CLIMATE CHANGE AND ITS IMPACT ON BIODIVERSITY

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Climate and Climate Change

The word ***climate*** refers to the long-term weather patterns within a defined region including temperature, humidity, wind, and amount and type of precipitation. Weather refers to hourly, daily, or weekly changes in the atmosphere, while climate is generally discussed, in terms of years, decades, centuries, and millennia.

Climate is the statistical description in terms of means and variability of key weather parameters for a given area over a period of time, usually about 30 years. Today, the commonly used term ‘climate change’ represents any change in climate over time, whether due to natural causes and/or as a result of human activities.

Climate change refers to significant and long-term changes to a region’s climate. These changes can occur over a few decades, or millions of years. Climate change alters entire **ecosys**tems along with all of the plants and animals that live there. As cli-mate has changed throughout Earth’s history, all living creatures have had to adapt, move, or die out. When these changes happen gradually, ecosystems and species are able to evolve together. A gradual change also gives species the opportunity to adapt to new conditions. But, when the change happens very quickly, like it is today, the ability of species to adapt quickly enough or relocate—assuming a suitable location exists—is a big concern.

GHGs and Climate Change

A major reason to implicate human or anthropogenic activities for climate change is the fact that these are closely linked with increasing concentrations of carbon dioxide, methane, nitrous oxide and other greenhouse gases (GHGs) known to trap the heat from solar radiation in the upper layers of the Earth’s atmosphere.

Earth’s atmosphere traps energy from the sun as heat and keeps our planet warm through a process called the **greenhouse effect**. Naturally occurring Green House Gases (GHGs) i.e. CO_2, CH_4, O_3 and water vapour**s** are responsible for slow increase in earth's temperature, which is necessary. But now, human activities have caused a significant and continuing increase in the levels of **greenhouse gases** in the atmosphere. More greenhouse gases means the atmosphere traps more heat. The processes of industry and burning fossil fuels for energy and transportation both release carbon dioxide (CO_2), the most common greenhouse gas behind water vapor. Livestock and landfills generate methane (CH4), a potent greenhouse gas. Vast amounts of greenhouse gases are also released every day by volcanic eruptions and forest fires. Greenhouse gases from all sources mix in the atmosphere and affect the entire Earth.

In 1896, the Nobel Laureate Svante Arrhenius predicted that increases of atmospheric CO_2 from burning fossil fuels would lead to global warming. He had also made calcultions which suggested that doubling of CO_2 concentrations (then about 260 ppm) in the atmosphere would raise the temperatures of the Earth by about 2 to 6 °C. At present, the CO_2 concentration alone is about 398 ppm, leaving aside the other greenhouse gases arising largely from anthropogenic causes. The CO_2 plus the other heat-trapping gases form what is referred to as ''CO_2 equivalent'', which now is about 470 to 480 ppm (Swaminathan and Keshavan, 2012). All these support the estimate by the Intergovernmental Panel on Climate Change (IPCC) that the Earth will warm by 1.4–5.8 °C during the current century (IPCC, 2001). Paul Crutzen (2002) assigns the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene—the warm period of the past 10–12 millenia.

Rising Temperature and its effects

As Earth warms and temperatures rise, regional climates are affected in different ways. Some areas of South and Southeast Asia are experiencing heavier monsoons and rising sea levels, while other areas, such as southern Africa and the American Southwest, are experiencing more severe droughts and crop failures.

Reduced snowpack and shrinking glaciers in the mountains mean less melting snow flowing into rivers, reservoirs, and lakes for fish and wildlife, and less water available for drinking and irrigation. Glaciers in the Himalayan Mountains supply year-round water to more than 2 billion people.

Warmer temperatures also produce increased evapo-ration, which leads to heavier rainfall and snowfall. But the increased precipitation is unevenly dis-tributed, leading to heavier rainfall in some loca-tions and droughts in others. Heavier snowstorms, stronger hurricanes, more intense heat waves, and extreme rainstorms and resulting flash floods are occurring more frequently around the globe (IFAW, 2013).

Warmer air temperatures also lead to higher ocean temperatures, and warmer oceans affect global ocean currents and associated weather patterns. The Gulf Stream—

a strong ocean current that brings warm water from the equator up the east coast of North America and across the North Atlantic to northern Europe—keeps winters in the United Kingdom as much as 9°F (5°C) warmer than they might otherwise be (IFAW, 2013).

International scientists suggest that the Gulf Stream will likely slow down as a result of climate change, reducing its warming effect. While global average temperatures continue to rise, the cooling effect due to the slowing of the Gulf Stream means that north-ern Europe may not experience as much warming as other regions (IFAW, 2013).

Impact on Animals

Warmer temperatures on land and sea, more intense storms and increasing numbers of floods, reduced snow pack and more frequent droughts, and rising sea levels: How will all of these climate changes affect life on Earth? Species have evolved to survive within certain temperature ranges and are able to tolerate variations in weather. The effects of climate change may push some species to the edge of extinction, while other species may flourish.

Warmer spring temperatures may cause birds to begin their seasonal migrations or nesting and cause bears to emerge from hibernation earlier than usual. When bears emerge before their regular food sources are available—80% of bears' diets are plants—they may starve or wander into towns in search of food. For those animals that rely on late summer plants to survive through the winter, warmer, drier summers may affect their ability to find enough food.

The annual flooding of the Brahmaputra River in the northwest corner of India has always been important to the health of Kaziranga National Park and the protected animals that live there, including elephants, rhinoceroses, and tigers. The increasing intensity of Asian monsoons in recent years has caused greater floods, displacing people and killing animals. Also, a 2012 study found that climate change could have a greater impact on Asian elephants dwindling numbers than previously thought. Researchers concluded that young elephants are particularly threatened by increasing temperatures, which can double their mortality risk. Elephants, like humans, reproduce later in life, so if calves die before they can mate, then the species will be unable to survive.

Animals that require cooler temperatures are shifting their ranges to higher elevations or towards the poles as the temperatures in their home ranges rise. The American pika, a small mammal related to rabbits and hares, is adapted to life in the alpine environ-ment. They are extremely sensitive to temperature and can die when temperatures reach only 78°F to 85°F (25.6°C to 29.5°C) (IFAW, 2012).

Though the exact impact of climate change on India's natural resources is yet to be studied in detail, pioneering studies show that endemic mammals like the Nilgiri tahr face an increased risk of extinction (Sukumar *et al.,* 1995). Further, there are indicative reports of certain species (e.g., Black-and rufous flycatcher (*Ficedula nigrorufa*) shifting their lower limits of distribution to higher reaches, and sporadic dying of patches of Shola forests with the rise in ambient surface temperatures.

The arctic fox lives in the open tundra, and preys on lemmings and voles that burrow underground. Mild winters and melting snow reduce the lemming and vole population by causing their burrows to collapse, thus limiting the arctic fox's major food source. As Arctic temperatures have risen, the red fox has expanded its range into the tundra, preying on the arctic fox and competing with it for food and habitat. And as the tundra's climate warms, experts predict it will be replaced by forest, which is an unsuitable habitat for the arctic fox. But shifting ranges is not always a problem—it can create opportunity, too. The red fox, for example, is taking advantage of the warming tundra to extend its range northwards. Anytime a new species enters a region, changes are inevitable. New species can bring parasites and diseases to which the resident species have no resistance. New species are also likely to disrupt the food web, either by predation or through increased competition (IFAW, 2012).

Sex determination in Reptiles : Temperature-dependent sex determination (TSD) is a type of environmental sex determination in which the temperatures experienced during embryonic development determine the sex of the offspring. It is most prevalent and common among amniote vertebrates that are classified under the reptile class. TSD differs from the chromosomalsex-determination systems common among vertebrates.

The eggs are affected by the temperature at which they are incubated during the middle one-third of embryonic development. This critical period of incubation is known as the thermosensitive period (TSP).

The warming of the habitats of species exhibiting TSD are beginning to affect their behavior and may soon start affecting their physiology. Many species begun to nest earlier and earlier in the year to preserve the sex ratio. It is likely that climate change will outpace the ability of many animals to adapt, and many will likely go extinct.

The following is a list of ten concerns related to climate change for nature and species. These threats are often interconnected and can exacerbate the many other exist-ing threats to wildlife such as habitat loss and fragmentation, invasive species, and disease.

- ✓ **Ocean Acidification:** We can only blame ourselves for the 30% drop in the pH of oceans—they absorb nearly a third of the carbon released into the atmosphere through human activity. This acidification renders some crustaceans and coral unable produce their protective shells and skeletons. Coral reefs, which serve as habitat for thousands of marine species, are being destroyed by bleaching due to ocean acidification. This destruction of marine life is a threat to the entire ecosystem humans included.

- ✓ **Extreme weather events:** Massive heat waves and drought have already grown more prevalent across the globe, expected to become more severe if the warming trend continues. In drought areas, habitats are altered, and plants and forests suffer from the lack of water. Increased wildfire activity due to hot, dry conditions poses a risk for safety of wildlife. It destroys important wildlife habitats, like the nesting habitat for Mexican spotted owls and forest habitat of endangered Amur tigers and critically endangered Amur leopards in Russia. Stronger and more frequent storms affect the distribution and concentration of the low links on the marine food chain—plankton and krill—thus having a domino effect on many ocean species.

- ✓ **Melting Sea Ice:** Arctic temperatures are rising twice as quickly of the rest of the world and sea ice is melting at an alarming rate. Some of the world's iconic species like polar bears, ringed seals, emperor penguins, and beluga whales all experience distinct pressures due to melting sea ice. For these and other species, disappearing ice disrupts the food chain, hunting habits, reproduction, protection from predators, and the ability to travel long distances—in other words, the foundations of their existence.

- ✓ **Sea-Level Rise:** Coastal wetlands are among the most productive of all natural ecosystems (Day *et al.*, 1989) and so the impacts of climate change will be extremely important in coastal regions and have ramifications far beyond them. In addition to the effects of rising temperatures and changes in rainfall, animals and plants in coastal habitats face another threat from climate change: rising sea level. This is due to a combination of melting polar ice caps, ice sheets and montane glaciers coupled with thermal expansion, wherein warm water occupies a greater volume than cold water. The IPCC predicts that in the next century, average sea level will rise by 0.18–0.59 m compared to the 1980–1999 levels (Parry *et al.*, 2007). Other climate models go even further, with estimates of 0.5–1.4 m – a rise that would inundate many low-lying areas. Human population and development pressure is in many cases likely to prevent coastal habitats from moving inland, thus leading to net habitat loss.

Such changes will have immediate impacts on many wildlife species (e.g. Michener *et al.*, 1997). Sea turtle populations are likely to be hit as their nesting beaches are inundated. It is predicted that a rise in sea level of 0.5 m will result in the loss of 32 percent of sea turtle nesting grounds (Fischlin *et al.,* 2007). Mangrove forests would seem to be preadapted to inundation, as they thrive in coastal locations below the high tide where their stilt roots are submerged in saline water on a daily basis. They cannot, however, survive permanent submersion due to rising sea levels, and mangrove die-off has been reported from several locations (e.g. Ellison, 1993).

The Sundarbans is the largest natural low-lying mangrove ecosystem in the world, distributed over 10 000 square kilometres. The sea level rise recorded over the past 40 years is responsible for the loss of 28 percent of the mangrove ecosystem. Modelling suggests that up to 96 percent of suitable tiger habitat in the Sundarbans could be lost in the next 50–90 years (Loucks *et al.*, 2010).

✓ **Disease and Pests:** Not only does climate change affect disease in human populations, it also alters the disease behavior in animals as well. The devastating amphibian disease chytrid fungus, likely exacerbated by warmer temperatures, has left many amphibian populations dwindling or extinct. Seasonal pests, like bark beetles in the US, breed longer in warmer weather and thirsty, drought-affected trees are more susceptible to infestation.

