Impact of Climate Change on the Hydrological Response of River Basins Intercepted by Large Dams

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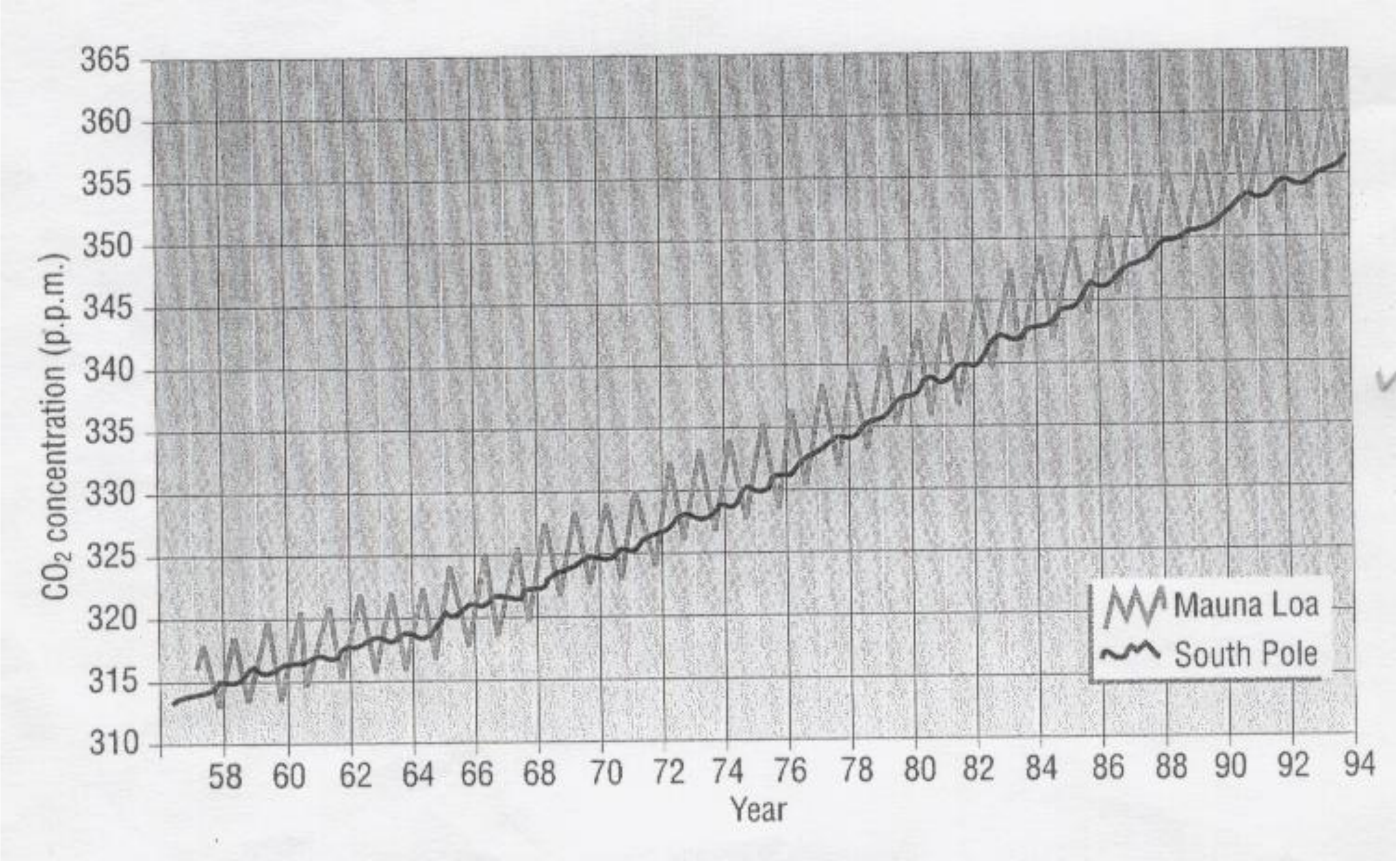
Introduction

- Climate change is a world wide phenomenon adversely impacting two critical hydrological parameters, temperature and precipitation.
- Precipitation covers both snowfall and rain.
- Variation of temperature (increase) leading to global warming over the last 200 years is the most important parameter.
- Global warming is primarily due to continuously increasing emission of Green House Gas (GHG), whose levels according to Inter-governmental Panel on Climate Change (IPCC) have increased by 35% and 148% respectively since the industrial revolution.
- Average warming over the globe is around 1^{o} C in ≈200 years
- The globe experienced stable temperatures for 10,000 years prior to 1850 AD, the decade 2001 to 2010 is the warmest since 1880 AD.

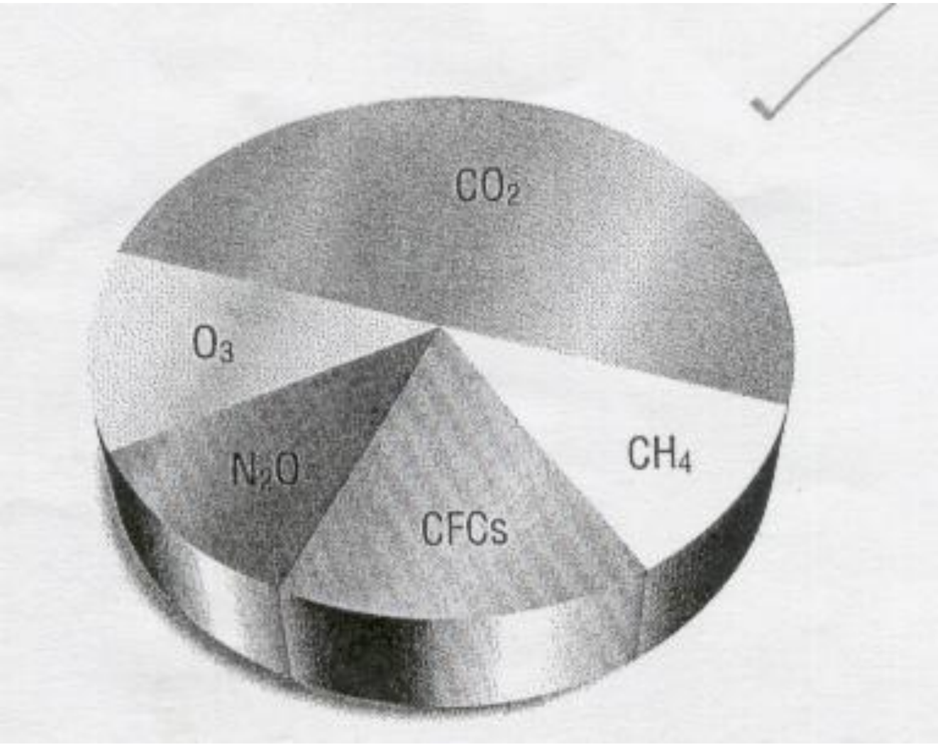
Introduction

- **Warming of the earth surface impacts the life of all living beings, flora and fauna, in addition to impact rainfall, evaporation, snow, stream flow and soil / vegetation behaviour.**
- **One of the worst warming episode is in the US when Chicago in Illinois experienced the catastrophic warming disaster when a heat wave caused 525 death in a five day period, July, 1995.**

Carbon Dioxide Concentration



Green House Gases



Likely contribution of different Gases

Global Warming

- **Times of India, Sept 28, 2006 reports**

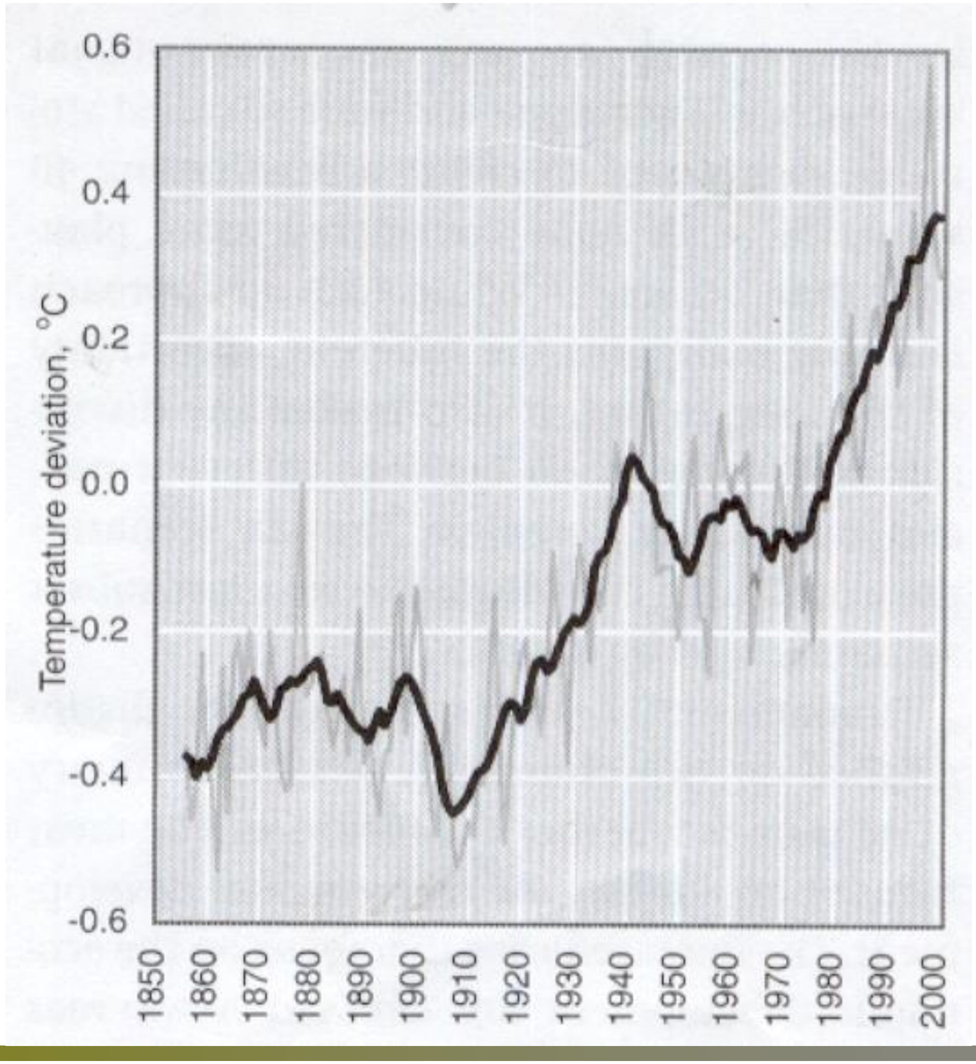
  Earth near hottest point in million years

  Wild patterns like El Nino may be stronger now

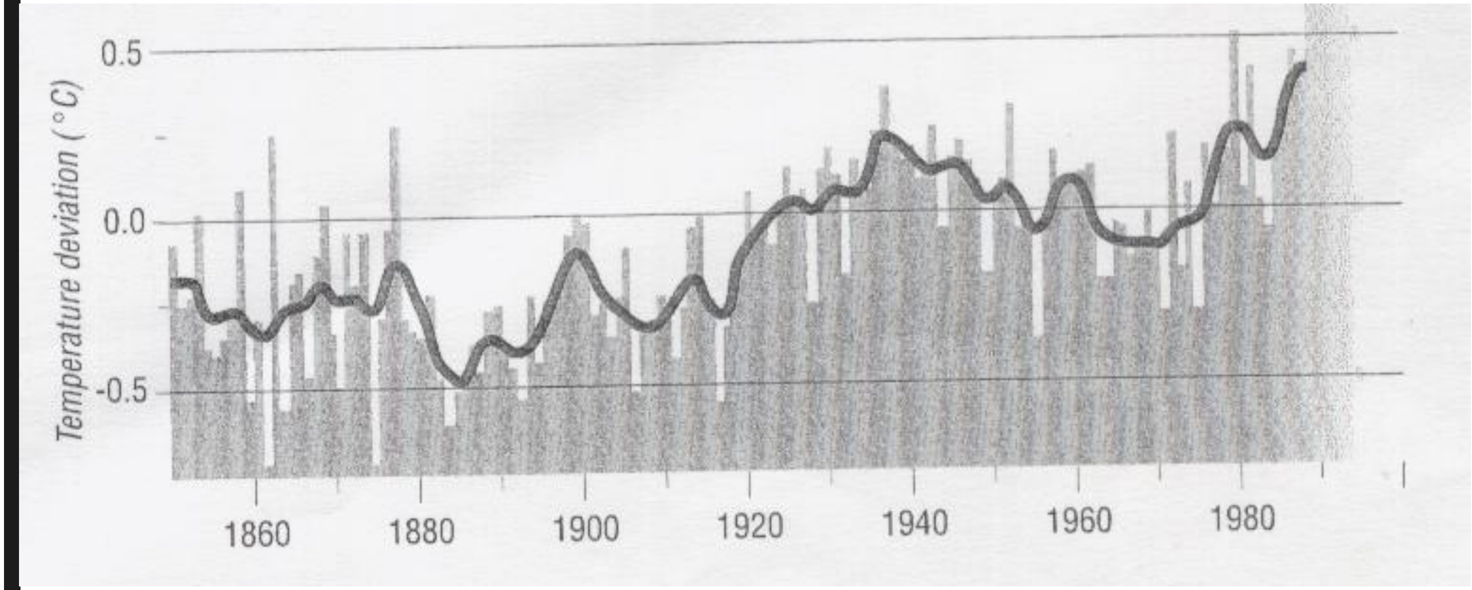
  NASA's climate scientist report that El Nino's may not be more frequent but normal weather would be disrupted globally, meaning wild patterns will be stronger when they occur. In 1998 a "Super El Nino" helped hit the earth to a record high & also in 2005.
- **Regarding global warming intuitively we might be tempted to think that warmer world means more evaporation and less water but more evaporation brings more precipitation. In fact global temperature has deviated by 0.80 degree centigrade between 1850 to 2000 most of it occurring between 1910-1945 and 1975 till today. The second period fits with the green house concern.**

- **Global warming is affecting western pacific as Water's of the western equatorial Pacific are warmer than the eastern equatorial Pacific and the difference in temperature could produce greater temperature swings between the normal weather patterns and El Nino.**
- **This phenomenon is attributable to Global warming**
- **In the last three decades global surface temperature is increasing by about 0.2^0 centigrade caused by human activities, notably increased release of greenhouse gases, notably carbon dioxide.**
- **Human caused global warming influences El Nino's by swaying tropical storms.**

