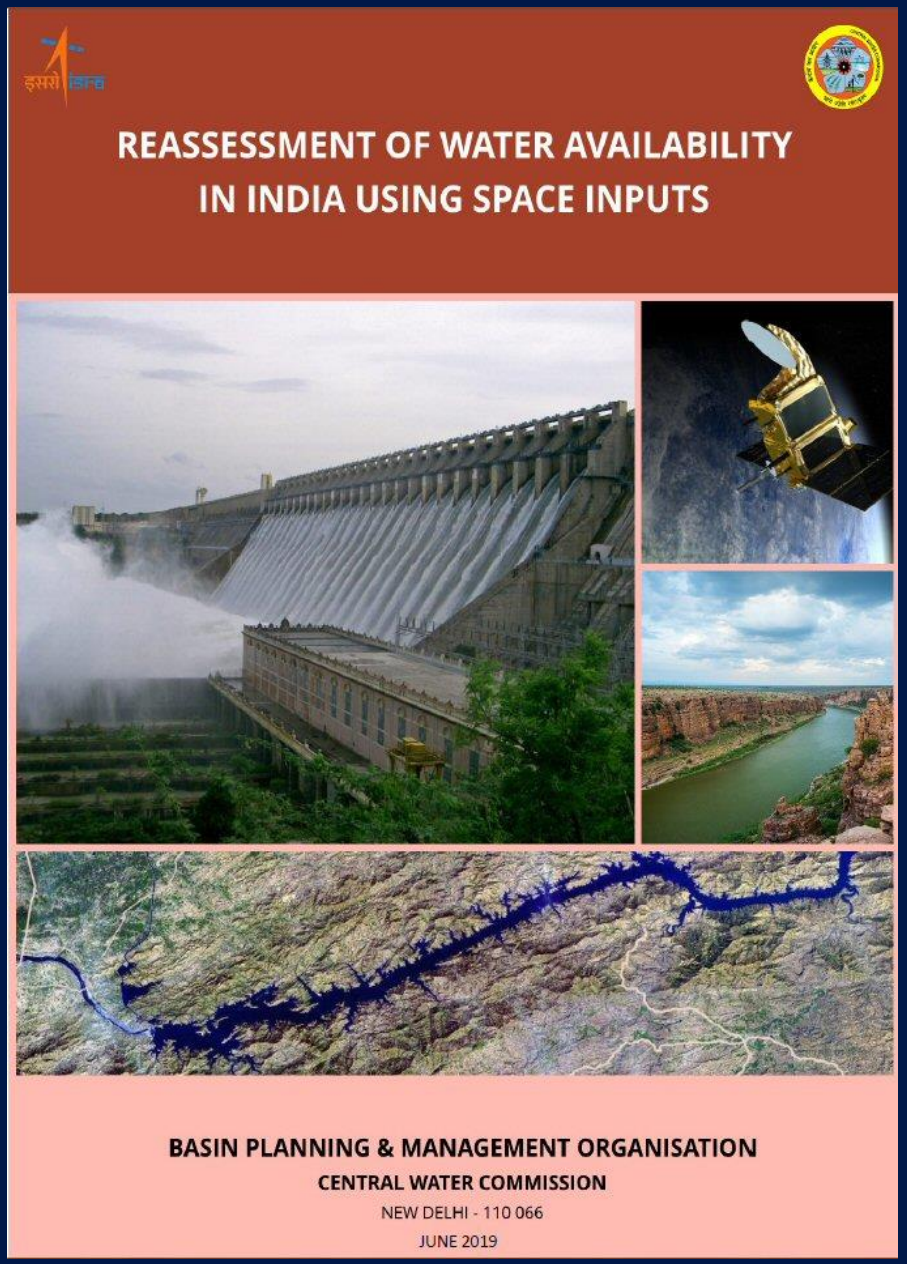
KRISHNA BASIN

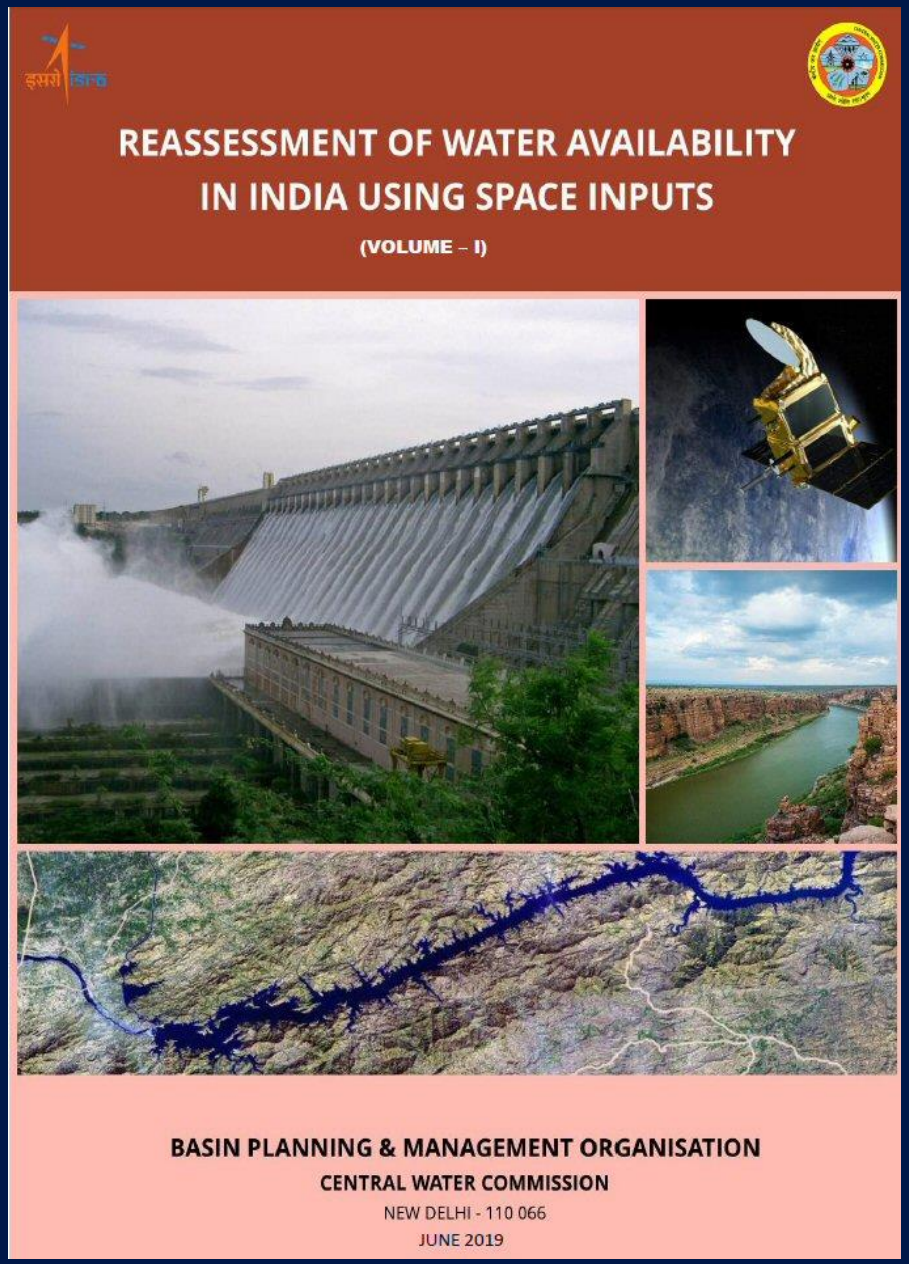


Reassessment of Water Availability in India using Space Inputs-Krishna

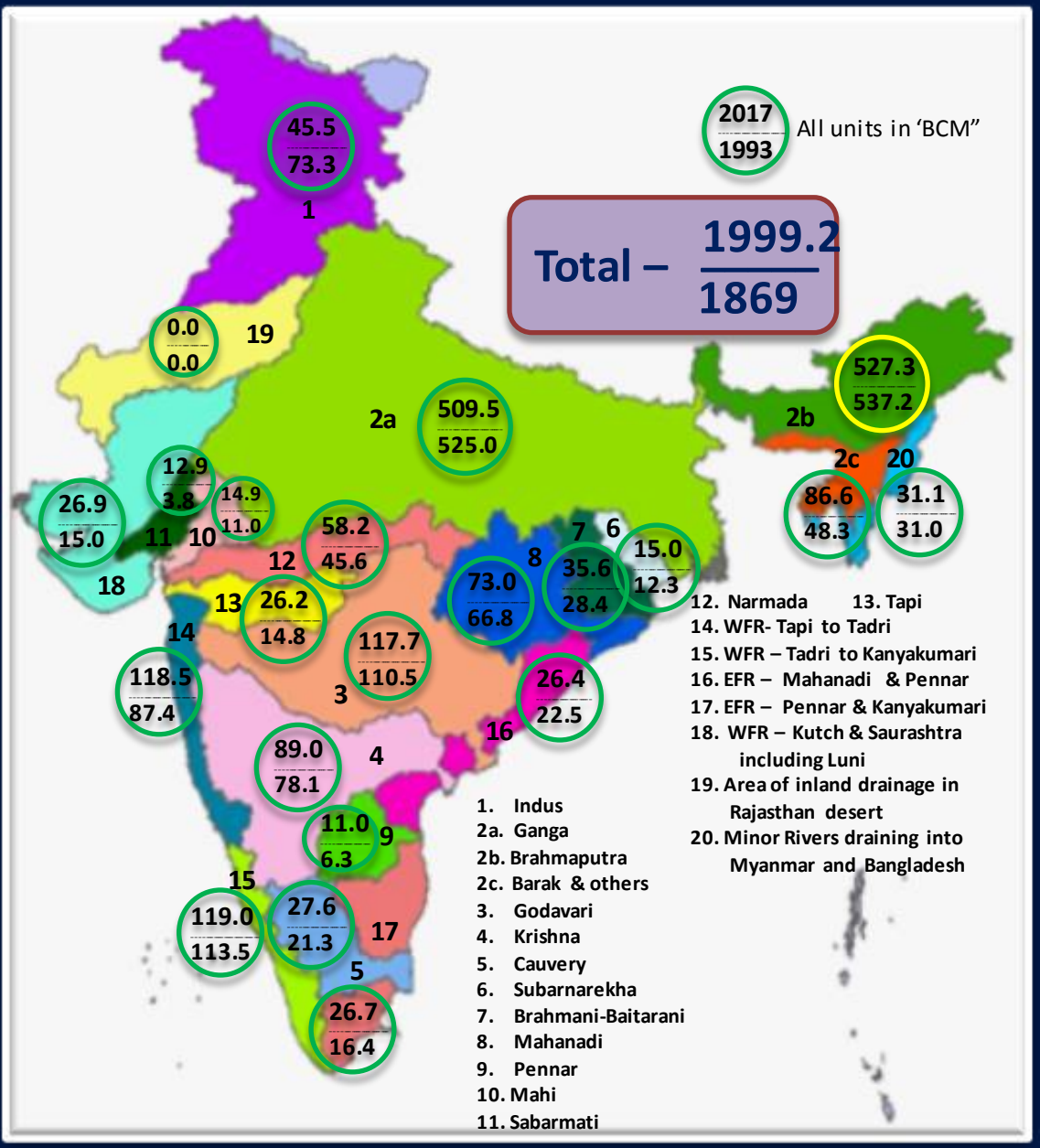
- Intra basin transfers
- Inter basin transfers
- Yearly variation in Irrigation Utilisation
- Annual Water Balance components
- Impact of change in Land use/Land cover
- Changes due to Water Infrastructure development

Reassessment of Water Availability in India using Space Inputs





Reassessment of Water Availability in India using Space Inputs



- The assessment was completed for all 20 river basins for a period of 30 years
- The total mean WRA of the country was assessed as 1999.2 BCM (CA=323 Mha) for mean annual rainfall of 3880 BCM
- Increase in WRA was observed in some river basins like Barak, Mahanadi, Godavari, Narmada, Sabarmati, etc
- Decrease in WRA was observed in some river basins like Indus, Brahmaputra, Ganga, etc
- No variations was observed in WRA in some river basins like Godavari, Mahanadi, WFR, etc

Reassessment of Water Availability in India using Space Inputs

Comparison of 1993 and Present study

S.No	1993	2017
1	All basins were not studied	All basins were studied
2	Period of study was not uniform	Period of study was uniform (1985-2015)
3	Rainfall is not considered	Rainfall grids were used
4	Utilisation data –assumptions were made	Irrigation consumptive use estimated using HM approach
5	Return flows assumed	No need of estimation
6	Ground water data for few basins and few years were used	Ground flux data for all basins computed

Reassessment of Water Availability in India using Space Inputs

Major Benefits

- *A shift from empirical method to Hydrologic Modelling using space inputs*
- *Latest update on country's water resources potential*
- *Impact of land use/land cover changes on water resources availability*
- *Standard Framework for periodic re-assessment and assessment under future climate scenarios*

Limitations:

- Average water resources availability is assessed using 30 year period data. Availability of land use/land cover for historic years prior to 2004-05 will improve accuracy of assessment

THANK YOU