Temperatures in the Himalayan ecosystem are increasing at a rate of 0.9 °C annually, which is considerably higher than the global average of 0.7 °C per decade. Changes in the For example, mosquito nets are now needed in Lhasa, the administrative capital of the Tibet Autonomous Region of China. Residents of the city, located 3 490 meters above sea level, have reported seeing mosquitoes for the first time ever. There are similar reports of flies at Mount Everest base camp in Nepal. The presence of these insects suggests the possible spread of vector-borne diseases, such as malaria and dengue fever, to areas where cooler temperatures previously protected people from these threats (FAO, 2012).

✓ **Range Shift:** Ecological communities of plant and animal species—called "biomes"—are shifting as the planet warms. Some species are able to adapt and move while others cannot, and these will disappear with their disappearing habitat.

In the Mandakini Valley of northern India, scientists report that the oak forests have been invaded by pine trees (between 1 000 and 1 600 m), particularly on south-facing slopes. This phenomenon can also be observed in many other valleys of the region. Many sources of water, such as springs, have dried up because of the disappearing oak trees and invading pines (FAO, 2012).

- ✓ **New Species Interactions:** The climate-induced variation of species' range and related biome shifts cause previously unacquainted species to come into contact with each other. This results in competition for resources and changes in the way predators interact with their prey. For example, red foxes have moved northward toward a warming tundra and compete for prey with native Arctic foxes.

- ✓ **Invasive Species:** Climate change and invasive species are two major threats to biodiversity. Put them together and the repercussions are projected to be widespread. Climate change will provide new ways for invasive species to encroach on new territory. Natural disasters like storm surges and high winds, which increase in number and severity as the earth warms, spread non-native plants and insects to new territories. For example, the winds of the 2005 hurricane season likely introduced cactus moths to Mexico, where their presence threatens endemic cactus species.

  Virtually all ecosystems worldwide have suffered invasion by the main taxonomic groups including India The major invasive alien plant species include *Lantana camara, Eupatorium odoratum, Eupatorium adenophorum, Parthenium hysterophorus, Ageratum conyzoides, Mikania micrantha, Prosopis juliflora* and *Cytisus scoparius*.

- ✓ **Interrupted Seasonal Cycles:** So many species are dependent upon climate to guide the patterns of their lives—like mating, reproduction, hibernation, and migration, to name a few. As these patterns shift to reflect changing climate, it causes a ripple effect and hampers the health of the entire ecosystem. The altered timing of animal behaviors that are guided by weather—such as migration by birds, hibernation for bears, bats, and even alligators—will result in mismatched timing between species and their food sources. For example, caribou migration patterns have been disrupted by an earlier flowering season of their plant food source, leading to food shortage late in the season and depleted number of offspring.

  Indian agriculture normally referred to as a "gamble with monsoon" would become even more to weather behaviour vulnerable. With lesser precipitation and increased evapotranspiration, survival and productivity of agri-horticultural crops would become a serious problem. The coastal soil and aquifers would become salinized and staple food crops like paddy would come under severe stress. With every 1°C rise in temperature, yield of rice and wheat will decrease. A rise in sea water temperature will affect mortality of fish and their geographical distribution (Swaminatha and Keshvan , 2012).

- ✓ **Changes in Human-Nature Interactions:** Melting sea ice opens the Arctic for oil drilling, bringing ships into previously untouched territory of Pacific walruses. Expansion of agriculture and the need for water will lead humans to infringe on native wetlands, destroying habitat of countless plant and animal species. Increased drought activity will force koalas out of the safety of eucalyptus trees in search of water, exposing them to risk of death from road traffic.

Conclusion

There is a growing realization among decision-makers that biodiversity is not an optional bonus in human affairs, but the very foundation of our existence. Moreover, biodiversity conservation tailored to changing climatic conditions is not only necessary to help species and habitats to adapt to change, but such action is also likely to mitigate climate change (FAO, 2012). In terms of agriculture, there is a need for climate resilient farming systems. Climate literacy should be spread and a cadre of Community Climate Risk Managers should be formed in villages. The calamity of climate change should be converted into an opportunity for developing and spreading climate resilient farming techniques and systems (Swaminathan and Keshvan, 2012).

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Crop water requirement

It is essential to know the water requirement of a crop which is the total quantity of water required from its sowing time up to harvest. Naturally different crops may have different water requirements at different places of the same country, depending upon the climate, type of soil, method of cultivation, effective rain etc.

The total water required for crop growth is not uniformly distributed over its entire life span which is also called crop period. Actually, the watering stops same time before harvest and the time duration from the first irrigation during sowing up to the last before harvest is called base period. Though crop period is slightly more than the base period, they do not differ from practical purposes. Figure 1 indicates the relative usage of water for a typical crop during its entire growth period.

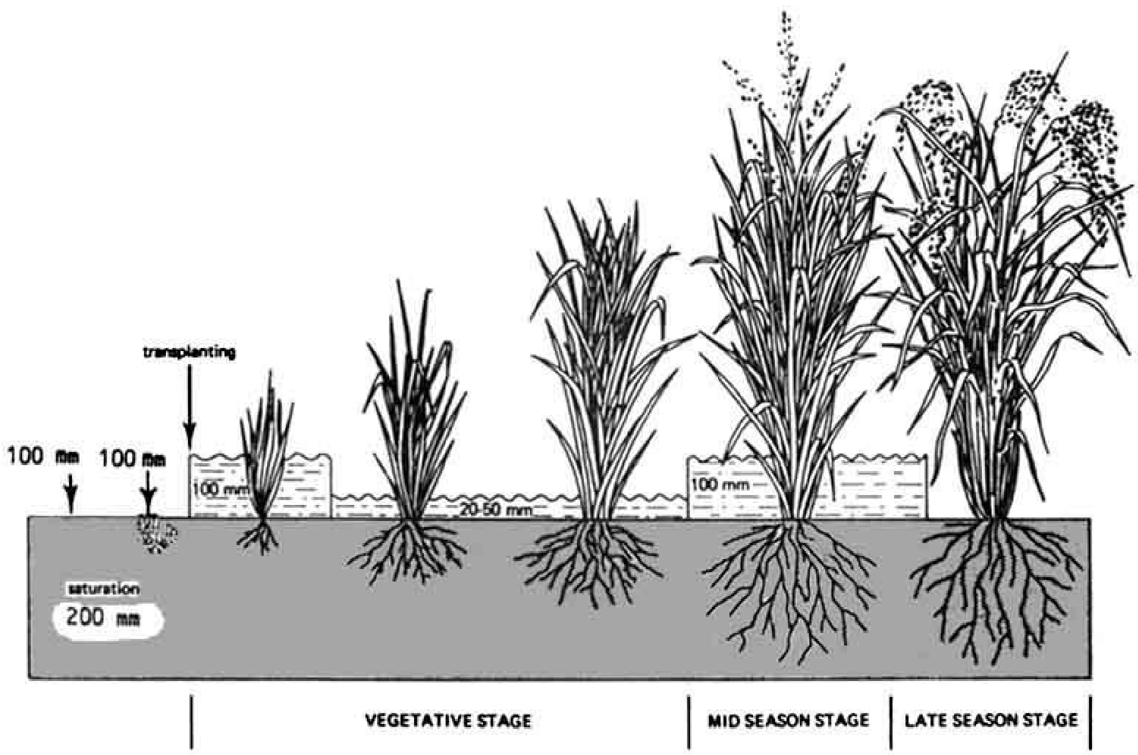


FIGURE 1. Variation in the requirement of water for paddy with stage of growth
(Image courtesy: Food and Agriculture Organisation, FAO)

Sometimes, in the initial stages before the crop is sown, the land is very dry. In such cases, the soil is moistened with water as it helps in sowing the crops. Thisis known as ***paleo*** irrigation. A term ***kor*** watering is used to describe the watering given to a crop when the plants are still young. It is usually the maximum single watering required, and other water ings are done at usual intervals.

The total depth of water required to raise a crop over a unit area of land is usuallycalled ***delta***. Some typical values of delta for common crops in some regions of India are as follows:

Rice

- 1000mm to 1500mm for heavy soils or high water table
- 1500mm to 2000mm for medium soils
- 2000 to 2500 for light soils or deep water table
- 1600mm for upland conditions

Wheat

- 250mm to 400mm in northern India
- 500mm to 600mm in Central India
- Barley: 450mm

Maize

- 100mm during rainy season
- 500mm during winter season
- 900mm during summer season
- Cotton: 400 – 500mm

Sugarcane

- 1400mm to 1500mm in Bihar
- 1600mm to 1700mm in Andhra Pradesh
- 1700mm to 1800mm in Punjab
- 2200mm to 2400mm in Madhya Pradesh
- 2800mm to 3000mm in Maharashtra

This information has been gathered from the ***Handbook of Agriculture*** (fifthedition, 2000) published by the Indian Council of Agricultural Research.

Duty of water

The term ***duty*** means the area of land that can be irrigated with unit volume of irrigation water. Quantitatively, duty is defined as the area of land expressed in hectares that can be irrigated with unit discharge, that is, 1 cumec flowing throughout the base period, expressed in days.

The duty of irrigation water depends upon a number of factors; some of theimportant ones are as follows:

- **Type of crop:** As different crops require different amount of water for maturity, duties are also required. The duty would vary inversely as the water requirement of crop.

- **Climate season and type of soil:** Some water applied to the field is expected to be lost through evaporation and deep percolation.

Evaporation loss has a direct bearing on the prevalent climate and percolation may be during drier seasons when the water table is low and soil is also dry. Percolation loss would be more for sandy soils than silty orclayey soils.

- **Efficiency of cultivation methods:** If the tillage and methods of water application are faulty and less efficient, then the amount of water actually reaching the plant roots would be less. Hence, for proper crop growthmore water would be required than an equivalent efficient system. Also, if the water is conveyed over long distances through field channels before being finally applied to the field, then also the duty will rise due to the losses taking place in the channels.

Crop growing seasons in India

Each crop has its own sowing and harvesting seasons and it is important to have a knowledge of this which may help to decide the total water demand in a field having mixed crops.

In India, the northern and north eastern regions have two distinct croppingseasons. The first coinciding mostly with the South western monsoon is called ***kharif*** , which spans mostly from July to October. The other, called ***rabi***, spans generally over October to March. The summer season crops or zaid crops are planted sometime between April and June. In southern part of India, there is no such distinct season, but each region has its own classification of seasons.

Generally, the kharif is characterized by a gradual fall in temperature, more numerous cloudy days, low intensity, high relative humidity and cyclonic weather. During Rabi, there is a gradual rise in temperature, bright sunshine, near absence of cloud days, and a lower relative humidity.

The following table indicates some the regional cropping calendars in India.