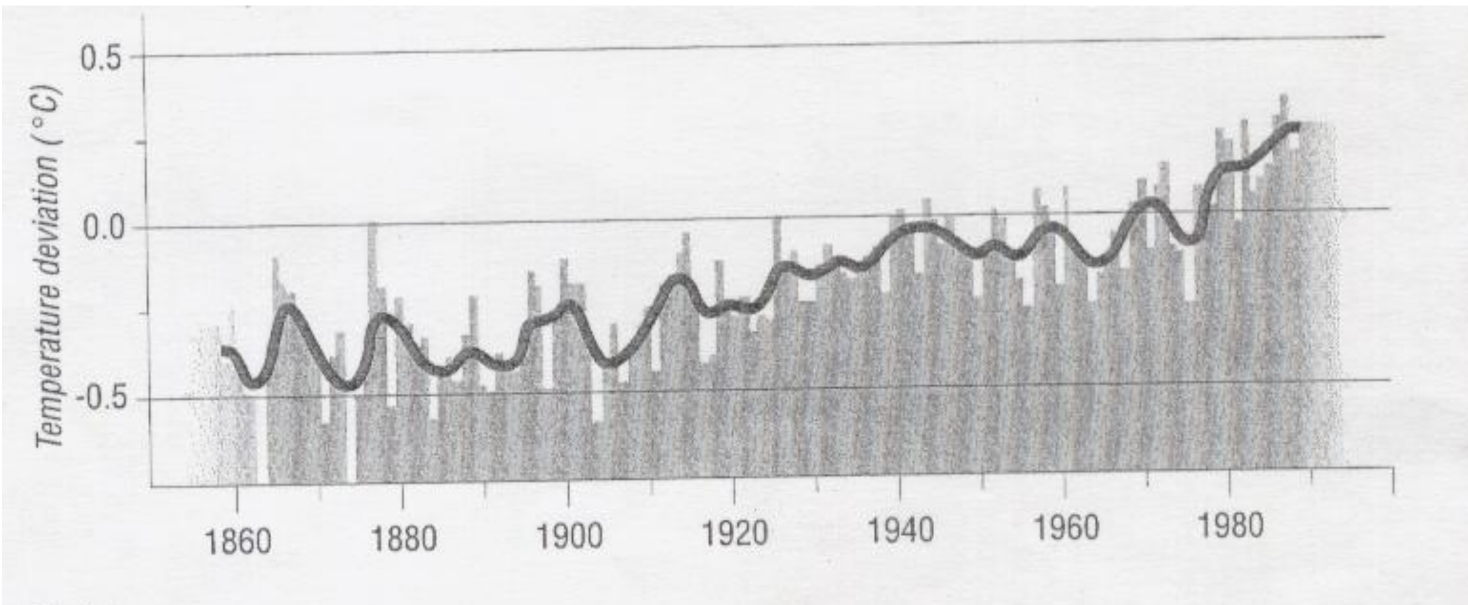
Global temperature (1856-2000)



Northern Hemisphere

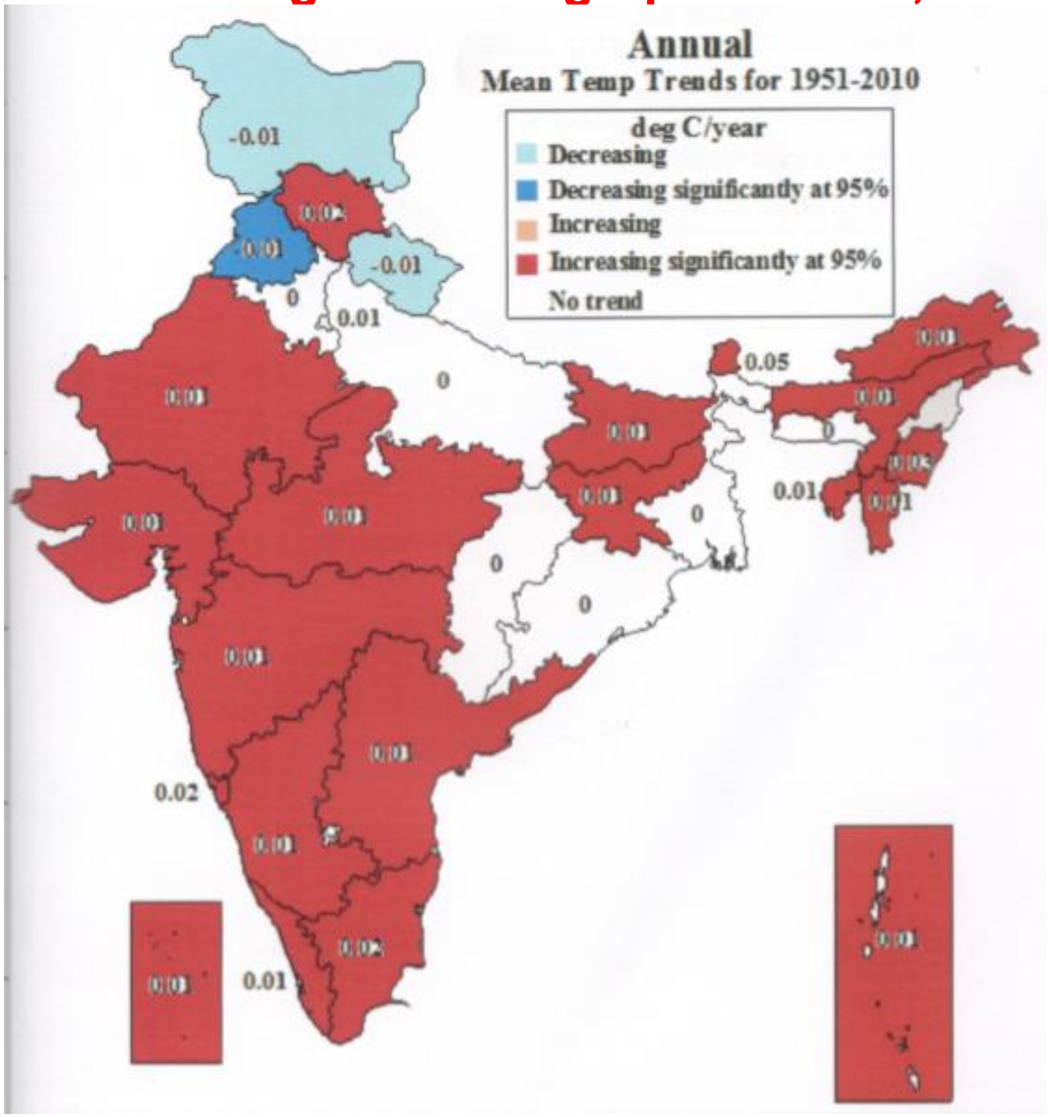


Southern Hemisphere



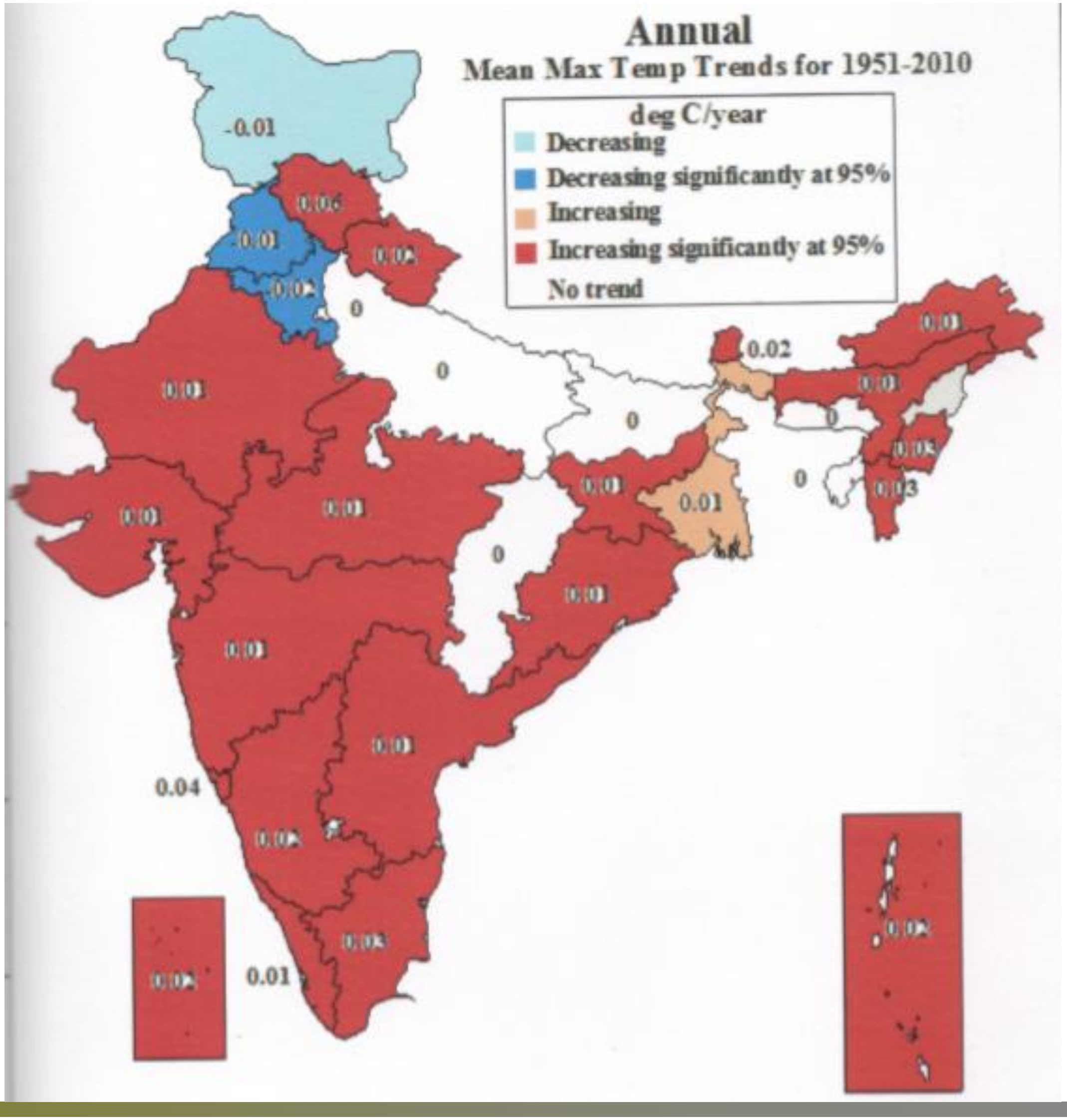
Climate Change Scenario, India
after Meteorological Monographs of IMD, 2013