State	Season	Local name	Growing month
Andhra Pradesh	Kharif	Serva or Abi	July – December
	Rabi	Dalwa or Tabi	December – April
	Summer	In limited areas	March/April – June
Assam	Pre-monsoon	Ahu	Mar/April– June/july
	-	Sali	June/July- Nov/Dec
	-	Boro	Nov - May
Bihar	Summer	-	March – July/Aug
	Autumn	-	May/June–

			Sept/Oct
	Winter	-	June – Nov/Dec
Gujarat	Kharif	Chomasu Dangar	June/July-Oct/Nov
	-	Unala Dangar	Dec – June
Haryana	Kharif	-	May/June–Sept/Oct
Himachal Pradesh	Kharif	-	June/July-Sept/Oct
Jammu & Kashmir	-	-	Jammu: June-Nov Kashmir: Last week of April - October
Karnataka	Kharif	-	June – Dec
	Summer	-	Jan-May/June
Kerala	first crop	Virippu	April-May/Sept-Oct
	Second crop	Mundakan	Sept-Oct/Dec-Jan
	Third crop	Punja	Dec/Jan-Mar/April
Madhya Pradesh	Kharif	-	June/July-Dec
Maharashtra	Kharif	-	June/July-Dec
Manipur	Kharif	-	Mar/June-Sept/Oct
Meghalaya	Kharif	-	May/June-Aug/Sept
	Rabi	-	----------------
Nagaland	Kharif	-	May/June-Nov/Dec
	Rabi	-	Feb - May
Orissa	-	Sarad	June-Dec
	-	Dalua	Dec-April
	-	Beali (short Duration)	April/May –Sept (Only in uplands)
Punjab	Kharif	-	May – Nov
Rajasthan	Kharif	-	June/July-Sept/oct
Tamil Nadu	-	Navarai	Jan-April
	-	Sornavari	April – July
	-	Kar or Kuruvai	June – August
	-	Samba	June/July-Nov/Dec
	-	Thaladi or Pishanam	Sept/Oct-Feb/March
Uttar Pradesh	Kharif	-	June – Oct
West Bengal	Pre-Kharif	Aus	April-Sept
	Kharif	Aman	June-Dec
	Summer	Boro	End Nov-Mid June

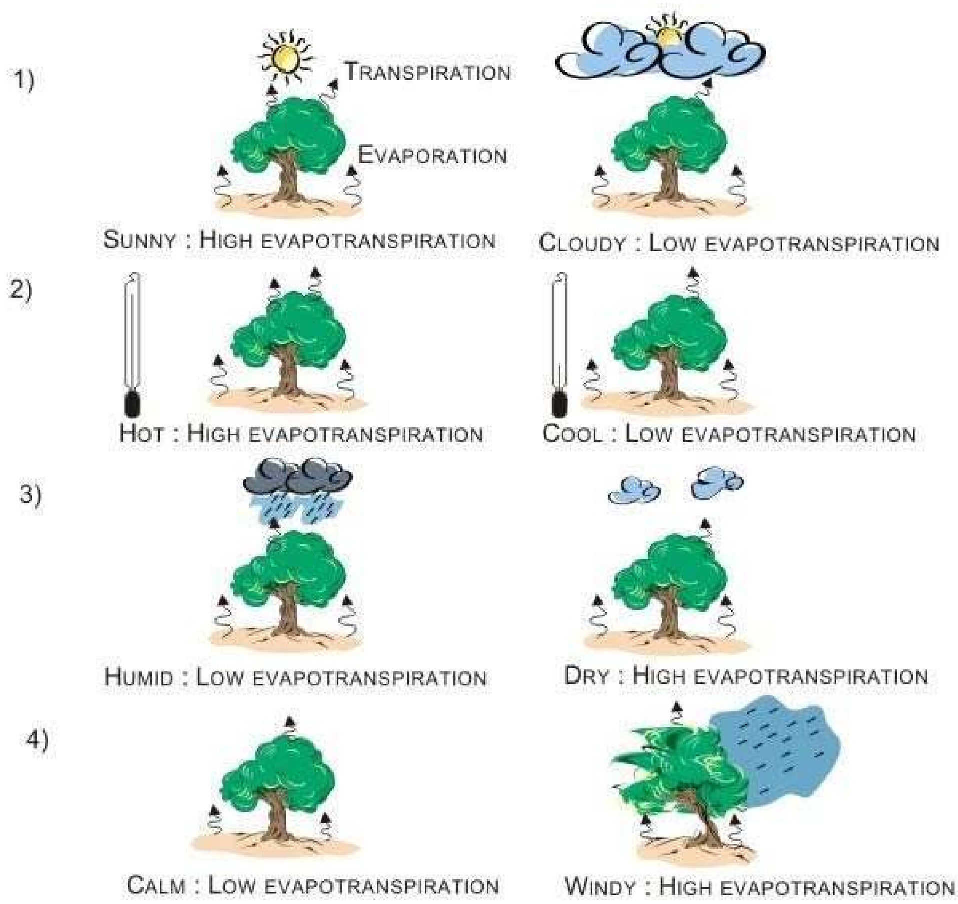
Variation of crop water requirement

The total water need for various plants, known as delta, has been discussed earlier. However, in planning the supply of irrigation water to a field crop, it is essential to estimate the water requirement of each plot of land growing a crop or crops at any point of time. This may be done by studying the dynamic interaction between a crop and the prevalent climate and the consequent water requirement.The demand would, naturally be also dependent on the type of crop and its stageof growth. Plant roots extract water from the soil. Most of this water doesn't remain in the plant, but escapes to the atmosphere as vapour through the plants leaves and stems, a process which is called ***transpiration*** and occurs mostly during daytime. The water on the soil surface as well as the water attaching to the leaves and stem of a plant during a rainfall also is lost to the atmosphere by evaporation. Hence, the water need of a crop consists of transpiration plusevaporation, together called ***evapotranspiration***.

The effect of the major climatic factors on crop water needs may be summarized as follows:

- Sunshine
- Temperature
- Humidity
- Wind speed

The variation of evapotranspiration upon these factors is illustrated in Figure 2.



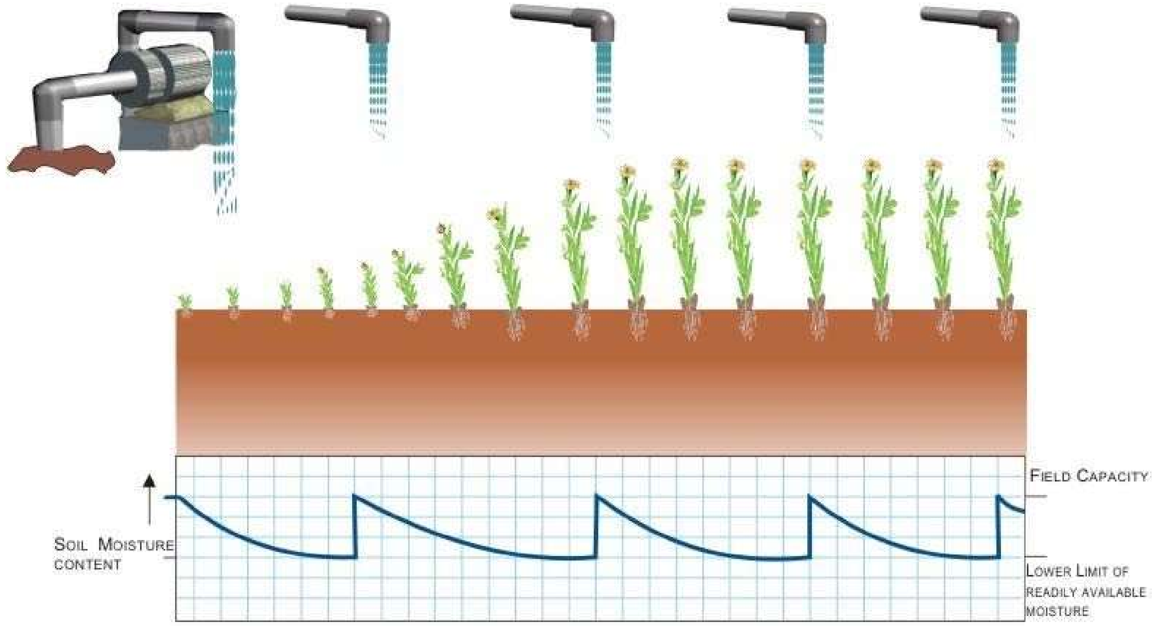
Crop	Variety	Crop growth stage				Total growth period
Cabbage/Carrot	Short duration	20 days	25 days	60 days	15 days	120 days
	Long duration	25 days	30 days	65 days	20 days	140 days
	K_C	0.45	0.75	1.05	0.9	
Cotton/Fiax	Short duration	30 days	50 days	55 days	45 days	180
	Long duration	30 days	50 days	65 days	50 days	195
	Kc	0.45	0.75	1.15	0.75	
Lentil/Pulses	Short duration	20 days	30 days	60 days	40 days	150
	Long duration	25 days	35 days	70 days	40 days	170
	K_C	0.45	0.75	1.1	0.5	
	Short	20	25	25	10	80

	duration					
Maize	Long duration	20	30	50	10	110
	Kc	0.4	0.8	1.15	1.0	
Onion (dry)	Short duration	15	25	70	40	150
	Long duration	20	35	110	45	210
	Kc	0.5	0.75	1.05	0.85	
Potato	Short duration	25	30	30	20	105
	Long duration	30	35	50	30	145
	Kc	0.45	0.75	1.15	0.85	

Application interval of irrigation water

The water need of a crop is usually expressed as mm/day, mm/month or mm/season, where season means the crop growing period. Whatever be the water need, it need not be applied each day. A larger amount of water may be applied once in a few days and it gets stored in the crop root zone, from where the plant keeps on extracting water.

Soon after irrigation, when the soil is saturated, up to the field capacity, the extraction of water from the soil by the plants is at the peak. This rate of water withdrawal decreases as the soil moisture depletes (Figure 3).



A stage is reached, in the moisture content of the soil, below which the plant is stressed to extract and unless the soil moisture is increased by application of water, the plant production would decrease. The difference of moisture content between field capacity (the maximum content of available water) and the lowest allowable moisture content is called the optimum soil water.

Naturally, a soil with greater water retentive capacity serves as a bigger water reservoir for crops and supply of irrigation can be delayed. Consequently, frequency of irrigation is lower and interval of irrigation is longer in heavier soils (clayey soils) and in soils with good organic content and low content of soluble salts.

Climate Change And Its Implications
(CCI)

Dr. Raji P

Lecture-18, 19 & 20


Indian
Agriculture

Share to total economy of India

2019-20	18.4%
2020-21	20.2%

Classification of crops

- Field crops: crop other than fruit and vegetables

wheat

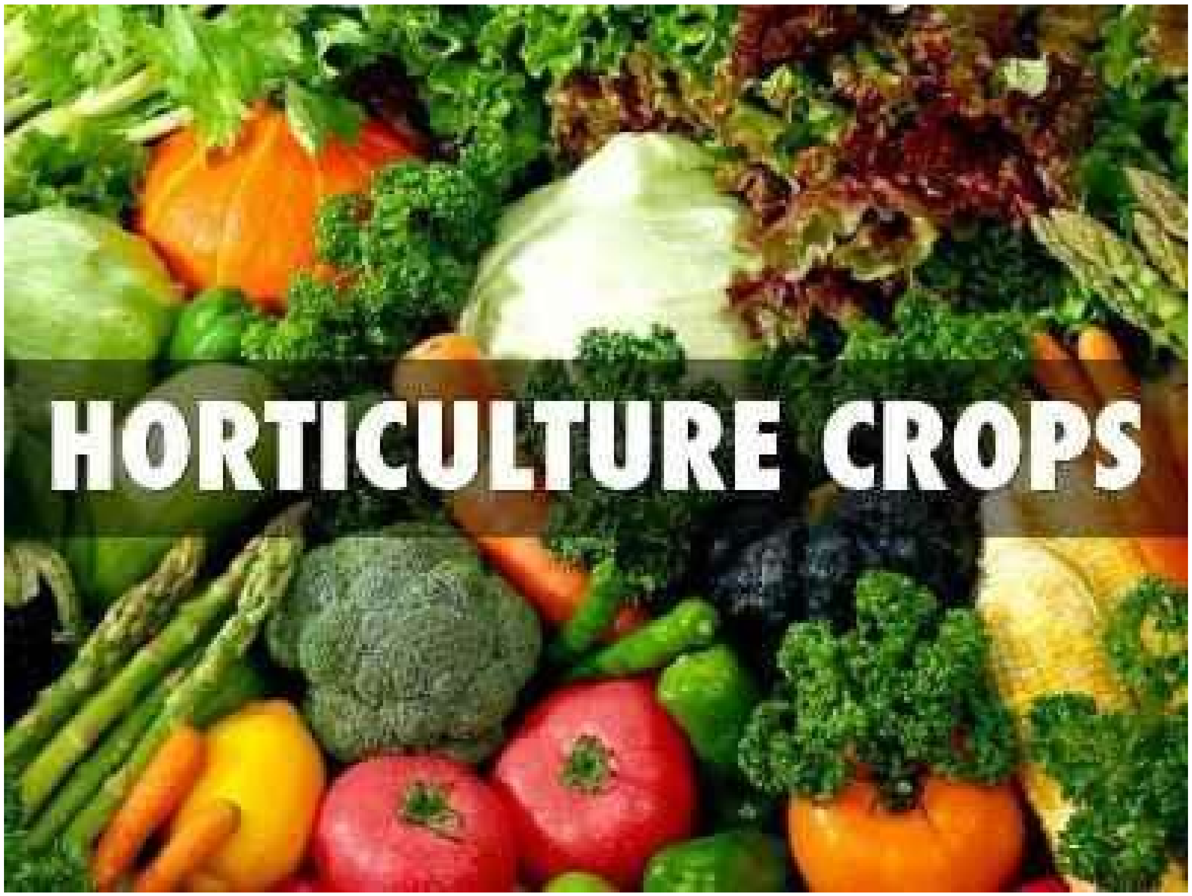
rice

barely

- Commercial crops/cash crops

- Oil seed crops:

- Horticultural crops:



- Tree, bush and perennial vine fruits

- Perennial bush and tree nuts

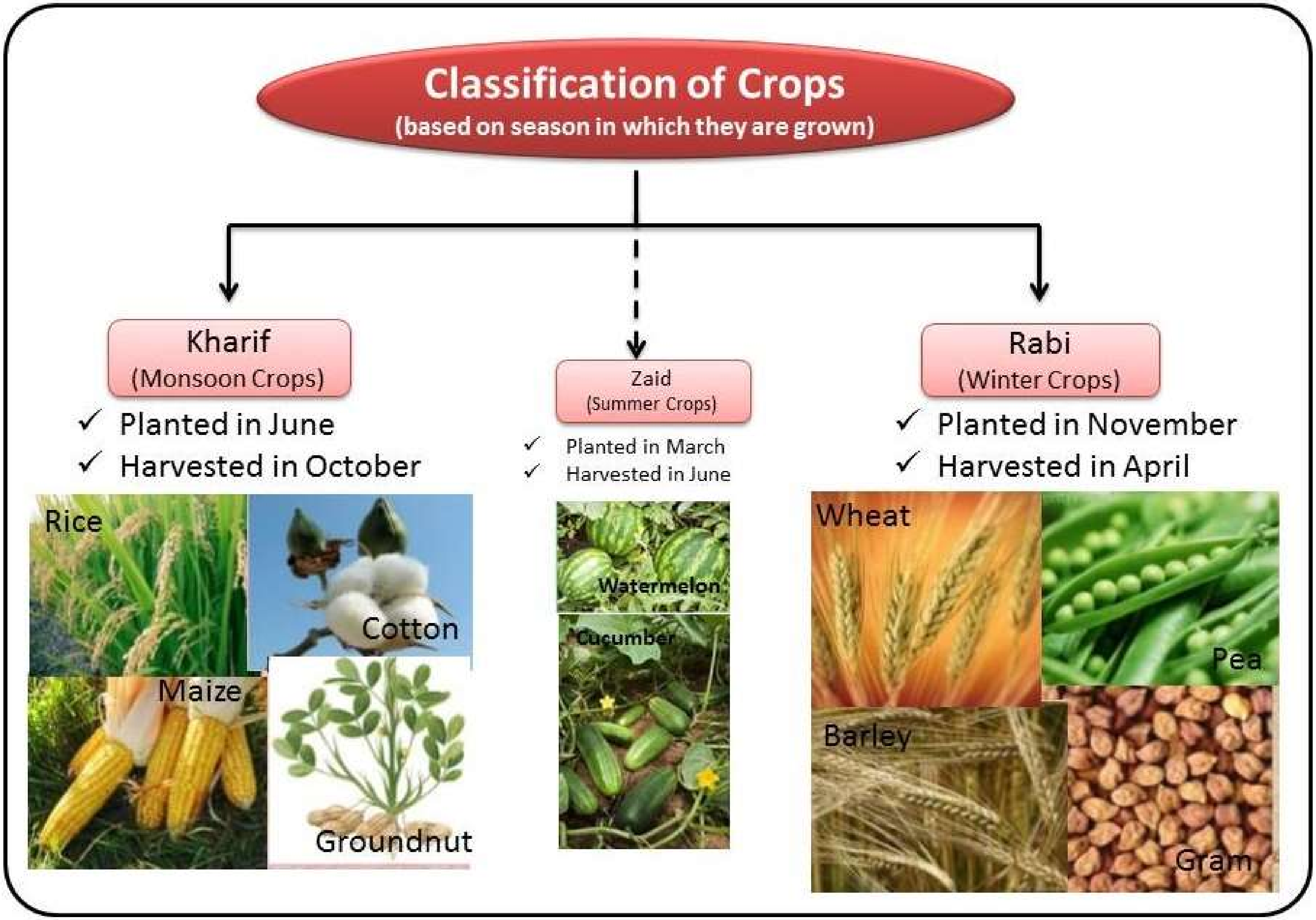
- Vegetables (roots, tubers, shoots, stems, leaves, fruits and flowers of edible and mainly annual plants)

- Trees, shrubs, turf and ornamental grasses propagated and produced in nurseries for use in landscaping or for establishing fruit orchards or other crop production units

- Plantation crops:

Coffee, tea, rubber, cocnut, banana, tobacco

Cropping seasons in India



State	Season	Local name	Growing month
Andhra Pradesh	Kharif	Serva or Abi	July – December
	Rabi	Dalwa or Tabi	December – April
	Summer	In limited areas	March/April – June
Assam	Pre-monsoon	Ahu	Mar/April– June/july
	-	Sali	June/July- Nov/Dec
	-	Boro	Nov - May
Bihar	Summer	-	March – July/Aug
	Autumn	-	May/June–

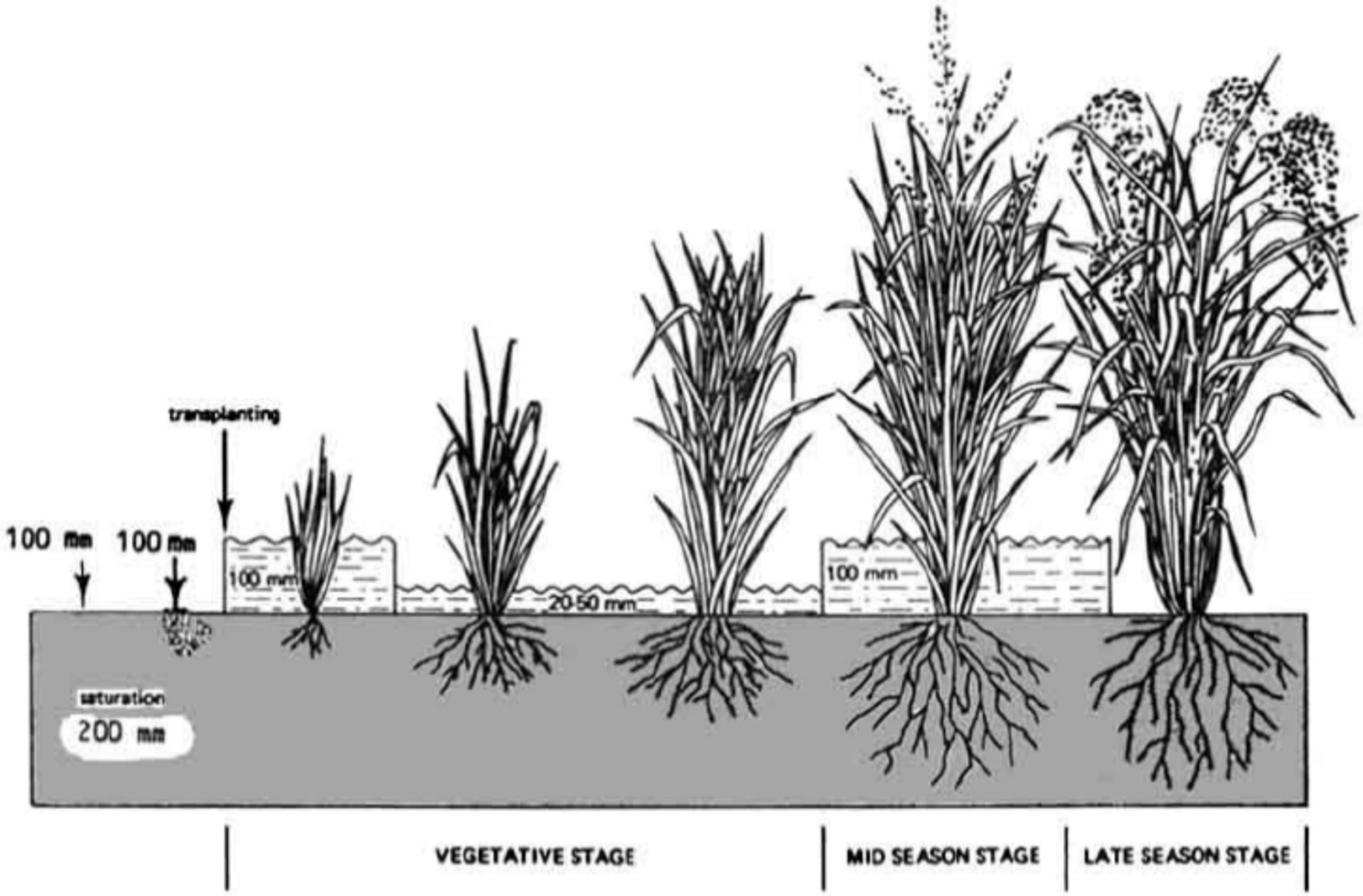
			Sept/Oct
	Winter	-	June – Nov/Dec
Gujarat	Kharif	Chomasu Dangar	June/July-Oct/Nov
	-	Unala Dangar	Dec – June
Haryana	Kharif	-	May/June–Sept/Oct
Himachal Pradesh	Kharif	-	June/July-Sept/Oct
Jammu & Kashmir	-	-	Jammu: June-Nov Kashmir: Last week of April - October
Karnataka	Kharif	-	June – Dec
	Summer	-	Jan-May/June
Kerala	first crop	Virippu	April-May/Sept-Oct
	Second crop	Mundakan	Sept-Oct/Dec-Jan
	Third crop	Punja	Dec/Jan-Mar/April
Madhya Pradesh	Kharif	-	June/July-Dec
Maharashtra	Kharif	-	June/July-Dec
Manipur	Kharif	-	Mar/June-Sept/Oct

Meghalaya	Kharif	-	May/June-Aug/Sept
	Rabi	-	----------------
Nagaland	Kharif	-	May/June-Nov/Dec
	Rabi	-	Feb - May
Orissa	-	Sarad	June-Dec
	-	Dalua	Dec-April
	-	Beali (short Duration)	April/May –Sept (Only in uplands)
Punjab	Kharif	-	May – Nov
Rajasthan	Kharif	-	June/July-Sept/oct

Tamil Nadu	-	Navarai	Jan-April
	-	Sornavari	April – July
	-	Kar or Kuruvai	June – August
	-	Samba	June/July-Nov/Dec
	-	Thaladi or Pishanam	Sept/Oct-Feb/March
Uttar Pradesh	Kharif	-	June – Oct
West Bengal	Pre-Kharif	Aus	April-Sept
	Kharif	Aman	June-Dec
	Summer	Boro	End Nov-Mid June

How climate influences agricultural production?