Temperature



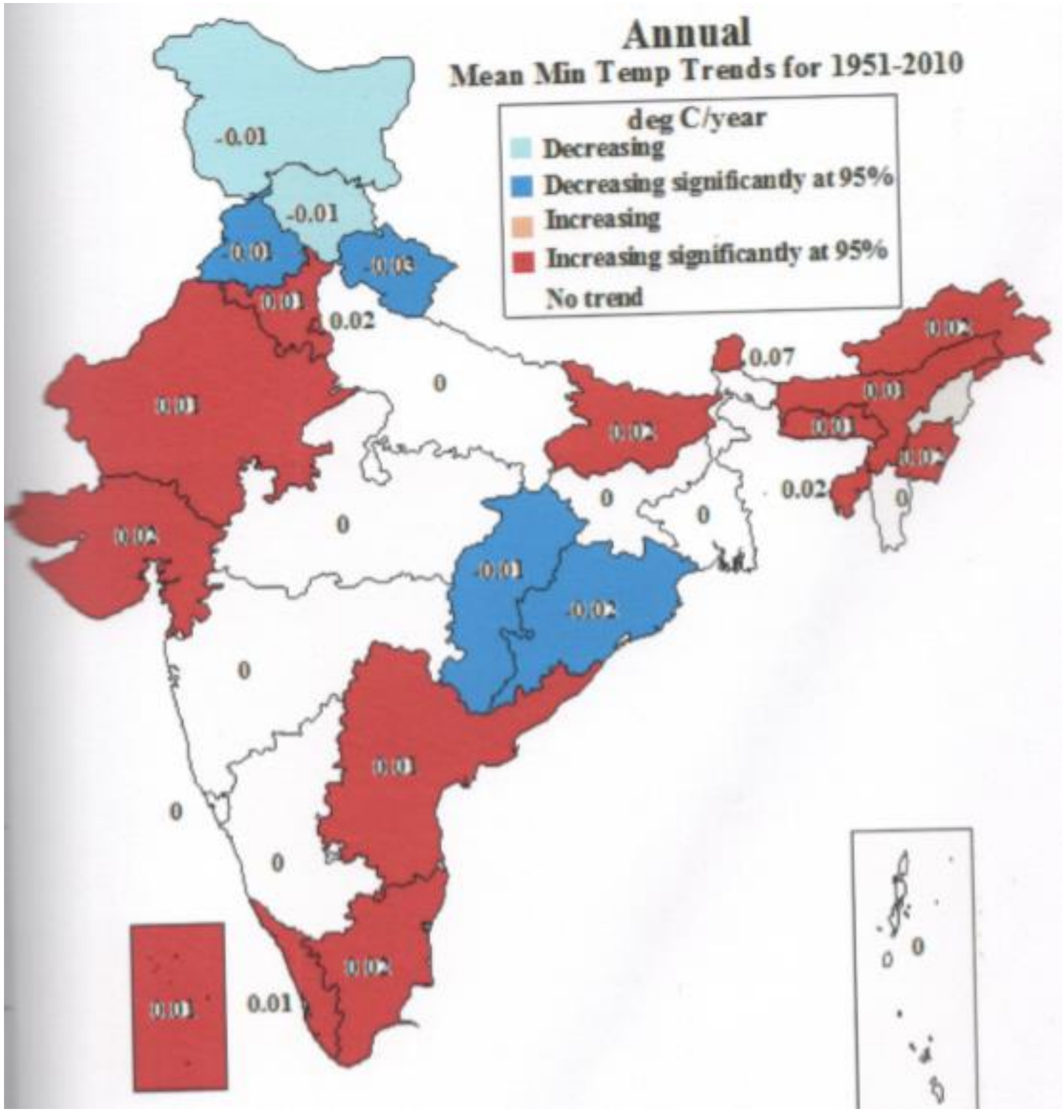
Climate Change Scenario, India

Temperature



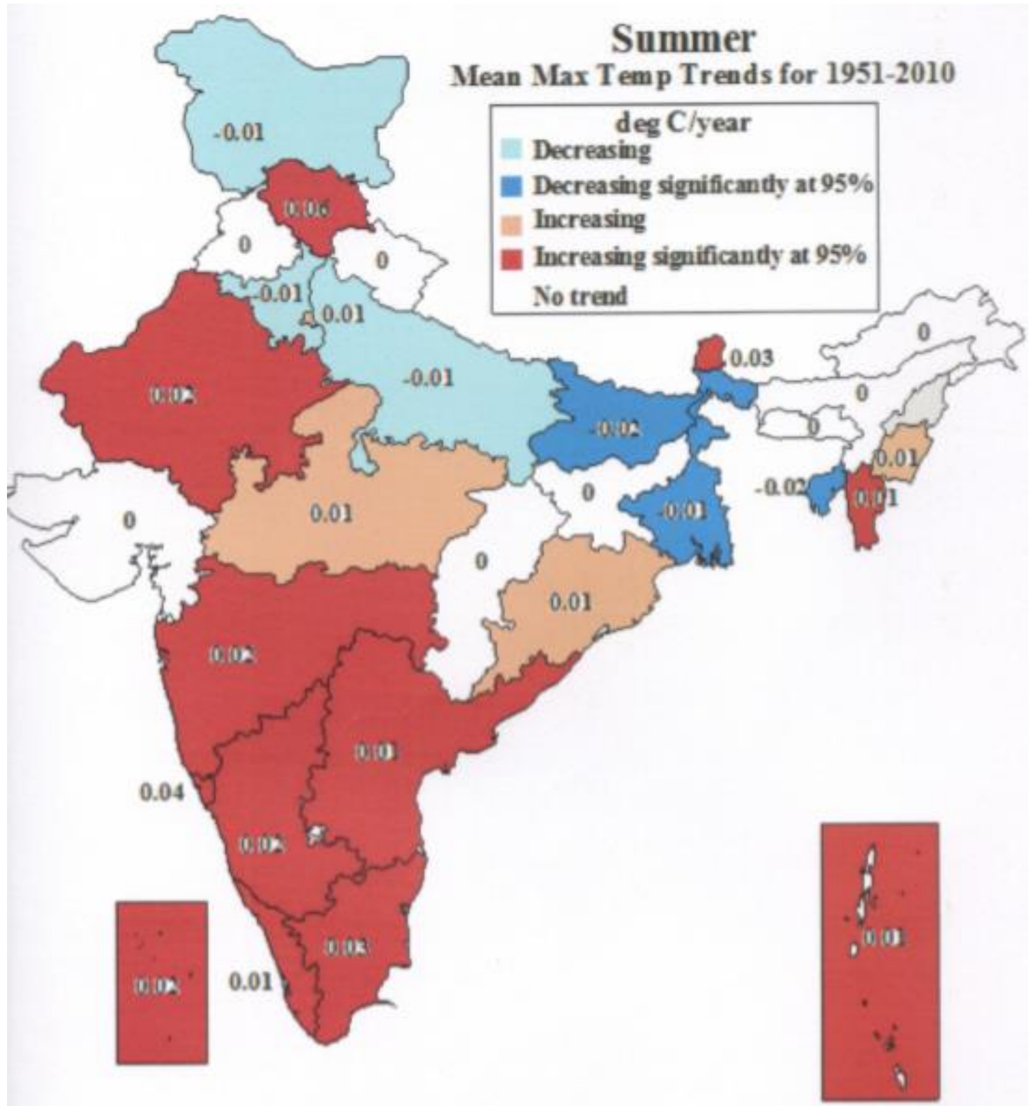
Climate Change Scenario, India

Temperature



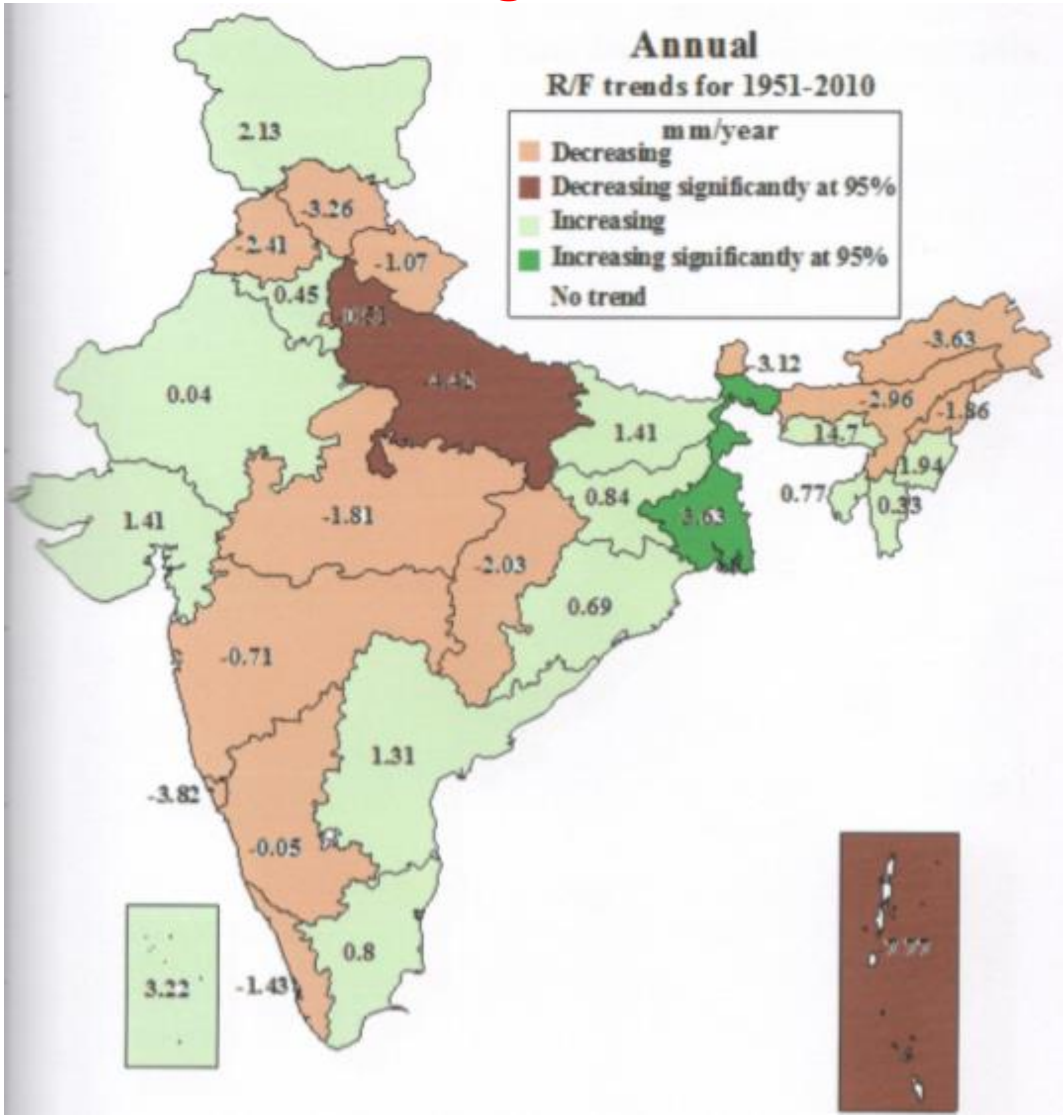
Climate Change Scenario, India

Temperature



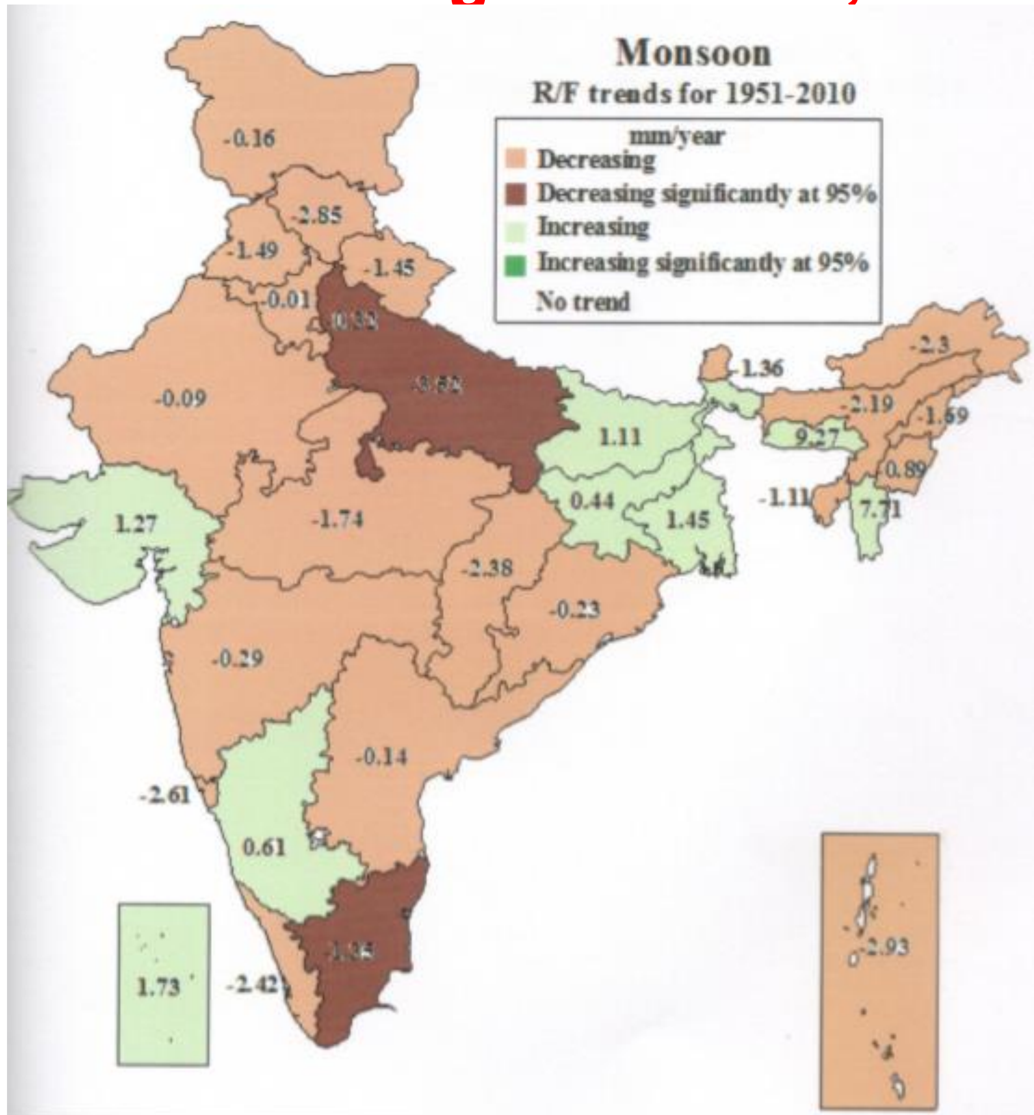
Climate Change Scenario, India

Precipitation



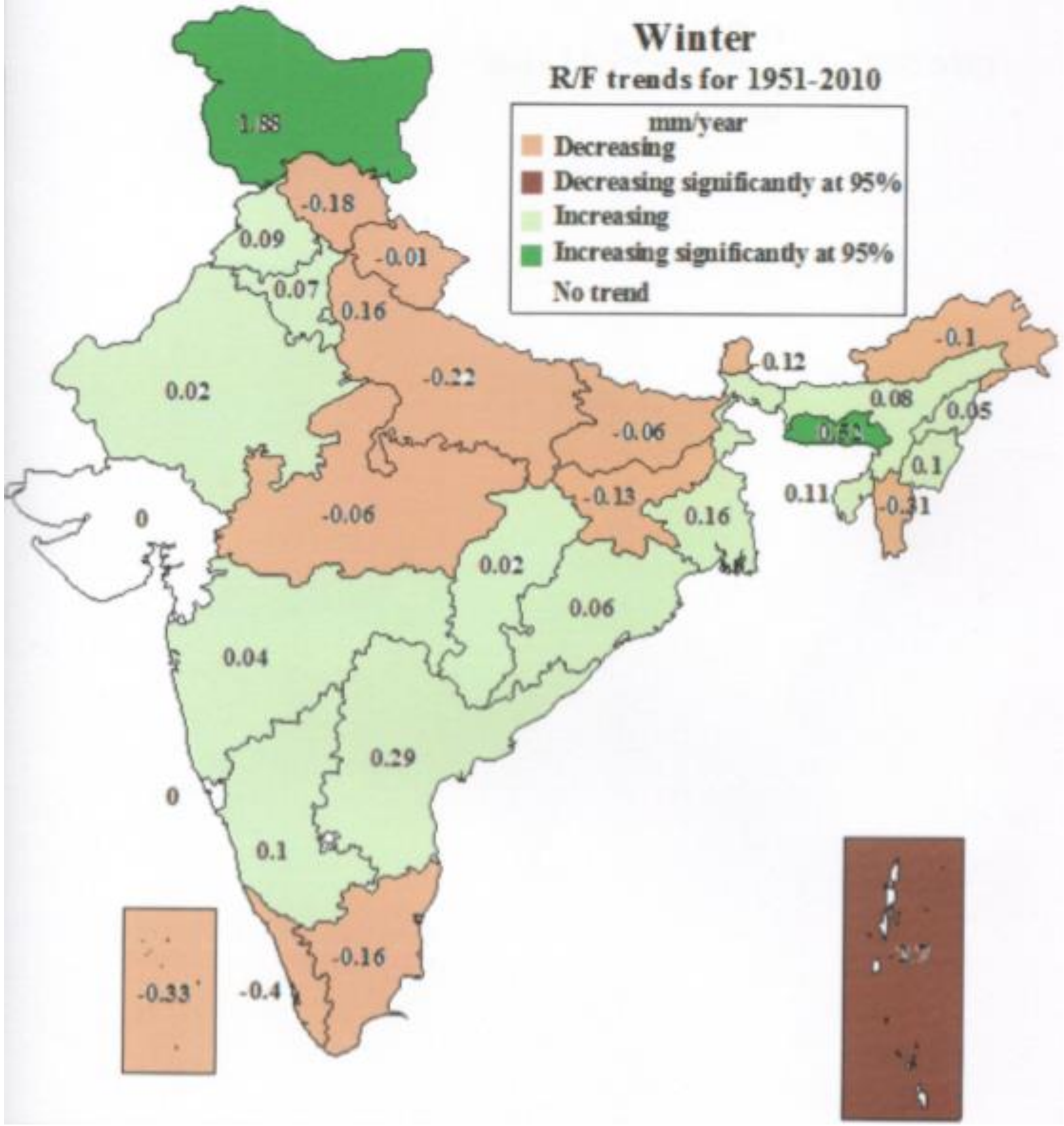
Climate Change Scenario, India

Precipitation



Climate Change Scenario, India

Precipitation



Heat Wave Situation

- Several incidents of heat wave both in India & abroad when 5 consecutive days experienced maximum temperature 5^{o} above the mean average maximum temperature.

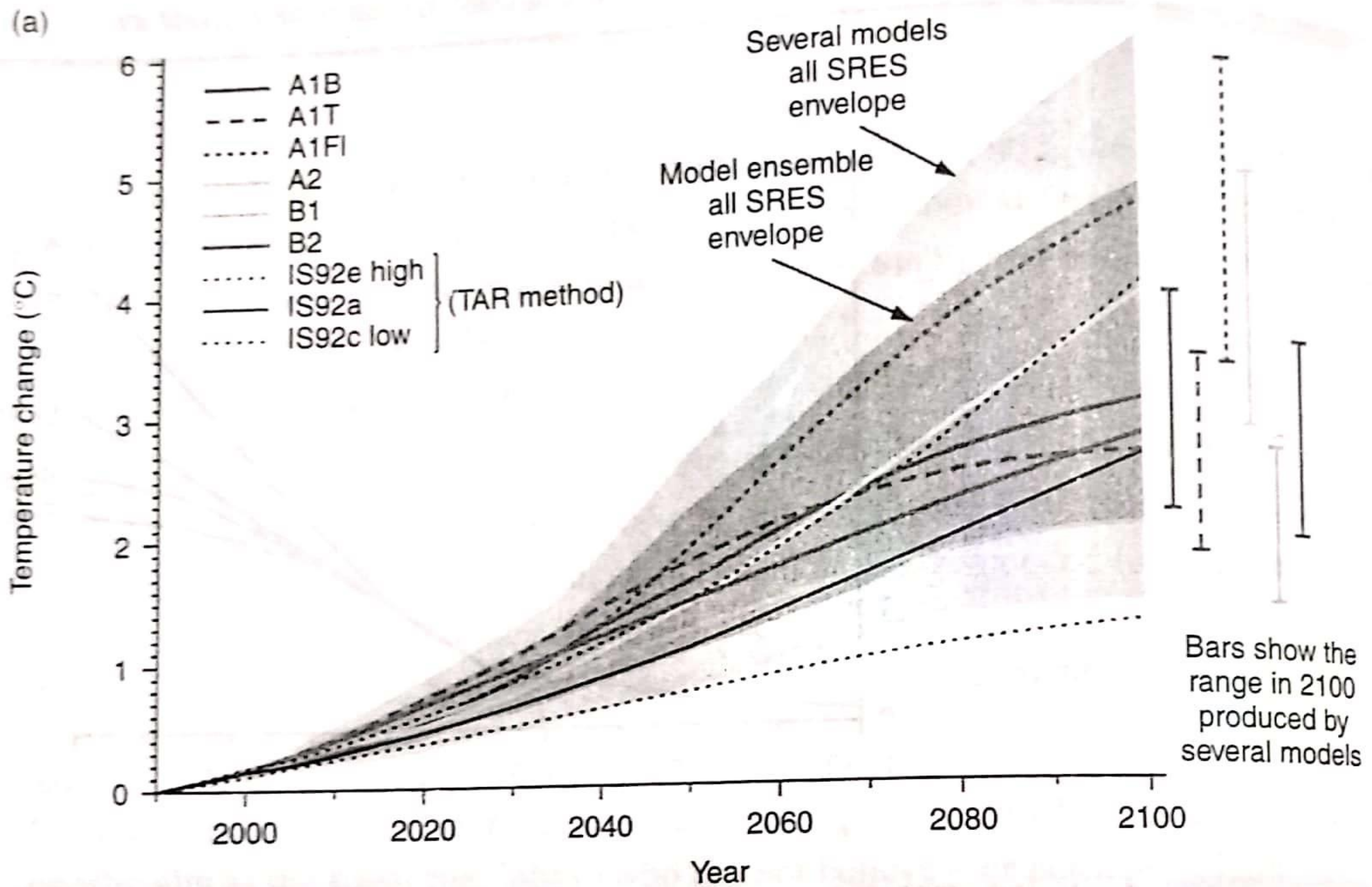
Year	No. of Deaths
2005	1075
2006	754
2007	932
2008	616
2009	1071
2010	1274
2011	793
2012	1247
2013	1216
2014	1677
2015	2422

Commitment of India

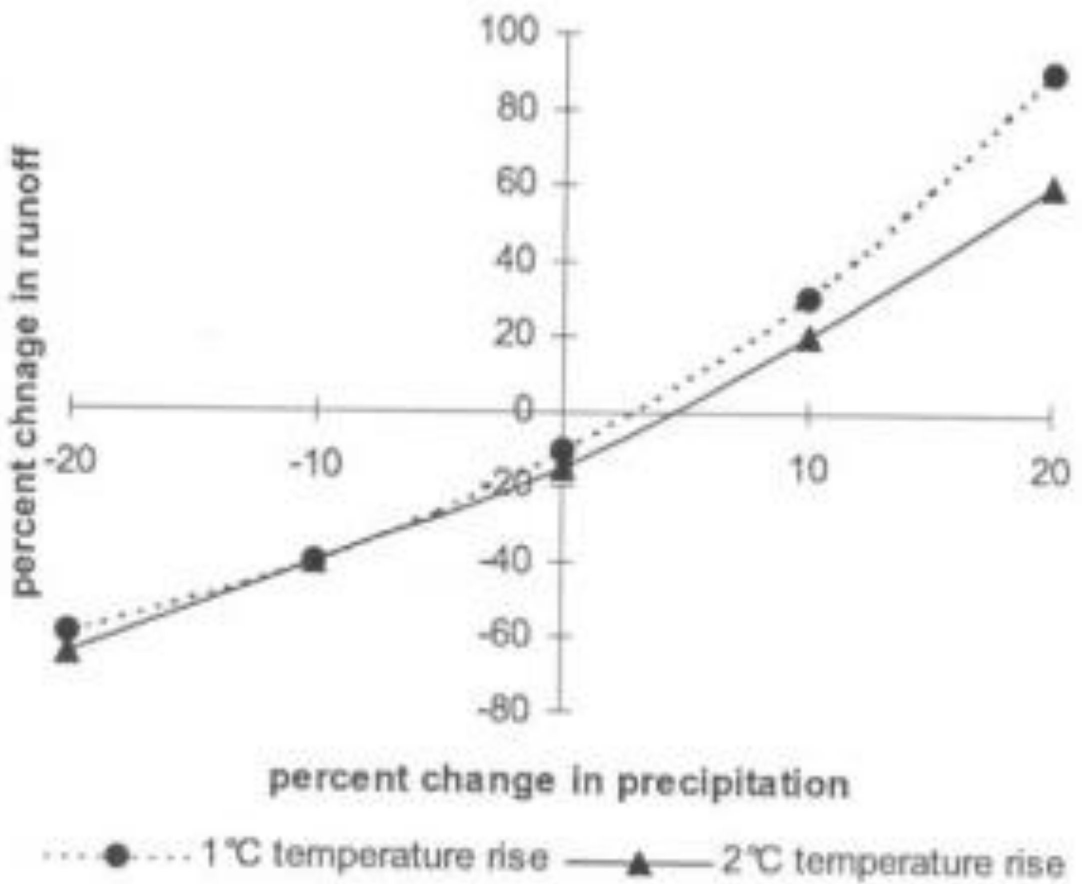
- India the fastest growing major economy is the 3rd largest green house gas emitter after China & US, accounting for 6.81% global emission of green house gasses.
- India's emission increased by 67.1% between 1990 & 2012 and projected grow by 85% by 2030.
- India has signed the Paris agreement on October 2, 2016 and committed to reduce energy emission by 30% to 35% from 2005 levels by 2030.
- Increase the share of non fossil fuel energy to 40% of India's energy mix by 2030.
- Create an additional carbon sink of 2.5-3 Billion tons by 2030, by increasing forest and tree cover.

Emission Scenario (SRES)-Temperature Change

IPCC, 2001 3rd Assessment Report
(Jonathan Cowie, Climate Change:Biological & Human Aspects, 2013)
Predicted envolve for 21st Century Global Climate Change



River Basin Response to Climate Change



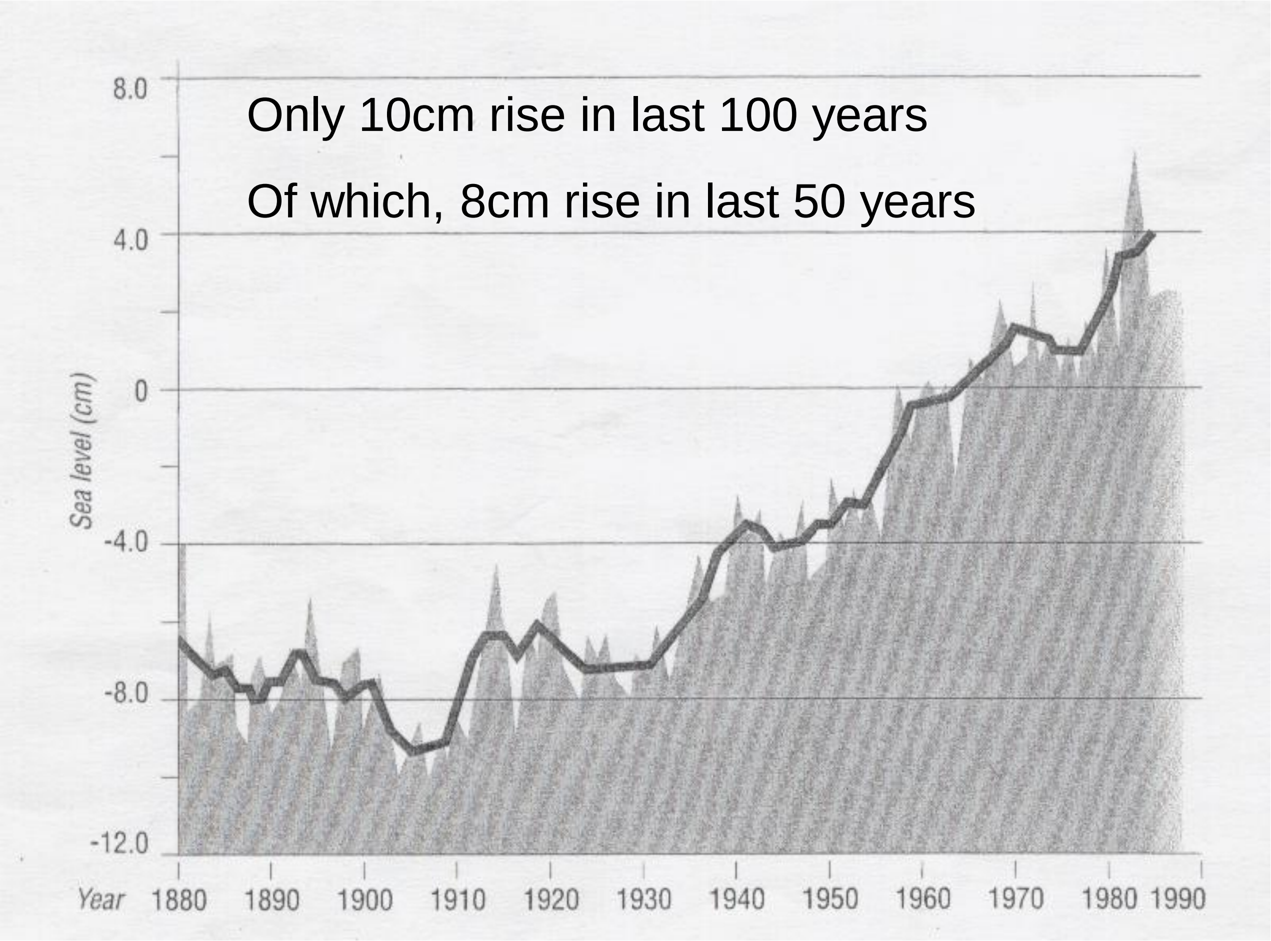
Climate Impact Assessment

The potential impact of climate change on water resources has been suggested since the 1980s, as work progressed on predicting climate change [5]. Although GCM's can be used to predict runoff directly, the coarse scale used means that this information is only useful for the most general studies. As a result, many studies have been carried out on individual basins, showing that river basins display a range of sensitivities to climate change [8]. Figure 1 shows the response of a typical river basin to variations in precipitation and temperature. It can be seen that increased temperature results in non-linear variations in runoff due to changes in precipitation.

Contd.

Later studies have considered not only the effect on river flows but also the impact on generation from hydroelectric stations [9]. In particular, one study examined a number of international river basins [4]. The study drew upon existing hydrological and dedicated basin models and the experience of international experts. For example, for one GCM scenario (GFDL), hydroelectric production on the Indus River would fall by 22%. Another study [2] qualitatively examined the effects of reduced hydroelectric output on sub-Saharan Africa and central Europe. However, to date, studies have failed to quantify the impacts in terms of the investment performance of plant or on the electrical network.

On Sea Level Rise



IPCC Assessment Ending 2007 on Temperature & Sea Level Changes

Change 1990–2100	1990 B-a-U above pre-industrial levels	2001 Several models, all SRES envelope above 1990	2007 A2 (B-a-U) scenario above 1980–99 mean
Warming			
High estimate	5.25°C	5.8°C	5.4°C (A1F1 scenario[b] 6.4°C)
Best estimate	3.25°C	2.0–4.5°C (model ensemble)	3.4°C
Low estimate	1.8°C	1.4°C	2.0°C (B1 scenario[c] 1.1°C)
Sea level			
High estimate[a]	110 cm	88 cm	51 cm (A1F1 scenario[b] 59 cm)
Best or average estimate[a]	65 cm (best estimate)	22–70 cm (all models, all SRES averages)	37 cm (A2 median value)
Low estimate[a]	22 cm	9 cm	23 cm (B1 scenario[c] 18 cm)

IPCC Observation

IPCC report, 2007 states, ‘warming of the climate system is unequivocal’ and that most of the observed increase in global average temperatures since the mid 20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentration.

Hydro Dams

It's easier to build a hydro plant where there is a natural waterfall. That's why the first hydro plant was built at Niagara Falls. Dams which are artificial waterfalls, are the next best way.

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Dams are built on rivers where the terrain will produce an artificial lake or reservoir above the dam. Today there are about 80,000 dams in the United States, but only three percent (2,000) have power generating hydro plants.

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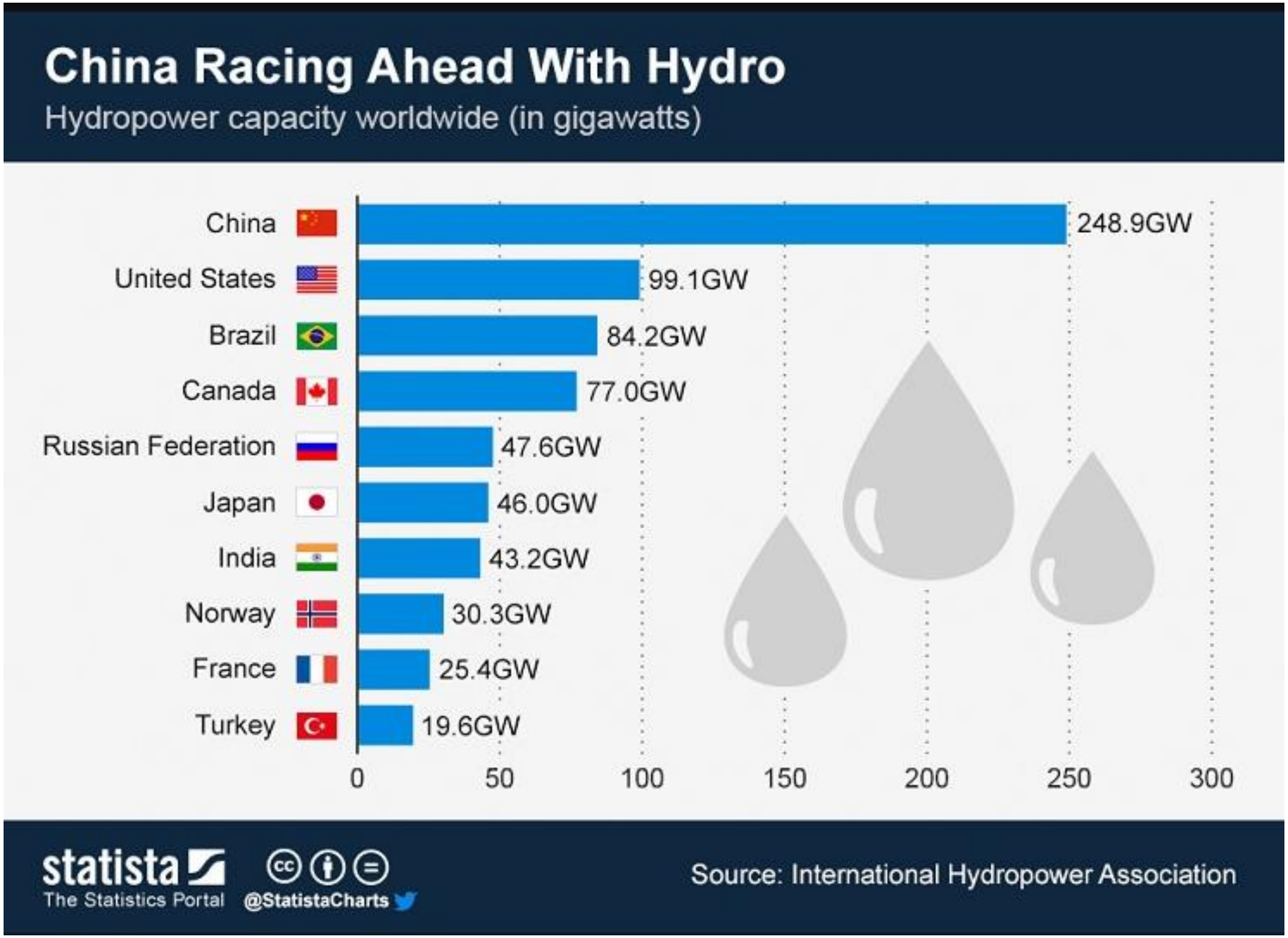
China Racing Ahead With Hydro
Hydropower capacity worldwide (in gigawatts)
China
248.9GW
United States
99.1GW
Brazil
84.2GW
Canada
77.0GW
Russian Federation
47.6GW
Japan
46.0GW
India
43.2GW
Norway
30.3GW
France
25.4GW
Turkey
19.6GW
0
50
100
150
200
250
300
statista
The Statistics Portal
@StatistaCharts
Source: International Hydropower Association