1. Crop water requirement



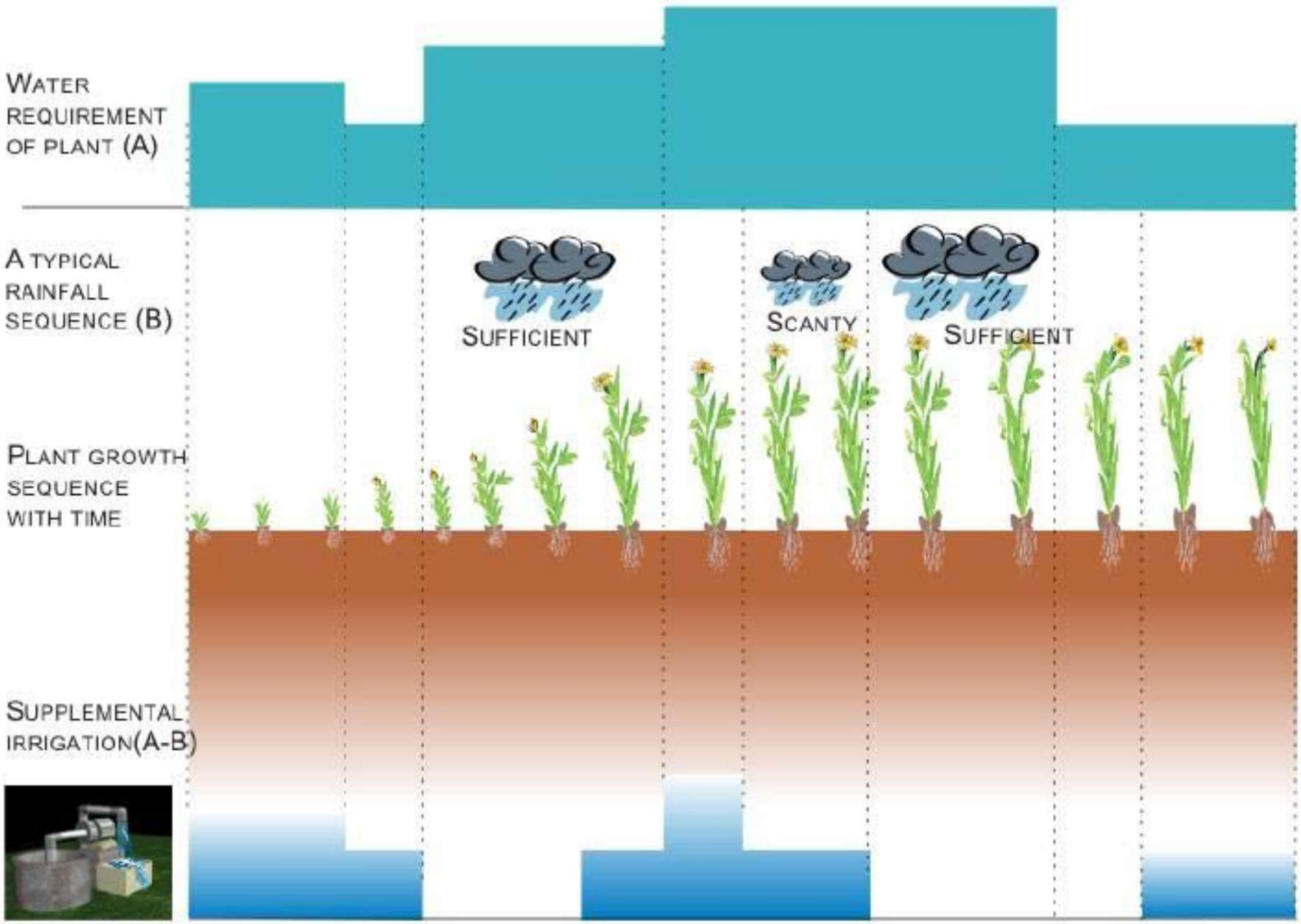
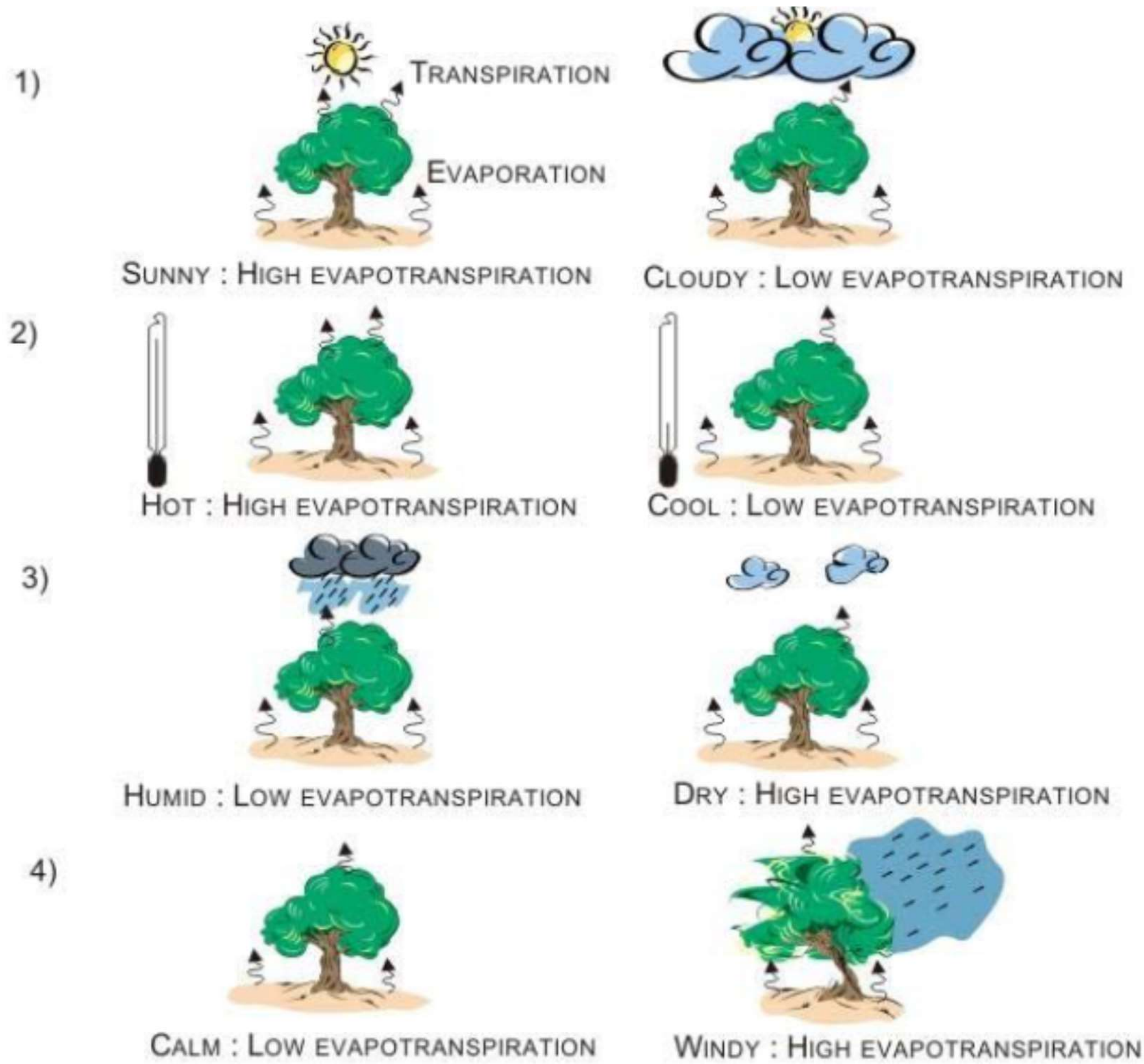


FIGURE 5 . Typical irrigation requirement of a crop and water provided naturally by rain or artificially by pumping

Major factors influencing irrigation requirement

- Sunshine
- Temperature
- Humidity
- Wind speed


1)
TRANSPIRATION
EVAPORATION
SUNNY : HIGH EVAPOTRANSPIRATION
CLOUDY : LOW EVAPOTRANSPIRATION
2)
HOT : HIGH EVAPOTRANSPIRATION
COOL : LOW EVAPOTRANSPIRATION
3)
HUMID : LOW EVAPOTRANSPIRATION
DRY : HIGH EVAPOTRANSPIRATION
4)
CALM : LOW EVAPOTRANSPIRATION
WINDY : HIGH EVAPOTRANSPIRATION

Estimating crop water requirement

CROPWAT (FAO model)

- CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO
- CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data
- The program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns
- Model can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.

Software

http://www.fao.org/land-water/databases-and-software/cropwat/en/

http://www.fao.org/3/X0490E/X0490E00.htm

CLIMWAT

CROPWAT

Impact of CC on CWR

- Saudi Arabia (Chowdhury et al., 2016): CWR might be increased in the range of 5.3–9.6% from 2011 to 2050 for the same level of crop productions. The increase in CWR was mainly due to the increase in temperature

Maize: 1.5%

Barley: 0.2%

Vegetables: 3.9%

Citrus: 1.5%

Grapes: 2%

- Thailand (Boonwichai et al., 2018): Temperature rises could increase crop water usage and higher rainfall alone may not be sufficient.
- IWR is expected to increase in the future.
- Rainfed rice yield may reduce by 14% under RCP4.5 scenario, and 10% under RCP8.5 scenario by 2080s.
- Due to the increment of crop water use and decrease in rice yield, CWP could reduce by 32% under RCP4.5 scenario, and 29% under RCP8.5 scenario by 2080s.

- Iraq (Salman et al., 2020): The comparison of CWD revealed an increase in agricultural water needs in the late period (1984–2013) compared to the early period (1961–1990) by 1.0–8.0, 1.0–14, 15–30, 14–27 and 0.0–10 mm for wheat, barley, millet, sorghum and potato, respectively

- USA (CA)-Hopmans and Maurer, 2008: Significant uncertainty in projected precipitation translates into uncertainty of future water supply, ranging from an increase of 10% to a decrease of 30% in 2100

- Gujarat, India (Parekh and Prajapati, 2013): Crop water requirement of all Hot Weather crops (Millet, Ground nut, Maize, Small vegetables and Tomato) in all future periods is increasing as compared to base period 2003-2009.

- Crop water requirement of Rabi crops (Wheat, Sorghum, Maize, Small Vegetables, Tomato, Gram and Cowpeas) shows negligible decrease in crop water requirement in the period 2011-2020 but all crops shows considerable increasing water requirement in the period 2021-2030 including the periods 2046-2065 and 2080-2099 as compared to base period 2003-2009.

2. Phenological shifts

- Phenology, or the timing of the annual cycles of plants and animals, is extremely sensitive to changes in climate

- Plants and animals may adjust the timing of certain phenological events, such as tree flowering or migration, based on changes in weather

- The majority of previous phenology studies have described phenology shifts in terms of thermal conditions
- Temperature has been proven to be the most significant factor in plant phenology
- It shows the highest relevance for plant phenology than other climatic factors such as sunshine, frost, and snowmelt
- Precipitation, which describes the moisture content of soil, also could be a factor that can affect plant phenology, especially in a dry environment

South Korea (Lee et al., 2020)

- The changes in the temperature and precipitation during the January–February–March period and the phenological shifts of all research species during 1920–2019 indicate that warm and dry spring weather advances the FFDs
- Moreover, the temperature has a greater impact on this phenological shift than precipitation. Earlier flowering species are more likely to advance their FFDs than later flowering species.
- The temporal asynchrony among plant species will become worse with climate change.