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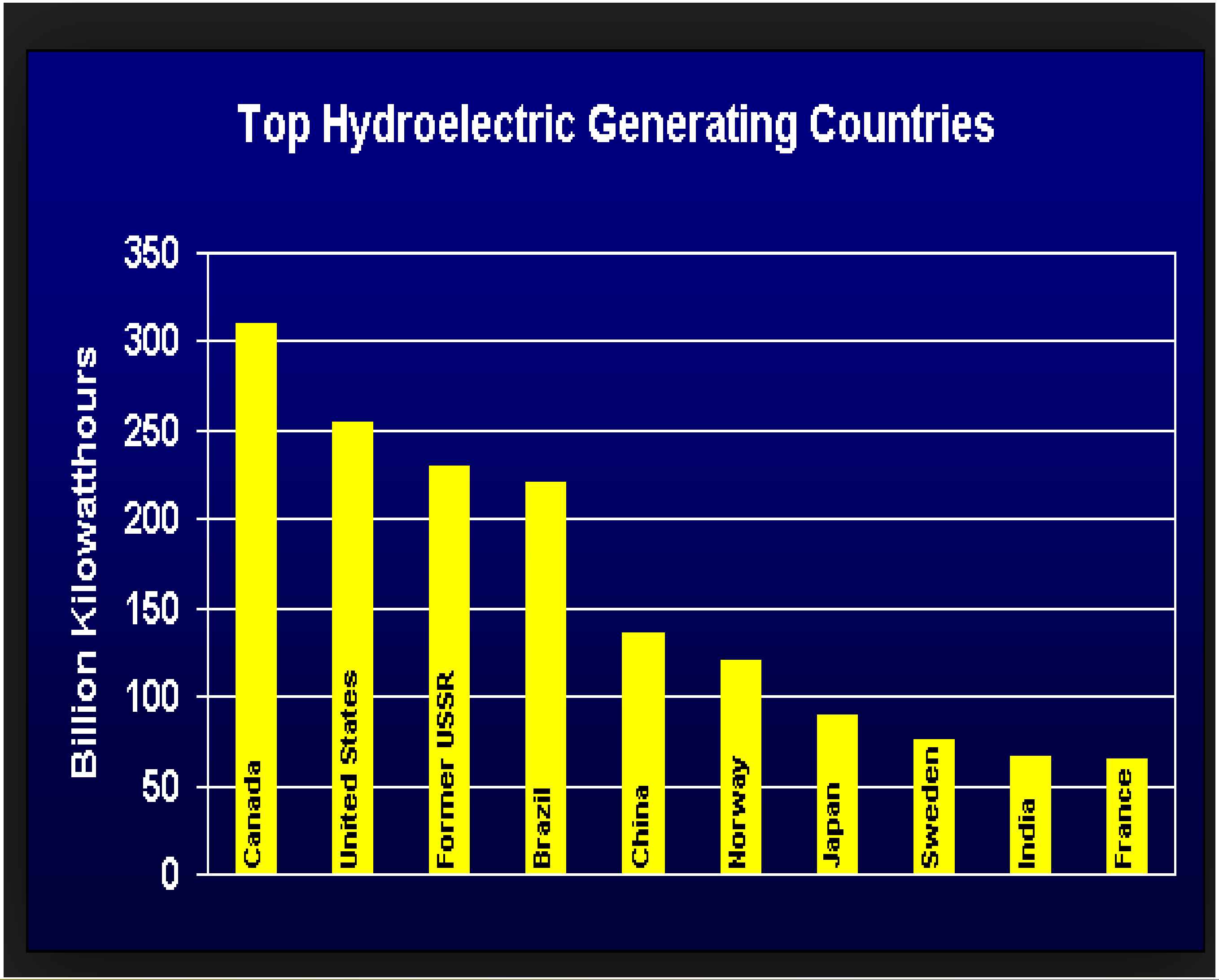
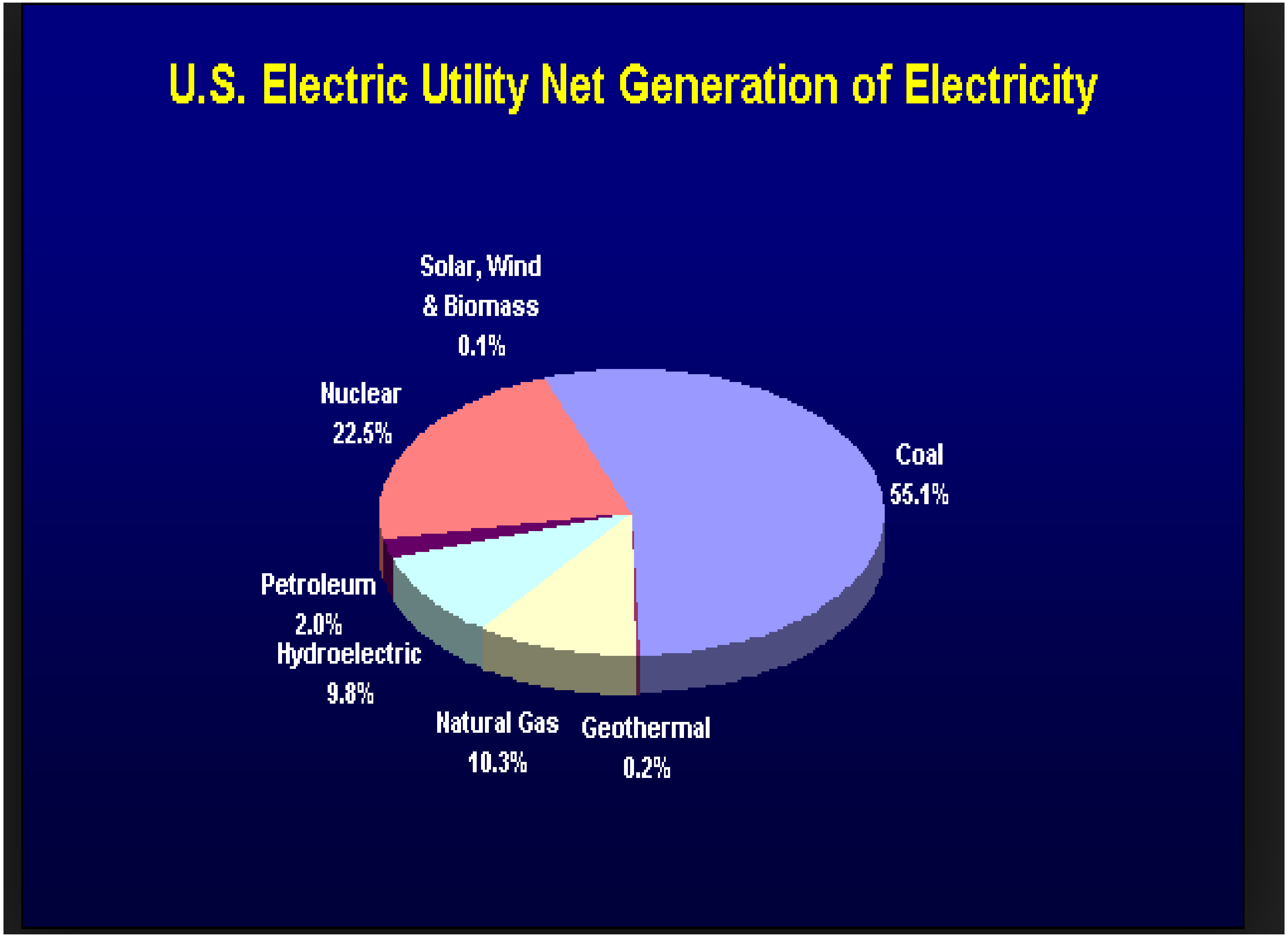
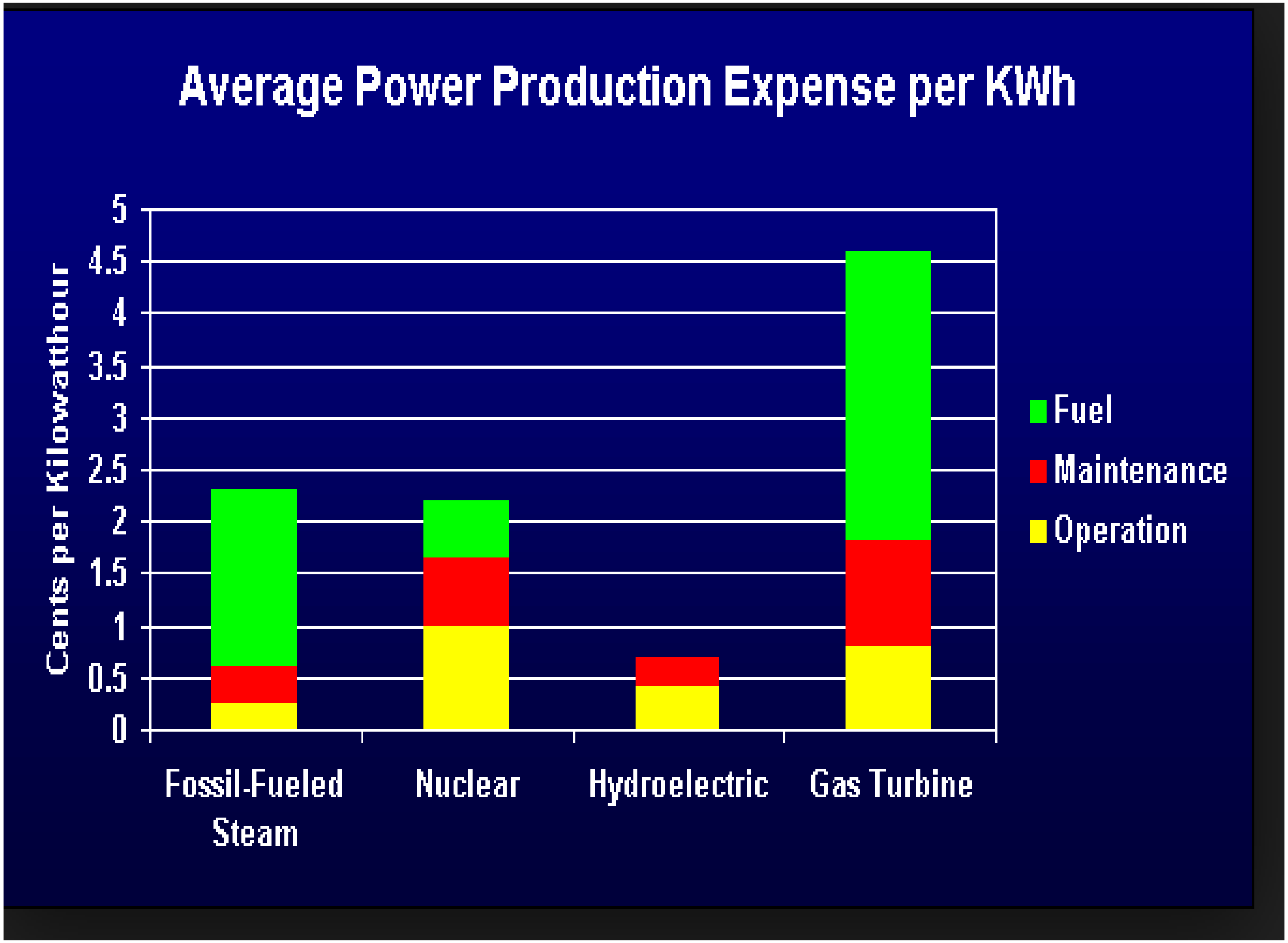

Top Hydroelectric Generating Countries
Billion Kilowatthours
350
300
250
200
150
100
50
0
Canada
United States
Former USSR
Brazil
China
Norway
Japan
Sweden
India
France

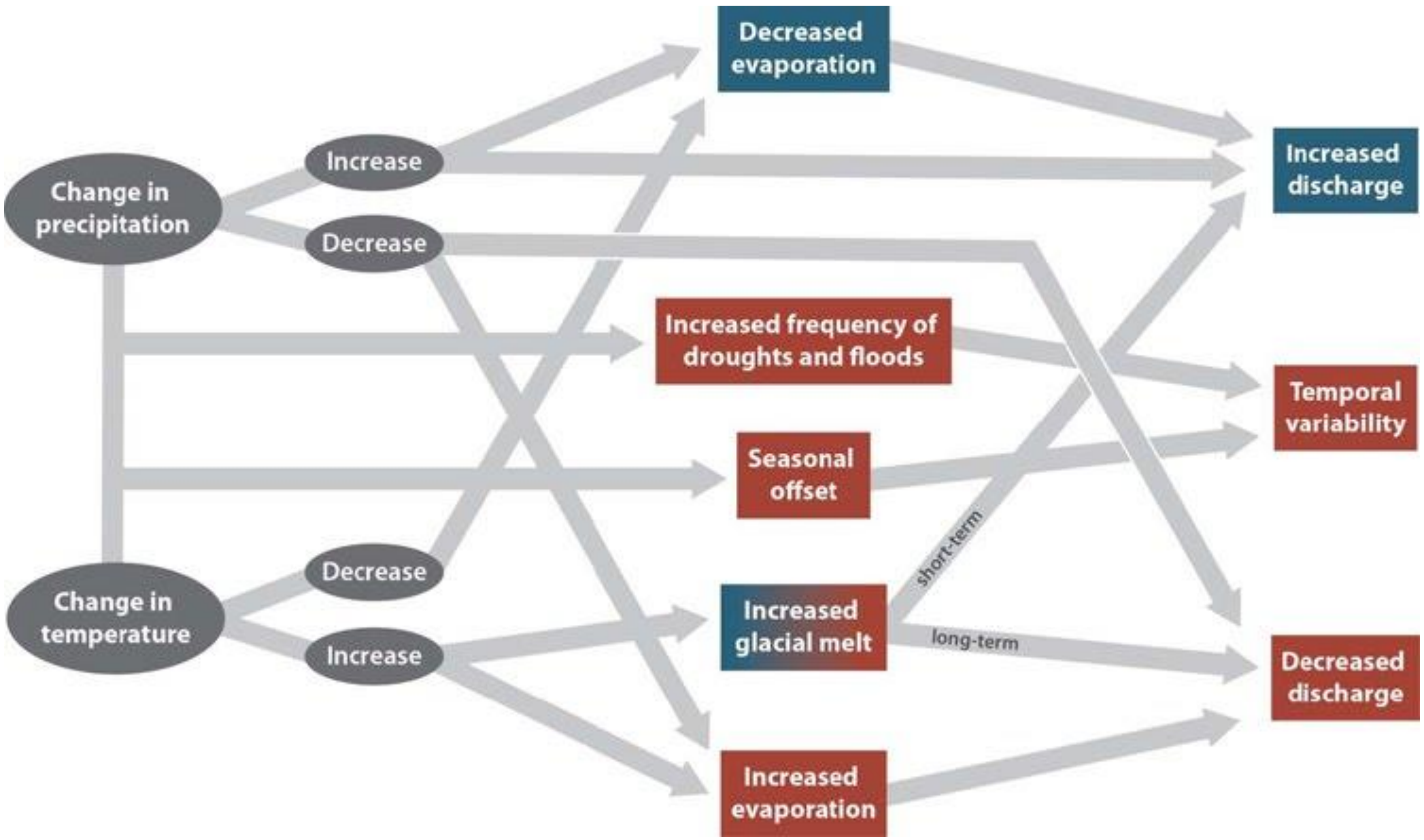
Contd.


U.S. Electric Utility Net Generation of Electricity
Solar, Wind & Biomass 0.1%
Nuclear 22.5%
Coal 55.1%
Petroleum 2.0%
Hydroelectric 9.8%
Natural Gas 10.3%
Geothermal 0.2%

Why Hydropower ?



Climate Change and Hydropower



Climate Change Impact on Hydro-Projects

- **HP generation utilising energy from water would be impacted by change in stream flow consequent to climate change.**
- **Temperature and precipitation change**
  - **Increase leads to greater evaporation from all water surfaces causing intensification of water cycle**
  - **Dry areas will become drier and wet areas weter**
  - **Robust model projection indicates increase in precipitation in the tropics and decrease in the sub-tropics.**
  - **Increase in precipitation in mid to high altitudes.**
  - **Evaporation from large reservoirs likely to increase causing loss of water for hydro-generation. In dry areas and shallow reservoirs with large surface area, this can be a negative issue.**
  - **In dry areas deeper reservoirs should be preferred.**
  - **Increase of global temperature leads to shifting of permafrost border and receding of glaciers.**

- Extreme Events
  - Increase variability of precipitation will pose significant problems for generation.
  - More severe and frequent floods will change the conventional wet and dry seasons.
  - Erratic dry spells will cause reduction in generation
  - Very high floods will cause stronger sediment and debris flow impacting hydro turbine and likely stoppage of generation, Ex- Nathpa-Jhakri HEP (1500 MW) on Sutlej.
  - High catchment erosion would be a consequence of intense precipitation causing loss of live storage.
  - Sudden intense precipitation would cause glacial lakes to overflow and cause devastating flood in the downstream, (Ex- Uttakhand Disaster-2013).

Examples of Hydro Projects Impacted by Climate Change

California, US

- Four year drought in 2014 caused catastrophic generation loss in HEPs in California in US, when half the capacity of the HEPs was only available.
- Three years ending October, 2014 because of loss of cheap power from HEPs was approx. US 1.4 billion.
- Additional combustion of fossil fuels caused 8% increase in CO_2 from coal fired plants.
- The Governor of California issued an executive order to make the sub-nation to extract more green house gases from the atmosphere than it emits by 2045.
- This was to conform to Paris accord 2015 limiting global warming to well below 2^{o} C.

Brazil

- **HE capacity of the most populous city Sao Paulo, Brazil was at near zero following prolonged drought worst since records began in 1930.**
- **Brazil generates 70% of its energy need from hydro. Serious shortage occurred in 2013 with all reservoir levels decreased.**
- **Brazil's National Institute for Space Research (INPE) find that contribution of World's large dams that emit 104 Mmt (Million Metric Ton) of methane annually from reservoir surfaces, turbines, spillways and rivers downstream responsible for atleast 4% of total warming effect of human activities.**

- **Dams are the largest single anthropogenic source of methane being responsible for 23% of all methane emission due to human activity.**
- **Methane is a much more heat trapping gas than CO_2 .**
- **As of May, 2007 dams in Brazil and India are considered responsible for a fifth of these countries total global warming.**
- **IPCC says that methane has a warming impact 72 times higher than CO_2, if measured over 20 years and 25 times higher if measured over 100 years.**

Latin America

- Extreme rainfall risel in 1970 led to 25% increase in hydro generation in South America from Paraguay and Parana rivers.
- In same period in Africa, severe drought & warming due to anthropogenic intensification of green house effect/soil use.

For South Asia

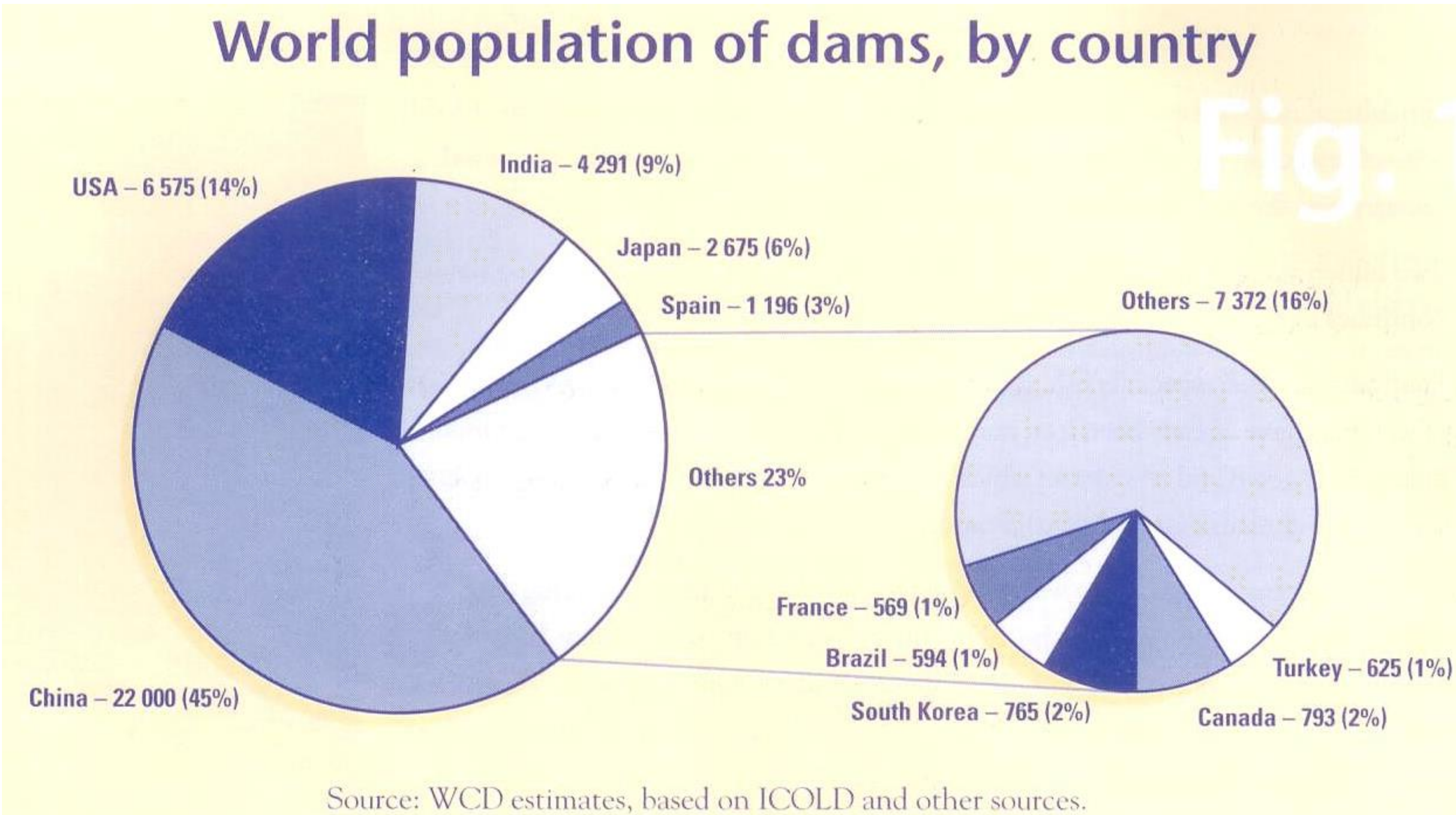
- Cascading impacts of climate change in the Hindukush Himalayas, the regions hydro-power sector ought to take note 'Melting Snow and Retreating Glaciers in a region parts of which are warming up at three times the global average will drastically change the seasonal flow of Aisa's major rivers.
- More intense floods/rainfall/periods of prolonged drought are predicted to wreak havoc for hydropower stations.

Hydro-potential of India

India has a hydro potential of 84000 MW at 60% load factor needing an installed capacity of 1,50,000 MW (CEA estimate).

Region	Principal Hydro	
	Potential at 60% Load Factor	Feasible Installed Capacity in MW
Northern	30155	53405
Western	5697	8928
Southern	10768	16446
Eastern	5590	10965
North Eastern	31857	58956
Total	84044	148700

Peak power demand 162 GW in 2017
Expected to reach 226 GW in 2022 & to reach 299 GW by 2027


World population of dams, by country
Fig. 1
USA – 6 575 (14%)
India – 4 291 (9%)
Japan – 2 675 (6%)
Spain – 1 196 (3%)
Others 23%
China – 22 000 (45%)
Others – 7 372 (16%)
France – 569 (1%)
Brazil – 594 (1%)
South Korea – 765 (2%)
Canada – 793 (2%)
Turkey – 625 (1%)
Source: WCD estimates, based on ICOLD and other sources.

Hirakud Dam on Mahanadi

Case of Odisha Dams

Hirakud Dam

- Built across river Mahanadi intercepting 83400 Km^2 out of total basin area of 1,41,600 Km^2 with installed capacity of 347.5 MW.
- Following basin parameters finalised at DPR stage
  - Average annual rainfall – 1369 mm
  - Average annual runoff – 48479 Mm^3
  - 75% dependable runoff – 42077 Mm^3
  - 90% dependable runoff – 30487 Mm^3

Year	Avg. annual runoff(Mm^3)
1926-35	47205
1936-45	51543
1946-51	44813
1959-68	37215
1969-78	34664
1979-88	28496
1989-98	33577
1999-06	29776

Contd.

- Value of 37215 Mm^3 for the period 1959-68 is attributable to the highest inflow of 90785 Mm^3 in the year 1961.
- Value of 33577 Mm^3 for the period 1989-98 is attributable to the inflow of 76591 Mm^3 in the year 1994.
- There has been no significant decrease in rainfall over the past 8 decades but rainfall has become erratic.

Simulation Study now undertaken leads to the reassessed Design Energy (DE) as 957.43 MU against the DE of 1174 Unit at the project planning stage.

Hirakud Hydrology

Annexure-3

Rainfall Considered at the DPR Stage

All Units are in mm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon
1891	12.2	8.6	82.6	13.5	42.2	47.8	483.1	350.0	423.7	18.8	0.5	5.1	1487.9	1323.3
1892	0.0	6.9	0.5	0.3	0.8	229.9	715.0	279.7	192.3	75.4	2.8	0.0	1503.4	1492.3
1893	26.2	49.5	47.2	4.6	34.3	259.8	414.0	348.5	306.6	72.1	21.1	0.0	1583.9	1401.1
1894	0.5	15.5	0.2	1.5	2.0	258.6	570.0	413.3	222.5	111.3	38.6	6.6	1640.5	1575.6
1895	1.0	7.1	22.9	22.6	5.6	404.1	338.8	401.1	33.3	32.5	1.0	0.0	1270.0	1209.8
1896	0.0	0.0	2.8	1.8	2.0	392.9	597.7	553.0	72.9	0.0	35.8	0.5	1659.4	1616.5
1897	10.7	33.5	42.9	46.2	21.3	136.7	306.1	463.3	185.2	122.2	1.5	0.0	1369.6	1213.4
1898	0.0	33.3	1.0	1.3	12.4	170.4	440.7	317.0	164.3	113.3	0.0	5.8	1259.6	1205.7
1899	0.5	7.9	0.8	39.9	21.3	171.2	243.1	368.3	61.7	1.0	0.0	0.0	915.7	845.3
1900	29.7	8.9	3.6	26.7	25.9	149.4	364.0	481.6	447.3	85.3	0.0	7.9	1630.2	1527.6
1901	44.7	103.4	29.5	8.9	11.9	69.3	363.2	430.8	197.6	29.2	1.0	0.0	1289.6	1090.2
1902	0.8	1.0	0.1	14.5	3.8	34.8	363.0	285.0	171.7	6.9	2.8	4.1	888.3	861.3
1903	3.8	13.5	0.5	6.6	37.3	93.7	399.0	372.4	215.6	177.5	0.3	0.1	1320.3	1258.3
1904	0.0	9.7	31.2	0.8	57.7	334.0	261.4	356.6	125.0	103.1	0.8	0.0	1280.2	1180.1
1905	45.2	14.7	16.8	23.6	22.1	38.4	397.0	266.4	322.8	7.1	0.0	0.0	1154.2	1031.7
1906	18.3	79.5	69.6	0.0	5.6	200.7	446.3	250.4	201.2	22.6	9.7	14.2	1318.0	1121.2
1907	4.6	27.2	27.4	48.5	3.0	266.4	218.2	442.7	167.4	1.3	9.9	18.3	1234.9	1096.0
1908	7.4	53.6	2.3	1.8	7.4	222.0	397.8	511.8	156.0	11.7	0.0	1.3	1372.9	1299.2
1909	3.6	4.6	5.3	132.8	6.9	209.8	440.9	190.5	136.9	9.9	0.0	60.2	1201.4	988.1
1910	5.8	1.0	1.3	17.0	9.4	227.8	286.5	444.0	244.6	78.5	22.1	0.0	1338.1	1281.4
1911	2.3	0.0	19.3	0.0	4.1	359.7	200.2	524.5	195.3	144.5	20.1	0.0	1469.9	1424.2
1912	4.1	97.5	0.5	19.1	5.8	60.5	426.5	414.0	182.4	6.4	6.1	0.0	1222.8	1089.7
1913	1.3	68.1	23.4	0.0	24.4	240.8	319.5	286.5	99.6	21.3	5.3	17.0	1107.2	967.7
1914	0.0	9.4	9.4	46.2	41.9	185.7	486.9	312.7	237.0	4.3	0.0	2.8	1336.3	1226.6
1915	29.0	32.3	18.8	15.0	13.2	105.7	360.4	389.4	275.6	124.2	20.8	0.0	1384.3	1255.3
1916	0.0	30.2	1.8	3.3	13.7	320.3	281.2	372.6	185.4	145.8	27.9	0.0	1382.3	1305.3
1917	1.3	79.0	30.2	9.4	32.0	302.0	364.0	438.4	269.2	141.0	0.3	0.8	1667.5	1514.6
1918	14.2	4.3	0.8	3.6	49.0	510.0	256.3	437.4	117.6	0.5	6.9	7.4	1407.9	1321.8
1919	89.9	62.2	28.7	11.4	39.1	416.3	401.1	507.7	130.0	114.3	7.9	0.0	1808.7	1569.5
1920	0.5	3.6	22.6	29.2	17.3	93.0	396.7	325.4	105.4	0.2	0.0	0.0	993.8	920.7
1921	44.2	0.5	0.0	3.0	0.0	331.7	279.1	374.4	218.9	7.9	0.0	0.0	1259.8	1212.1
1922	23.6	1.0	0.5	14.7	5.1	187.2	390.7	253.7	299.5	9.9	12.2	1.0	1199.1	1141.0
1923	4.8	24.4	18.3	3.0	3.3	69.6	375.2	503.7	207.0	55.6	8.4	2.0	1275.3	1211.1
1924	33.5	4.6	4.8	4.3	16.5	62.7	306.3	302.8	248.7	82.3	106.4	0.8	1173.7	1002.8
1925	0.0	0.3	0.8	6.9	84.3	301.8	541.5	406.9	170.9	55.6	21.8	0.8	1591.6	1476.8
1926	30.5	13.5	101.4	54.3	47.7	37.4	309.0	548.6	318.0	69.5	0.0	1.9	1531.8	1282.5
1927	3.7	53.0	20.9	2.6	10.1	194.8	427.8	456.2	168.2	79.6	22.3	0.0	1439.4	1326.7
1928	2.0	11.5	8.3	12.1	14.6	230.1	392.4	247.9	155.9	101.9	0.0	1.3	1177.8	1128.2
1929	14.8	16.8	0.2	4.7	1.5	184.1	593.8	407.5	170.3	88.4	0.0	38.3	1520.4	1444.1
1930	0.0	3.5	6.6	38.0	7.4	189.2	465.0	247.8	180.3	31.2	93.2	4.0	1266.1	1113.5
1931	10.4	41.2	11.8	5.2	9.5*	117.9	319.6	527.5	166.0	148.9	60.4	0.2	1418.7	1279.9