3. Geographical shift -MaxEnt

- Changes in suitable locations for their growth

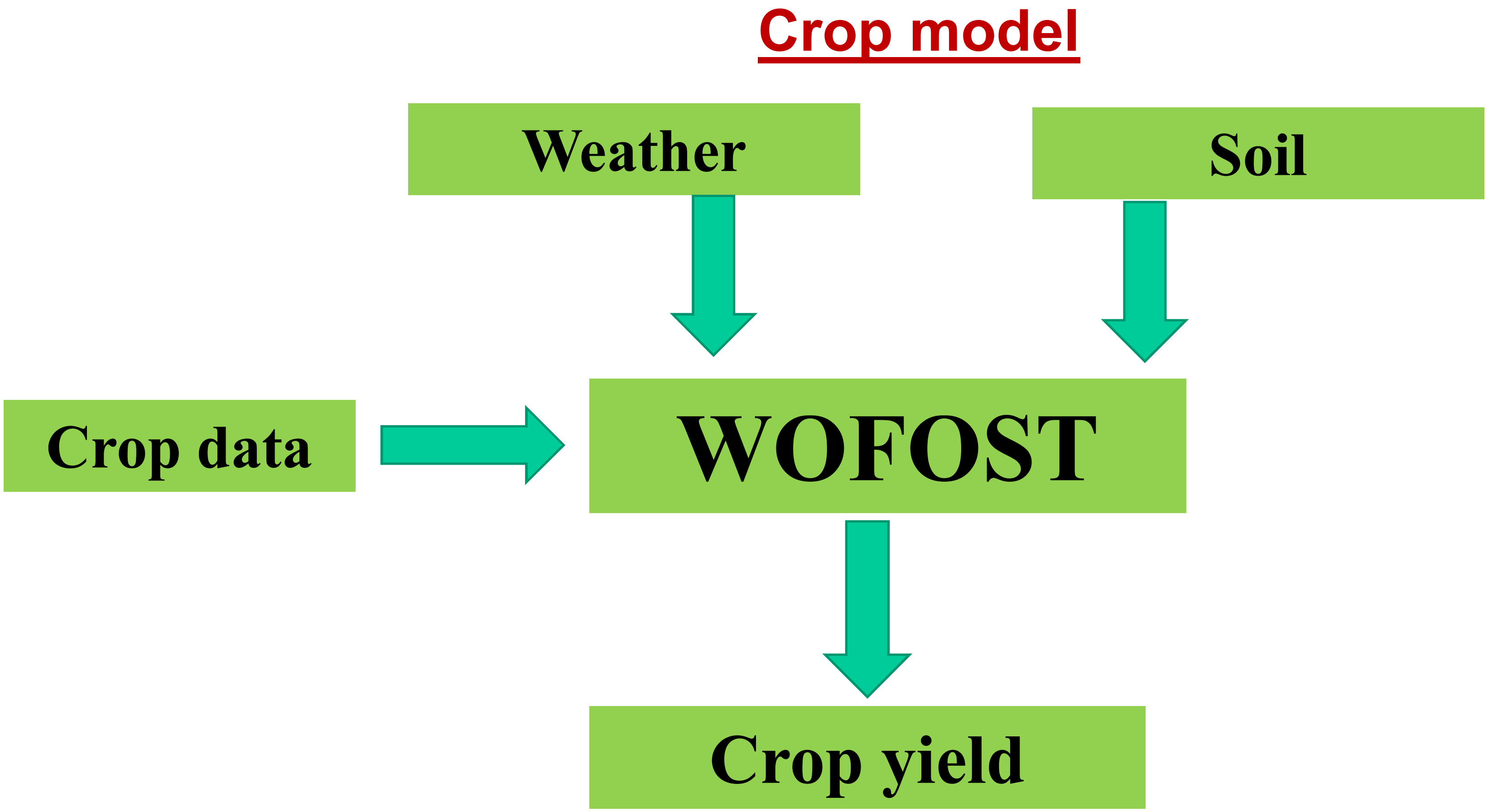
- Future geographical/climate suitability of rice in India (Tutorial)

Assignment-3

- Predict the future climate/geographical suitability of potato in India using the MaxEnt model.

- Submission date: **10.11.2021**

4. Yield variations/reductions

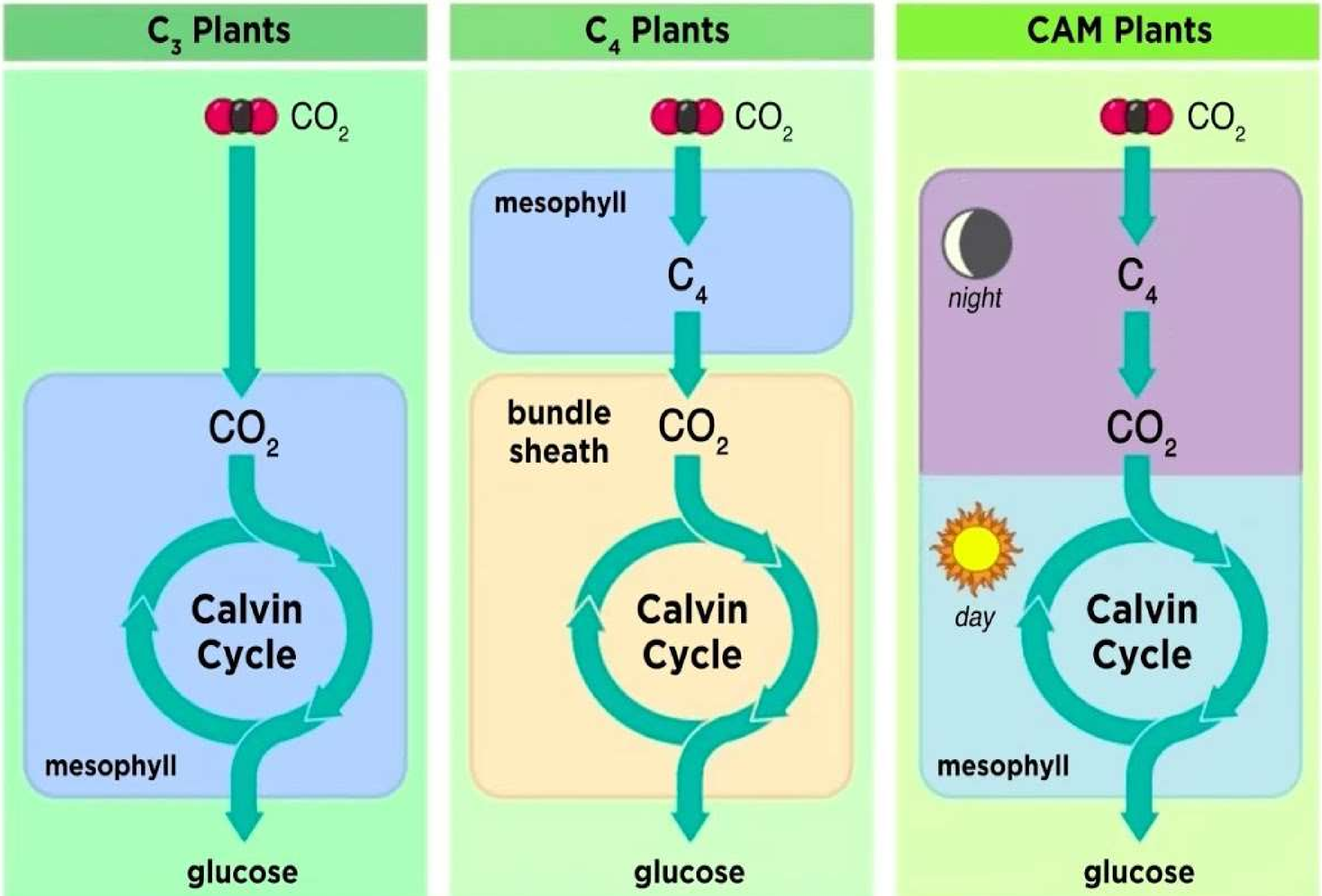


1. **Increased conc. of CO_2**:

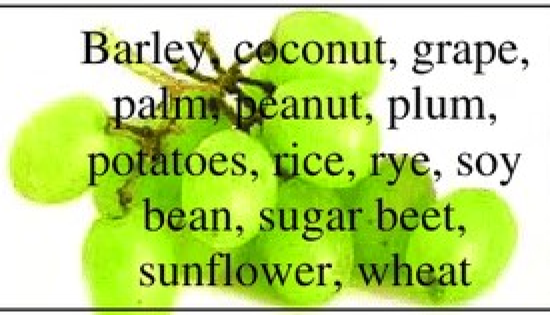
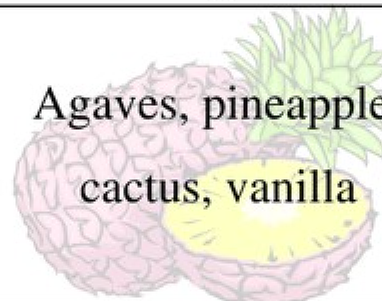
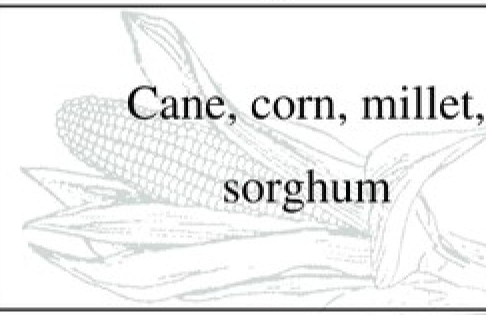
- A higher concentration of carbon dioxide in the atmosphere will have different effects on different crops

- In C_3 plants: the photosynthesis relies on the concentration of carbon dioxide that is naturally available in the atmosphere. A higher concentration of carbon dioxide in the atmosphere will have a small fertilizing effect on these crops, if all other factors remain favorable

- C_4 plants have the capacity to increase the carbon dioxide concentration within their leaves before the photosynthesis begins. This is why increased concentrations of carbon dioxide in the atmosphere will not provide benefits to C_4 plants under normal conditions



C_3 Plants
CO_2
CO_2
Calvin Cycle
mesophyll
glucose
C_4 Plants
CO_2
mesophyll
C_4
bundle sheath
CO_2
Calvin Cycle
glucose
CAM Plants
CO_2
night
C_4
CO_2
day
Calvin Cycle
mesophyll
glucose

C3 plants	*CAM plants*	*C4 plants*
 Barley, coconut, grape, palm, peanut, plum, potatoes, rice, rye, soy bean, sugar beet, sunflower, wheat	 Agaves, pineapple, cactus, vanilla	 Cane, corn, millet, sorghum

2. **Changes in temperature**:

- The increase in average temperature during the growing season typically causes plants to use more energy for respiration for their maintenance and less to support their growth

- With a 1°C increase in average temperatures, yields of the major food and cash crop species can decrease by 5 to 10 percent (Lobell and Field, 2007; Hatfield *et al*., 2009)

- With higher average temperatures plants also complete their growing cycle more rapidly (Hatfield *et al*., 2011)

- Higher nighttime temperatures may increase respiration at night causing declines in yield (e.g. rice) and flowering or reproduction (e.g. beans)

- Extremely high temperatures above 30°C can do permanent physical damage to plants and, when they exceed 37°C, can even damage seeds during storage

3. **Changes in precipitation**:

- The impact of changes in precipitation will be particularly marked when they are combined with temperature alterations that affect the crop's evaporative demands

- This may lead to different forms of moisture stress depending on the phenological stage the crop has reached

- The specific impacts of changes in precipitation regimes on crops vary significantly because around 80 percent of the cropped area is rainfed and produces 60 percent of world's food (Tubiello *et al*., 2007).