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon
1932	0.0	21.3	3.0	7.7	14.1	122.9	502.5	279.6	285.6	52.7	31.5	0.1	1321.1	1243.4
1933	20.9	102.3	13.7	25.4	104.9	287.4	401.3	381.0	270.8	31.6	6.5	1.8	1647.7	1372.2
1934	0.8	0.2	1.7	5.8	0.0	264.0	399.0	413.7	332.5	48.7	13.5	2.0	1481.9	1457.9
1935	4.1	17.7	3.3	33.3	2.0	135.1	551.1	250.6	245.6	1.4	0.0	5.3	1249.6	1183.9
1936	35.3	39.7	17.1	5.3	32.6	416.3	397.6	431.3	237.8	74.9	11.9	3.7	1703.5	1557.9
1937	0.0	50.3	20.7	81.0	12.0	18.4	469.1	415.5	236.0	78.6	4.5	0.4	1386.6	1217.7
1938	11.7	24.5	4.3	3.9	49.8	253.8	378.1	382.0	276.1	102.2	4.1	0.1	1490.6	1392.2
1939	7.6	25.6	60.9	15.1	0.0	212.8	408.1	539.2	193.0	61.8	0.2	0.0	1524.5	1414.9
1940	0.6	27.2	23.6	13.8	19.5	213.4	558.6	396.4	54.5	70.9	1.5	22.0	1402.2	1293.8
1941	29.4	16.1	19.7	2.3	30.0	224.5	235.4	248.2	131.4	65.7	6.5	0.3	1009.7	905.2
1942	16.4	49.7	5.8	6.3	5.7	148.9	522.4	404.1	299.9	17.7	0.2	2.2	1479.4	1393.1
1943	127.1	2.8	3.6	16.6	27.9	198.6	428.5	377.2	380.2	38.4	0.0	0.0	1600.8	1422.9
1944	12.7	52.6	95.5	14.6	7.6	62.7	537.2	414.0	216.4	129.0	2.5	0.1	1544.9	1359.4
1945	19.1	3.8	0.0	48.0	2.3	134.9	396.2	304.8	363.2	64.0	2.0	0.3	1338.7	1263.1
1946	0.0	9.0	1.7	19.2	9.2	266.4	311.9	448.3	187.5	37.1	28.4	0.7	1319.4	1251.2
1947	24.6	37.3	10.7	3.3	7.6	132.6	479.3	513.1	227.8	52.1	0.0	9.1	1497.6	1404.9
1948	32.3	5.1	7.4	10.9	5.8	193.8	364.7	447.0	170.2	33.0	39.4	0.0	1309.6	1208.8
1949	0.0	3.6	2.9	4.6	47.8	181.6	322.6	369.6	251.5	145.0	0.0	1.0	1330.1	1270.3
1950	0.0	42.0	47.0	13.2	1.3	185.3	359.4	335.3	148.8	17.5	7.1	1.2	1158.1	1046.3
1951	3.7	1.5	101.6	61.2	24.2	104.4	306.6	407.2	140.5	107.0	3.8	0.0	1261.6	1065.6

Source: Report on Hirakud Dam Project (Revised)-1953

Contd.

Runoff in to Hirakud Reservoir (1959-2006)

All units are in Mm³

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon
1959	189	104	1	78	17	191	5587	17544	17071	2227	498	203	43710	42620
1960	196	32	134	68	64	512	7235	21656	4989	4033	544	210	39673	38425
1961	228	333	72	97	49	6634	26937	17927	29877	6685	1280	666	90785	88060
1962	327	131	105	64	51	370	3396	7011	5544	810	395	144	18346	17130
1963	69	84	137	41	6	846	5444	13000	13688	2153	713	210	36388	35129
1964	125	53	110	9	14	1461	14988	17531	8621	4587	912	316	48726	47188
1965	200	49	197	163	39	335	3227	3335	5582	636	207	39	14011	13115
1966	120	97	6	0	76	84	4883	9916	2027	398	153	131	17891	17308
1967	22	0	21	92	39	471	6229	20047	9298	1219	346	328	38114	37265
1968	247	256	136	32	63	497	4805	13399	3371	1263	332	111	24511	23335
1969	79	55	57	26	59	1073	5367	12039	4479	815	370	134	24554	23773
1970	126	57	133	20	0	1646	12376	16729	10157	1914	344	150	43652	42822
1971	144	120	86	60	55	5668	12303	16271	8500	2593	647	255	46704	45335
1972	162	127	39	14	0	33	4639	8440	6831	1255	642	353	22534	21198
1973	96	105	38	60	0	131	9767	14395	15866	8876	2302	370	52007	49035
1974	221	125	7	4	0	152	3083	9949	1231	969	312	80	16131	15383
1975	33	31	11	11	0	346	7793	17829	8236	4323	1132	274	40019	38528
1976	171	117	37	25	0	30	6124	15473	7738	328	157	37	30237	29693
1977	18	0	0	0	0	1869	8668	13662	9238	1842	525	226	36048	35279
1978	95	147	127	12	0	977	6169	18038	7006	1042	513	300	34424	33231
1979	141	170	0	0	0	89	2173	6943	814	692	106	43	11170	10710
1980	0	0	0	0	0	2667	11324	9601	18146	1137	392	112	43379	42875
1981	120	32	0	35	0	239	4572	10564	6333	1789	385	132	24200	23497
1982	150	153	206	0	0	196	1882	13684	4684	1069	434	122	22580	21515
1983	62	138	25	0	7	80	3562	11106	11506	3794	439	227	30946	30048
1984	355	280	163	118	0	1604	7859	18310	4435	954	406	227	34711	33163
1985	387	238	157	33	0	32	7410	13711	11620	2186	491	238	36503	34959
1986	313	413	207	141	0	8093	13842	11750	1739	1398	771	351	39018	36822
1987	337	201	189	22	23	0	8577	3678	5886	1300	883	307	21402	19441
1988	199	197	319	99	0	764	4730	9823	3122	1129	289	147	20818	19569
1989	185	95	104	36	0	1005	5180	6774	4455	1089	313	197	19432	18502
1990	185	107	75	57	221	1385	7980	7312	14732	9513	1344	619	43629	40921
1991	639	440	353	120	96	270	4899	18378	5611	1392	626	556	33380	30550
1992	397	179	33	47	6	432	4152	13115	6545	642	547	465	26560	24886
1993	252	39	17	117	0	1079	4493	9135	8199	3224	784	313	27654	26131
1994	242	205	69	28	4	8689	28334	19549	14631	3233	962	646	76591	74436

Contd.

Monsoon Weighted Average Rainfall of Hirakud Catchmnet computed by Hirakud Dam Project (1959-2006)

Year	Jun	Jul	Aug	Sep	Oct	Monsoon
1959	41.8	299.2	419.3	334.2	62.8	1157.2
1960	194.6	489.0	599.1	113.7	103.0	1499.3
1961	313.0	601.6	277.0	621.4	115.5	1928.4
1962	167.0	352.0	333.6	192.3	9.7	1054.6
1963	169.5	503.8	461.7	383.3	70.0	1588.3
1964	178.7	533.1	418.8	172.8	57.0	1360.4
1965	134.6	301.0	203.8	235.4	0.0	874.8
1966	308.0	345.6	270.3	71.8	38.3	1034.1
1967	251.5	462.0	672.8	191.0	2.3	1579.6
1968	131.0	369.9	452.8	171.7	64.7	1190.2
1969	128.3	396.9	253.4	116.9	51.1	946.7
1970	243.5	348.7	253.0	199.5	12.7	1057.4
1971	331.5	399.1	421.1	137.5	109.2	1398.4
1972	112.0	229.0	424.5	172.5	42.4	980.3
1973	121.9	455.3	524.4	384.7	90.3	1576.5
1974	105.6	365.0	424.2	56.0	73.4	1024.2
1975	96.3	623.6	347.8	151.3	55.3	1274.2
1976	56.4	393.0	420.8	134.9	1.6	1006.7
1977	151.0	229.9	293.9	166.9	11.4	853.1
1978	168.8	308.7	328.1	101.6	12.6	919.8
1979	115.6	227.5	245.2	79.7	23.6	691.5
1980	269.9	320.5	236.6	374.6	16.0	1217.5
1981	77.4	340.4	312.6	219.6	15.0	965.0
1982	80.0	203.0	500.0	53.9	58.4	895.2
1983	123.1	276.3	448.5	340.2	42.4	1230.5
1984	337.1	294.0	431.7	80.8	38.3	1181.9
1985	96.1	418.8	437.7	259.5	48.4	1260.5
1986	347.6	430.2	277.3	86.1	41.7	1182.9
1987	32.0	554.0	126.0	113.0	47.0	872.0
1988	171.0	213.0	321.0	128.0	9.0	842.0
1989	78.0	295.0	305.0	165.0	11.0	854.0
1990	165.9	297.0	193.0	312.3	152.5	1120.6
1991	57.9	382.0	441.0	141.5	26.0	1048.4
1992	49.9	353.1	367.7	163.3	0.4	934.3
1993	122.6	348.0	308.5	280.6	69.7	1129.3
1994	363.1	619.8	392.4	202.1	60.0	1637.3
1995	46.3	457.4	322.4	90.3	58.3	974.7
1996	129.6	297.3	393.1	120.0	19.6	959.7
1997	80.9	334.3	371.2	185.1	7.3	1032.2
1998	184.9	269.2	238.7	318.7	53.1	992.7
1999	176.7	267.8	411.8	224.7	79.8	1113.6
2000	113.4	324.0	179.2	123.1	6.9	804.1
2001	230.7	560.8	325.1	72.5	77.0	1162.0
2002	217.3	143.1	360.1	237.9	30.9	973.2
2003	170.5	357.2	440.5	416.4	148.7	1538.7
2004	95.9	356.7	339.8	131.2	38.3	926.6
2005	179.7	423.1	251.7	182.9	60.4	1107.4
2006	51.3	358.2	355.1	117.9	16.0	917.4

Source: Master Control Station, Hirakud Dam Project, Burla

Contd.

Runoff used at DPR stage (1926-52)

All units are in Mm^3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Monsoon
1926	330	219	293	233	180	138	2915	21728	22338	4033	784	361	53554	51152
1927	229	249	212	137	126	1340	12448	21960	11504	3632	604	300	52742	50885
1928	202	180	138	232	138	1673	12175	4372	5327	3512	634	253	28835	27058
1929	194	179	141	101	76	555	18268	23315	9460	3267	1180	635	57370	54865
1930	314	173	153	143	101	662	9477	12813	4856	1766	2013	380	32857	29574
1931	55	358	211	127	99	233	4545	22295	7563	6034	1835	555	43910	40671
1932	268	192	176	147	134	218	12379	15479	10557	1309	1798	545	43203	39943
1933	406	817	289	166	285	4073	15573	20739	11963	2217	1758	780	59066	54564
1934	396	238	196	163	153	1503	13172	19840	16276	4128	1948	837	58850	54919
1935	445	313	231	211	173	223	16818	11847	9223	1243	609	332	41667	39354
1936	240	272	194	160	173	7954	14882	21065	13911	4759	1922	621	66154	62571
1937	323	332	268	219	194	2996	16214	22626	12066	2730	893	335	59195	56632
1938	275	207	162	107	123	2741	8153	15292	16313	4505	938	359	49175	47003
1939	270	190	196	149	99	1051	12638	19590	NA	NA	1385	329	35896	33279
1940	252	208	185	100	102	1666	25355	18806	2678	1104	465	302	51223	49609
1941	242	181	166	129	126	1359	5512	6315	2311	1472	348	205	18366	16969
1942	170	131	132	113	76	471	15528	19947	16202	1687	642	239	55340	53835
1943	534	274	148	126	122	1514	13514	21257	22817	3087	1033	413	64839	62189
1944	372	822	418	332	162	266	14611	30985	7926	5208	1358	469	62929	58997
1945	346	181	158	138	132	1206	10667	12584	22273	3359	938	337	52319	50088
1946	228	155	154	132	126	3510	13282	30787	8876	3302	1012	480	62045	59757
1947	261	261	190	99	37	85	10381	17595	15115	3413	550	312	48299	46589
1948	302	155	86	51	32	625	7754	20209	8187	3055	1055	565	42077	39831
1949	243	175	95	48	44	629	6577	18790	9351	4990	1518	459	42918	40336
1950	213	166	227	94	30	836	11817	20653	7253	1081	433	252	43054	41640
1951	178	110	147	436	67	233	2824	16568	6036	2964	617	309	30487	28624
1952	153	81	54	28	33	734	10021	19067	18712	2882	528	269	52562	51415

Source: Report on Hirakud Dam Project (Revised)-1953

Upper Kolab Hydro Project, 320 MW

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- Upper Kolab project intercepting 1630 Km^2 of Kolab river, a tributary of Godavari was planned in the year 1971 for irrigation of 44544 ha and hydro generation of 320 MW and Design Energy of 832 MU.
- The project was commissioned in the year 1989
- The project planning considered an average monsoon rainfall of 1568 mm considering the long term rainfall data of 1946 to 1970.
- The average annual yield was 1704 Mm^3 and 90% dependable yield as 1469 Mm^3.
- The salient hydro-meteorological data enclosed as annexures.