4. **Pests**:

- The distribution of insect pests is influenced by temperatures

- With global warming, insects, whose body temperature varies with the temperature of the surrounding environment are most likely to move pole-wards and to higher elevations (Bebber *et al*., 2013)

- Pest distribution will also respond to changes in cropping patterns to cope with climate change

Crop yield losses

- Future climate change could reduce yields in the short-run (2010–2039) by 4–9 per cent and in the long-run (2070–2099) due to lack of adaptation by about 25 per cent (Guiteras, 2009)

- The projected agriculture output loss by 2100 lies between 10–40 per cent in India (Aggarwal, 2008)

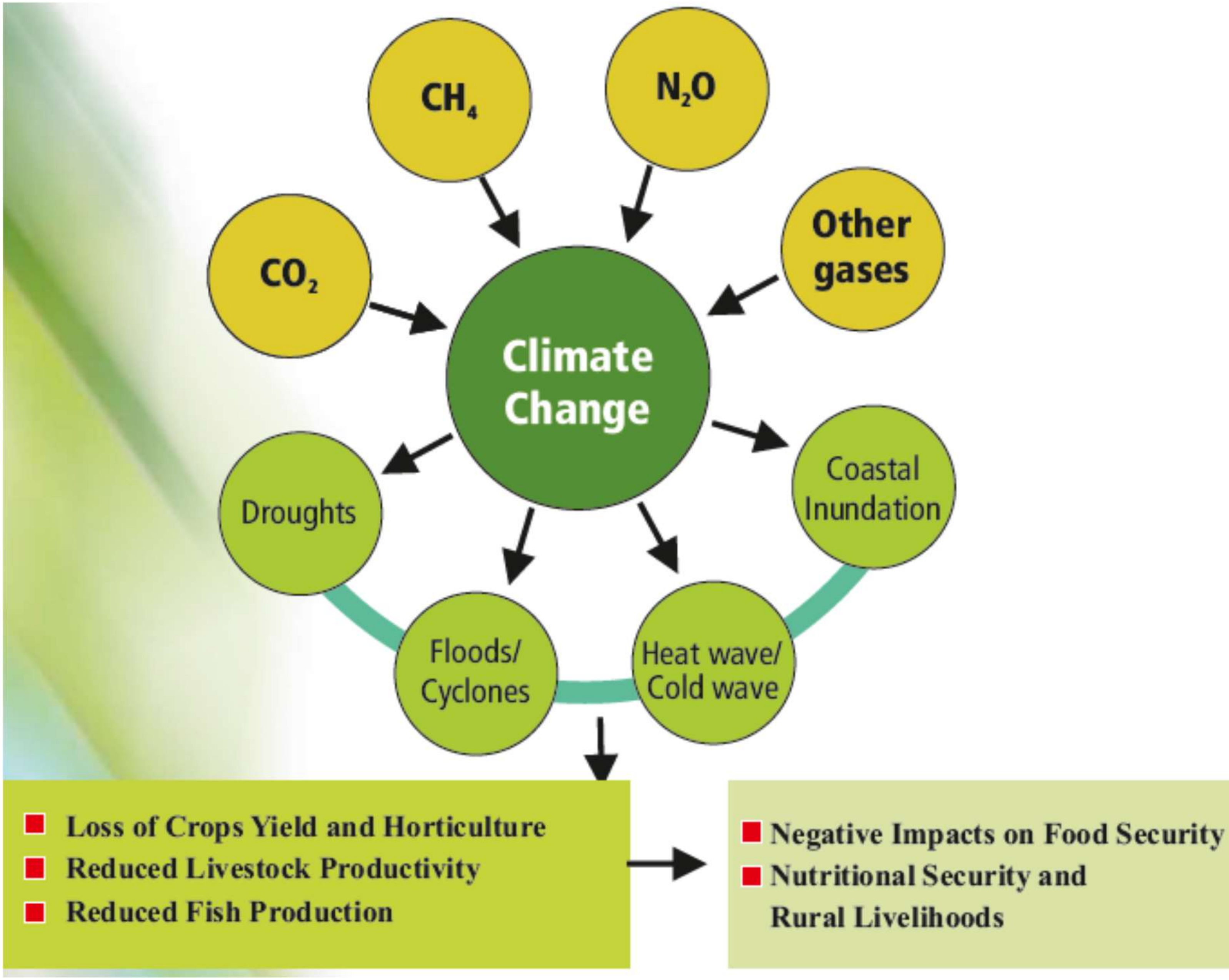
- Kumar and Parikh (2001) reported that the anticipated 2 °C upsurge in temperature and 7 per cent upturn in rainfall can diminish farm returns by 9 per cent

- Sanghi and Mendelsohn (2008) reported that net revenue of agriculture in India could drop by 4–26 per cent

Global crop yield losses

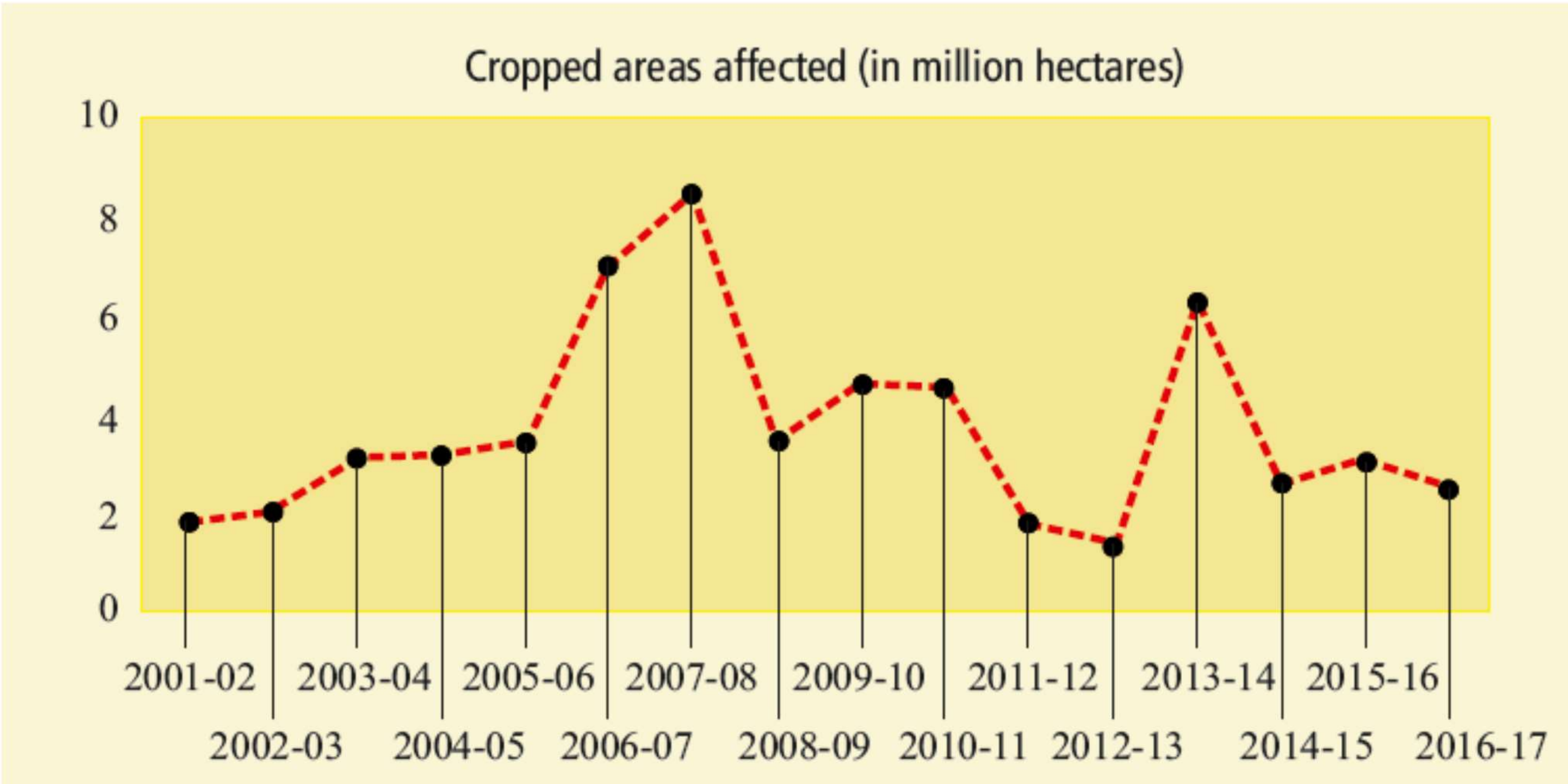
Scenario	Yield changes (%) due to temperature changes by the end of century				
	Wheat	Rice	Maize	Soybean	Mean
RCP2.6	-6.9 [-15.0, -1.4]	-3.3 [-9.2, 0.8]	-8.6 [-18.6, -1.8]	-3.6 [-11.2,1.7]	-5.6 [-14.4, -0.1]
RCP4.5	-11.4 [-21.7, -3.9]	-5.5 [-13.8, 1.0]	-14.2 [-27.9, -4.9]	-5.9 [-17.0, 3.1]	-9.2 [-21.2, -0.3]
RCP6.0	-14.0 [-25.7, -5.1]	-6.8 [-16.8, 1.3]	-17.4 [-33.1, -5.8]	-7.2 [-20.2, 3.6]	-11.3 [-25.6, 0.1]
RCP8.5	-22.4 [-40.2, -8.5]	-10.8 [-25.3, 2.4]	-27.8 [-50.4, -9.7]	-11.6 [-31.0, 6.0]	-18.2 [-38.6, -0.7]

Source: Chuang Zhao et al. PNAS 2017;114:35:9326-9331


CH_4
N_2O
CO_2
Other gases
Climate Change
Droughts
Coastal Inundation
Floods/ Cyclones
Heat wave/ Cold wave
Loss of Crops Yield and Horticulture
Reduced Livestock Productivity
Reduced Fish Production
Negative Impacts on Food Security
Nutritional Security and Rural Livelihoods

Economic losses in India due to climate change on agriculture

- Government of India's economic survey (2018) estimated that the annual loss of US$ 9-10 billion was due to the adverse effects of climate change