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- Revised DE study undertaken indicate the following

	Current (1963-64 to 2005-06)	DPR Stage (1963-70)
Maximum Monsoon Rainfall	1637 mm	1609 mm
Minimum Monsoon Rainfall	812 mm	1165 mm
Average Monsoon Rainfall	1233 mm	1415 mm
Average Annual Runoff	1319 Mm^3	1704 Mm^3
75% Dependable Runoff	1041 Mm^3	1568 Mm^3
90% Dependable Runoff	960.13 Mm^3	1469 Mm^3

- Reassessed DE (2006) is 643.86 MU against 832 MU in project formulation stage.

Upper Kolab Hydrology

Weighted Average Monsoon Rainfall (mm) of
UKHEP Catchment (DPR Stage)

Units are in mm

Year	Jun	Jul	Aug	Sep	Oct	Monsoon
1946-47	202	438	432	127	85	1284
1947-48	208	397	476	263	110	1454
1948-49	209	216	457	450	90	1422
1949-50	196	192	317	374	486	1565
1950-51	218	240	282	243	112	1095
1951-52	173	530	439	203	138	1483
1952-53	128	408	367	382	195	1480
1953-54	344	198	696	312	170	1720
1954-55	89	326	325	350	170	1260
1955-56	189	180	586	331	344	1630
1956-57	256	724	430	260	245	1915
1957-58	152	458	645	210	40	1505
1958-59	143	389	412	286	445	1675
1959-60	358	454	398	300	155	1665
1960-61	328	332	223	182	105	1170
1961-62	215	443	352	252	221	1483
1962-63	255	626	310	295	170	1656
1963-64	190	273	287	339	250	1339
1964-65	246	275	592	276	145	1534
1965-66	176	509	285	155	34	1159
1966-67	186	476	271	296	79	1308
1967-68	413	482	365	234	5	1499
1968-69	99	249	194	332	390	1264
1969-70	225	669	272	227	69	1462

Upper Kolab Dam Project, Project Report, Volume-I, 1972, Statement A-9

Upper Kolab Hydrology

Weighted Average Rainfall of Upper Kolab Catchment (1970-71 to 2005-06)

All units are in mm

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual	Monsoon
1970-71	198	395	580	194	71	0	59	1	7	2	67	65	1639	1438
1971-72	256	269	275	166	44	0	0	0	0	0	37	35	1083	1011
1972-73	147	350	142	376	74	19	0	0	0	34	42	17	1201	1089
1973-74	143	412	254	148	152	14	0	9	0	9	31	9	1191	1120
1974-75	182	186	361	178	221	4	0	9	14	18	28	68	1269	1127
1975-76	415	218	368	380	257	21	0	0	9	10	27	25	1725	1637
1976-77	68	383	435	127	42	65	0	0	3	18	156	77	1394	1055
1977-78	103	384	472	348	57	125	4	0	25	10	70	67	1666	1364
1978-79	211	353	568	159	110	26	1	0	13	0	23	87	1551	1402
1979-80	305	182	294	228	118	17	6	0	0	0	0	0	1151	1127
1980-81	285	418	343	415	69	4	0	31	0	48	28	153	1797	1532
1981-82	163	250	310	320	15	1	0	0	5	31	33	74	1202	1058
1982-83	122	295	435	143	144	0	3	0	4	1	30	65	1257	1138
1983-84	310	304	364	259	238	7	11	2	14	0	126	69	1667	1436
1984-85	219	375	[illegible]	112	59	0	3	41	0	9	34	12	1533	[illegible]
1985-86	250	364	289	229	123	0	0	19	61	24	41	77	1486	1245
1986-87	202	324	494	141	123	47	5	11	0	22	67	117	1553	1284
1987-88	144	331	283	145	159	153	1	0	9	11	49	71	1356	1062
1988-89	133	358	251	211	72	0	0	0	0	40	19	58	1143	1025
1989-90	227	236	299	148	67	0	0	0	32	67	20	374	1470	977
1990-91	163	260	381	217	303	36	3	1	0	19	40	24	1447	1324
1991-92	207	515	400	201	128	37	0	0	0	0	26	37	1551	1449
1992-93	155	421	397	291	79	88	0	0	0	6	14	36	1487	1342
1993-94	127	387	268	267	94	8	0	0	3	1	45	37	1236	1142
1994-95	158	476	336	392	63	9	0	5	0	9	19	264	1732	1425
1995-96	58	554	306	231	127	26	0	4	0	23	52	21	1403	1277
1996-97	123	424	335	176	44	6	0	14	0	0	53	47	1222	1102
1997-98	149	229	203	187	44	41	22	0	10	23	43	58	1008	812
1998-99	160	342	134	107	158	179	0	0	0	0	1	179	1260	901
1999-00	342	256	288	258	71	9	0	0	18	6	5	61	1314	1215
2000-01	235	260	343	115	25	2	6	0	0	9	54	35	1084	978
2001-02	222	477	276	110	53	33	0	40	0	1	36	33	1281	1139
2002-03	126	160	309	119	99	0	0	0	2	35	67	2	919	813
2003-04	61	439	467	213	213	3	65	33	0	10	47	32	1583	1393
2004-05	350	316	306	127	200	25	0	1	0	1	11	26	1363	1299
2005-06	224	267	243	444	194	20	0	0	0	38	69	197	1697	1373

Upper Kolab Hydrology

Inflow into Kolab dam (1946-47 to 70-71) in Mm^3 (at DPR Stage)

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual	Monsoon
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	89	58	45	34	32	34	43	1568	1234
[illegible]	[illegible]	[illegible]	[illegible]	314	192	89	58	45	34	32	34	43	1767	1433
[illegible]	[illegible]	[illegible]	[illegible]	477	284	89	58	45	34	32	34	43	1857	1522
[illegible]	[illegible]	[illegible]	[illegible]	410	486	89	58	45	34	32	34	43	1859	1524
[illegible]	[illegible]	[illegible]	[illegible]	254	152	89	58	45	34	32	34	43	1689	1355
[illegible]	[illegible]	[illegible]	[illegible]	258	145	89	58	45	34	32	34	43	1570	1236
[illegible]	[illegible]	[illegible]	[illegible]	429	306	89	58	45	34	32	34	43	1878	1544
[illegible]	[illegible]	[illegible]	[illegible]	356	242	89	58	45	34	32	34	43	1934	1600
[illegible]	[illegible]	[illegible]	[illegible]	387	264	89	58	45	34	32	34	43	1577	1243
[illegible]	[illegible]	[illegible]	[illegible]	377	372	89	58	45	34	32	34	43	2007	1673
[illegible]	[illegible]	[illegible]	[illegible]	311	253	89	58	45	34	32	34	43	2092	1758
[illegible]	[illegible]	[illegible]	[illegible]	268	85	89	58	45	34	32	34	43	1779	1445
[illegible]	[illegible]	[illegible]	435	332	411	89	58	45	34	32	34	43	1918	1584
[illegible]	[illegible]	[illegible]	429	349	225	89	58	45	34	32	34	43	1908	1573
[illegible]	[illegible]	[illegible]	[illegible]	139	107	89	58	45	34	32	34	43	1319	984
[illegible]	[illegible]	[illegible]	447	297	219	89	58	45	34	32	34	43	1763	1428
[illegible]	[illegible]	[illegible]	347	329	211	89	58	45	34	32	34	43	1906	1571
[illegible]	[illegible]	[illegible]	242	320	240	117	71	58	45	39	38	34	1469	1067
[illegible]	[illegible]	[illegible]	571	266	267	92	66	55	38	33	40	66	1810	1420
[illegible]	[illegible]	[illegible]	233	150	70	40	38	41	28	25	24	24	1071	850
[illegible]	[illegible]	[illegible]	329	368	125	87	67	52	36	52	39	42	1562	1187
[illegible]	[illegible]	[illegible]	446	214	91	63	62	48	37	34	38	35	1643	1326
[illegible]	[illegible]	[illegible]	225	341	583	102	57	36	25	17	22	28	1595	1309
[illegible]	[illegible]	[illegible]	381	252	89	156	48	31	25	23	29	30	1544	1205
[illegible]	[illegible]	[illegible]	540	241	109	43	46	36	28	23	17	29	1430	1208

[illegible] Dam Project, Project Report, Volume-I

Upper Kolab Hydrology

The inflow computed from observed runoff by CWC (1972-73 to 86-87)

All units are in Mm^3

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual	Monsoon
[illegible]	46	299	110	354	142	59	29	17	17	20	13	16	1122	951
[illegible]	42	221	228	146	173	53	23	29	19	17	26	22	1109	919
[illegible]	55	77	285	158	179	61	37	29	19	15	12	20	960	767
[illegible]	185	144	393	438	252	59	33	29	22	14	15	14	1598	1412
[illegible]	18	154	397	225	58	51	36	25	18	16	43	40	1121	892
[illegible]	35	250	363	431	116	102	55	36	27	21	24	38	1507	1205
[illegible]	58	211	780	261	139	61	45	31	22	17	13	20	1667	1458
[illegible]	165	125	267	143	182	48	27	21	17	12	15	18	1041	883
[illegible]	105	320	360	535	105	50	44	38	22	25	19	32	1655	1426
[illegible]	50	104	242	237	62	40	31	24	16	16	17	52	890	695
[illegible]	35	116	414	221	121	70	33	23	18	13	15	26	1105	907
[illegible]	157	157	297	203	200	66	43	33	26	18	44	26	1341	1084
[illegible]	63	184	558	128	68	27	22	25	15	12	13	18	1132	1001
[illegible]	74	185	256	190	138	36	38	33	27	18	21	28	1043	842
[illegible]	67	176	568	250	110	70	30	28	18	13	14	30	1374	1171

Source: History of Upper Kolab

Upper Kolab Hydrology

[illegible] Upper Kolab Reservoir (1987-88 to -2006-07)

All units are in Mm^3

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual	Monsoon
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	80	31	29	27	29	28	29	1015	760
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	121	45	33	14	24	26	25	26	1013	819
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	87	31	24	17	33	35	19	314	1216	743
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	546	107	59	47	52	45	49	35	2162	1768
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	163	93	71	55	46	48	49	36	1732	1333
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	131	73	35	45	56	46	35	36	1610	1284
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	110	39	35	33	25	25	31	33	1070	848
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	133	58	35	34	31	33	40	186	1954	1536
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	239	80	22	40	33	34	39	26	1727	1453
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	134	52	139	46	37	36	41	37	1493	1105
[illegible]	[illegible]	[illegible]	[illegible]	143	71	47	32	26	23	27	39	33	848	621
[illegible]	[illegible]	[illegible]	[illegible]	88	153	187	43	34	27	25	27	70	1045	632
[illegible]	[illegible]	[illegible]	[illegible]	306	119	67	45	35	42	29	25	32	1475	1201
[illegible]	[illegible]	[illegible]	[illegible]	198	85	38	29	26	21	20	40	23	1017	821
[illegible]	[illegible]	[illegible]	[illegible]	151	101	60	36	43	35	38	56	27	1578	1282
[illegible]	[illegible]	[illegible]	[illegible]	117	81	26	21	20	25	21	28	12	736	583
[illegible]	[illegible]	[illegible]	[illegible]	315	267	73	70	54	41	35	34	44	1613	1262
[illegible]	[illegible]	[illegible]	[illegible]	207	244	73	46	44	36	29	34	30	1566	1274
[illegible]	[illegible]	[illegible]	[illegible]	383	217	92	48	40	36	43	51	65	1315	941
[illegible]	[illegible]	[illegible]	[illegible]	498	184	94	54	50	41	39	40	61	2549	2170

Source: Office of the Executive Engineer, Uper Kolab dam Division

Balimela HEP on Sileru River

Balimela HEP on Sileru River

- Balimela HE Project, a joint project of Odisha and Andhra Pradesh, intercepting 4908 Km^2 of Sileru basin in conjunction with Jalaput dam (upstream) has been operational in 1972, to feed power plant of 360 MW.
- Another two units of 75 MW have been installed to increase the capacity to 510 MW.
- AT the project formulation stage the average rainfall was decided as 1387 mm, maximum rainfall 1827 mm, minimum rainfall 1086 mm. Current average rainfall is 1484 mm.
- The average annual runoff was considered as 4210 Mm^3, 75% dependable runoff 2868 Mm^3 and 90% dependable runoff as 2350 Mm^3 at formulation stage.

Balimela HEP on Sileru River

- Revised DE study has the following findings;

	DPR (1942-52)	Current (1976-77 to 2001-02)
90% dependable yield	2350 Mm^3	2575 Mm^3
75% dependable yield	2868 Mm^3	2936 Mm^3
Average yield	4210 Mm^3	3519 Mm^3

The reassessed DE is 928.6 MU against DE of 1183 MU at the project formulation stage.

Conclusion

- The phenomenon of climate change primarily the warming of entire globe has been broadly examined with reference to the exhaustive study of IPCC (2007).
- Although the macro change such as monthly & annually have not undergone very high changes in India (IMD, 2013), there has been several incidents of heat wave both in India & abroad.
- WMD defines heat wave as period of five or more consecutive days during which the daily maximum temperature exceeds the average maximum temperatures by 5^{o} C.
- In India on an average 5-6 heat wave events occur every year in Central and Northern states.

Contd.

- All across the globe there has been incidence of extremely intense short duration rainfall (comparatively to the past) but more pronounced drought of longer duration.
- In Hoover dam, US the first hydro electric major dam (1930) the 17 massive turbines with installed capacity of 2100 MW, the generation shrunk to 1570 MW in 2015 because of drought in Colorado basin.
- University of Wisconsin study predicts future drought in Colorado basin will cut hydroelectric capacity upto 20%.
- In the US where the hydro electric projects constitute 10% (1997) of total generation, the actual generation reduced the hydro contribution to 5.97% (2008).

Contd.

- In New Zealand the hydro power generation has dropped by 10%
- Lake Baikal world's largest fresh water lake has shrunk to its lowest level, 30% below the normal.
- The prediction of climate change for India does indicate a pessimistic forecast lower yield of basins likely from prolonged drought, more in the Himalayas.
- The case study of three major HEPs in Odisha show conclusively the reduction of inflow and DE over the recent years.
- For hydro projects the lesson is to carefully assess weather parameters and improve the efficiency of existing plants and take major operational change decision.
- Develop appropriate of hydrological models for a river basin which can be (a) Empirical, (b) Conceptual, (c) Deterministic.