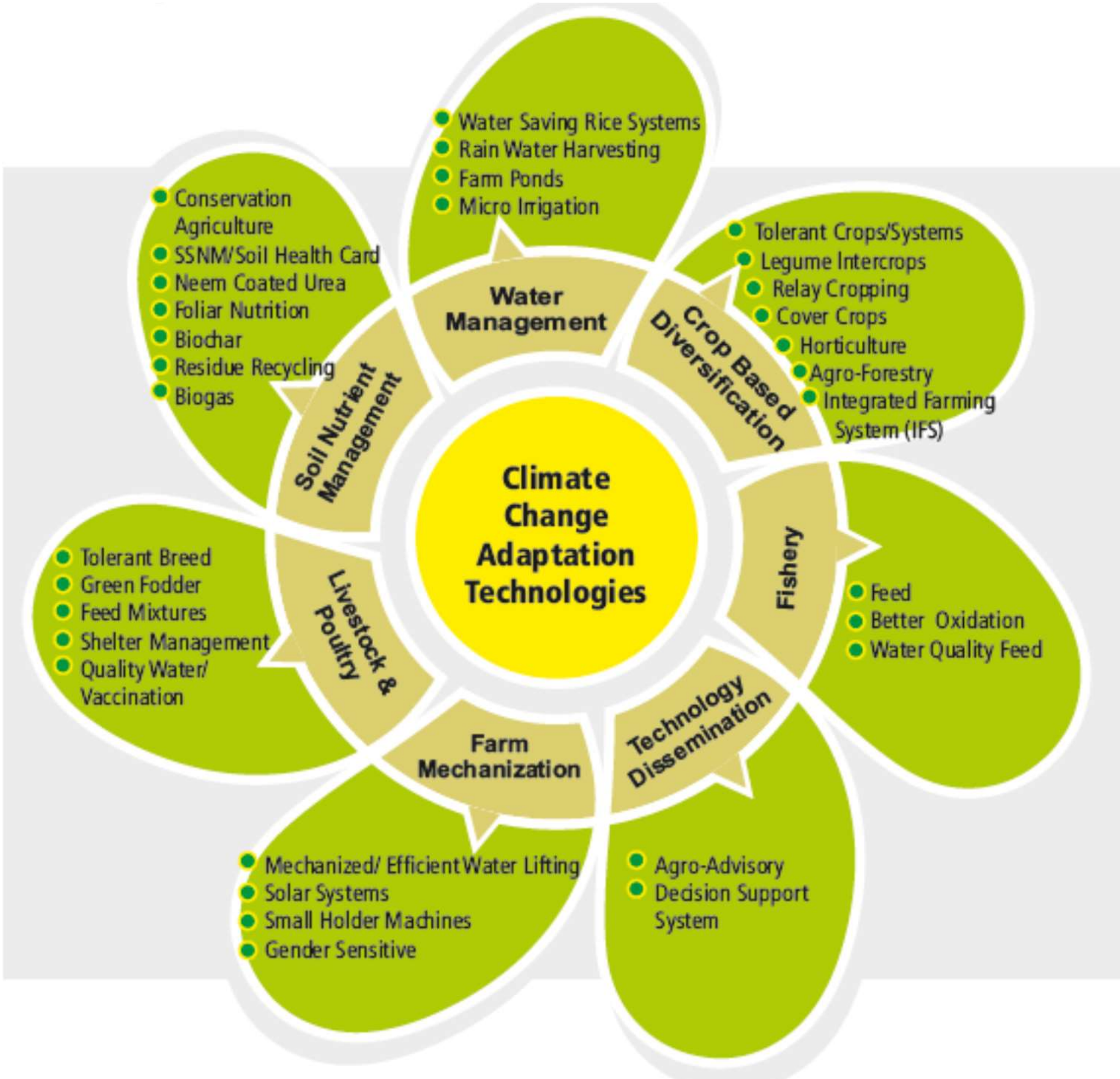
Adaptations & Mitigations

- Adaptation led Mitigation' to climate change is the only option to prepare our community, locality, country, and the societies for the consequences of same

- 'Adaptation' is nothing but the adjustments in human or natural ecosystem in response to climate change, and it moderately harm or destruct the opportunities

- Practically, it means changing the regular activities because of change in climate but not completely different, rather purposefully modifying the existing practice

- 'Mitigation' is any technological modification that reduces the addition of inputs and its emission (GHGs into atmosphere) per unit of output (IPCC)


Climate Change Adaptation Technologies
Water Management
Water Saving Rice Systems
Rain Water Harvesting
Farm Ponds
Micro Irrigation
Crop Based Diversification
Tolerant Crops/Systems
Legume Intercrops
Relay Cropping
Cover Crops
Horticulture
Agro-Forestry
Integrated Farming System (IFS)
Fishery
Feed
Better Oxidation
Water Quality Feed
Technology Dissemination
Agro-Advisory
Decision Support System
Farm Mechanization
Mechanized/ Efficient Water Lifting
Solar Systems
Small Holder Machines
Gender Sensitive
Livestock & Poultry
Tolerant Breed
Green Fodder
Feed Mixtures
Shelter Management
Quality Water/ Vaccination
Soil Nutrient Management
Conservation Agriculture
SSNM/Soil Health Card
Neem Coated Urea
Foliar Nutrition
Biochar
Residue Recycling
Biogas

Government of India Initiatives for Climate Change Adaptation

National Mission on Sustainable Agriculture (NMSA):

- This Mission was structured under the *National Action Plan on Climate Change* (NAPCC) during 2014-15

- It aimed to synergize resource conservation, enhancing or restoring the soil fertility, thereby, improving productivity with focus on soil health management, Integrated Farming System (IFS), integrated animal component and Water Use Efficiency (WUE) specifically in drylands or rainfed agriculture areas

National Adaptation Fund for Climate Change (NAFCC):

- This Scheme was implemented during 2015-16 mainly for supporting concrete adaptation activities dealing with mitigating the adverse effects of global climate change in sectors such as agriculture, water, forestry, animal husbandry, tourism, *etc.*

Pradhan Mantri Krishi Sinchayee Yojna (PMSKY):

- This Scheme was planned and formulated to give more priority on water conservation and its management in agriculture with the vision to extend the area under irrigation from 1st July 2015

- The main motto of this Scheme is 'Har Khet Ko Paani' to improve water use efficiency, 'More crop per drop' to provide end-to-end solutions in water source creation, distribution channels and its management

Pradhan Mantri Fasal Bima Yojna (PMFBY):

- This Scheme was introduced on 14th January, 2016 in order to reduce the agricultural distress and farmer's welfare without affecting substantial hikes in the Minimum Support Prices (MSP) on agricultural produces during monsoon fluctuations or any other natural calamity by providing full insured amount on crop losses

Soil Health Card (SHC):

- This Scheme was launched in February, 2015 by the Central Govt. to issue soil health cards (SHC) to the farmers providing detailed information on test based soil nutrient status of their own land along with recommended dose of fertilizers for improving productivity through judicious use of inputs

- The Govt. of India targeted to issue 10.48 crores of SHCs since inception of the Scheme

Green India Mission (GIM):

- This Mission was started in February 2014 and outlined under NAPCC

- The main objective of this Mission was to protect, restore and enhance the diminishing forest cover in India, and to fight climate change with adaptation and mitigation measures

National Water Mission (NWM):

- A Mission was mounted to ensure Integrated Water Resource Management (IWRM) for conserving the water sources and minimizing its wastage, and also to optimize Water Use Efficiency (WUE) by 20 per cent including agriculture sector.

Paramparagat Krishi Vikas Yojna (PKVY):

- It is an extended component of Soil Health Management (SHM) launched in 2015 under NMSA with the objective of supporting and promoting organic farming through adoption of organic village by cluster approach, which in turn result in improvement of soil health

National Action Plan on Climate Change (NAPCC) and State Action Plan on Climate Change (SAPCC):

- The NAPCC was released on 30th June 2008 in order to create awareness among public, Govt. agencies, industries, scientists and the society on the risks posed by global climate changes, and steps to encounter the same

- It pulls all the existing Government's national plans on energy efficiency agriculture, renewable energy, water, and others

- The SAPCC have enlisted climate adaptation and mitigation strategies aligned with eight national missions under NAPCC

Agricultural Contingency Plans and National Innovations on Climate Resilient Agriculture (NICRA):

- Agricultural Contingency Plans are technical documents comprising integrated information on field crops, livestock, horticulture, poultry and fishery and technological solutions for all weather-related problems for the respective farming activities

- These are useful to plan earlier towards sustainable agriculture system during weather aberrations and extreme climatic conditions

Sub-mission on Agro-forestry:

- This Mission was launched during 2016-17 with the objective of planting trees on farm bunds

- Agroforestry has the potential to bring sustainability in agriculture and also achieving the optimum productivity by mitigating the impact of climate change

National Livestock Mission:

- This Mission was initiated by the Ministry of Agriculture and Farmers‘ Welfare and got commenced from 2014-15 focussing mainly on livestock development through sustainable approach ultimately protecting the natural environment, ensuring bio-security, conserving animal bio-diversity and farmers‘ livelihood

Innovative Poultry Productivity Project:

- The National Livestock Mission launched this Project on pilot basis during 2017-18 in 15 recognized poultry potential states to provide nutritional support to the poor farmers and also give supplementary income

- The State Action Plan on Climate Change (SAPCC) is a flexible and dynamic policy framework follows a continuous interaction process for bringing changes in national, state and local levels

- It was directed by National Government to create a coherent national framework under the line of NAPCC

Climate Change And Its Implications (CCI)

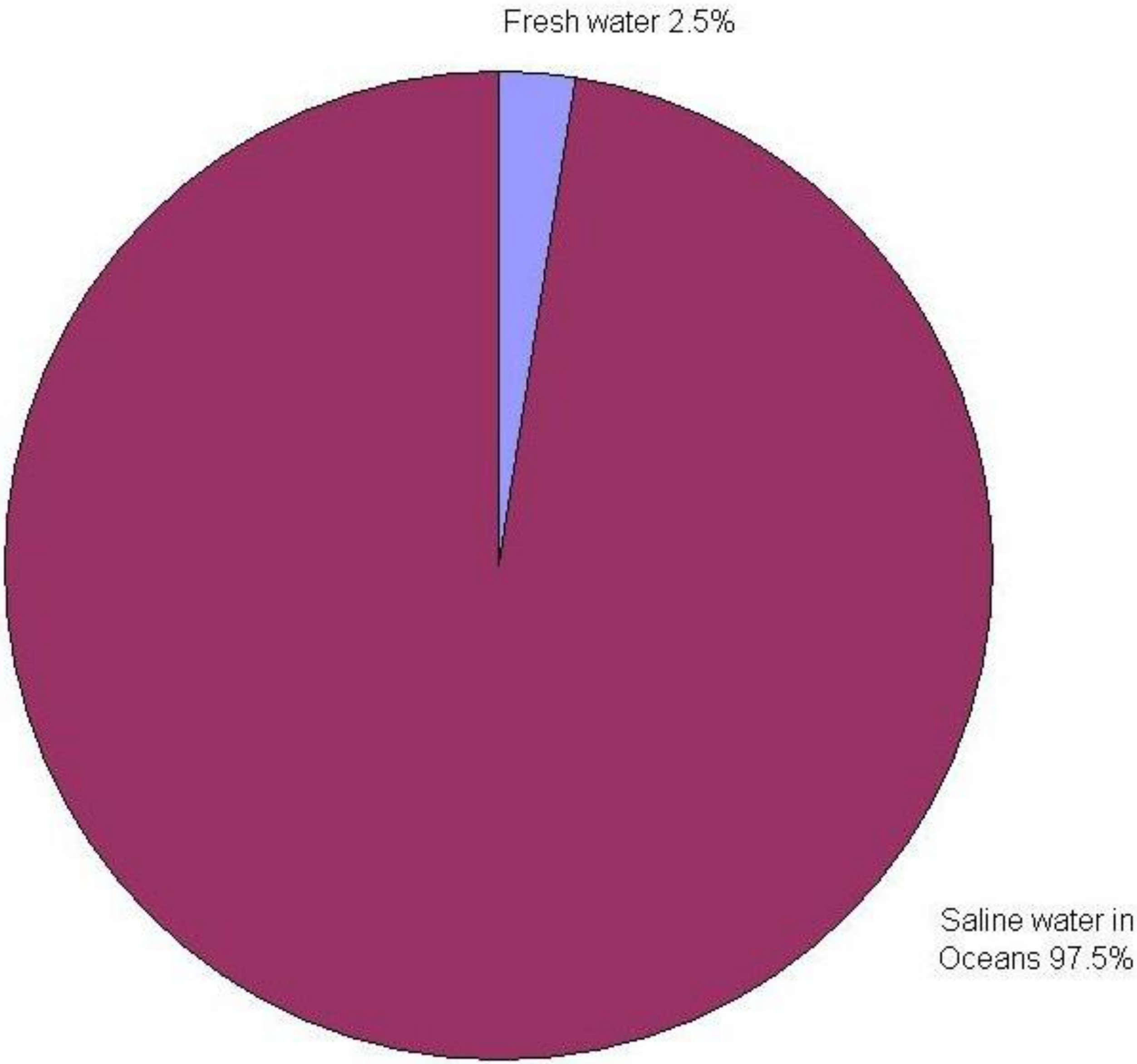
Dr. Raji P

Lecture-21&22

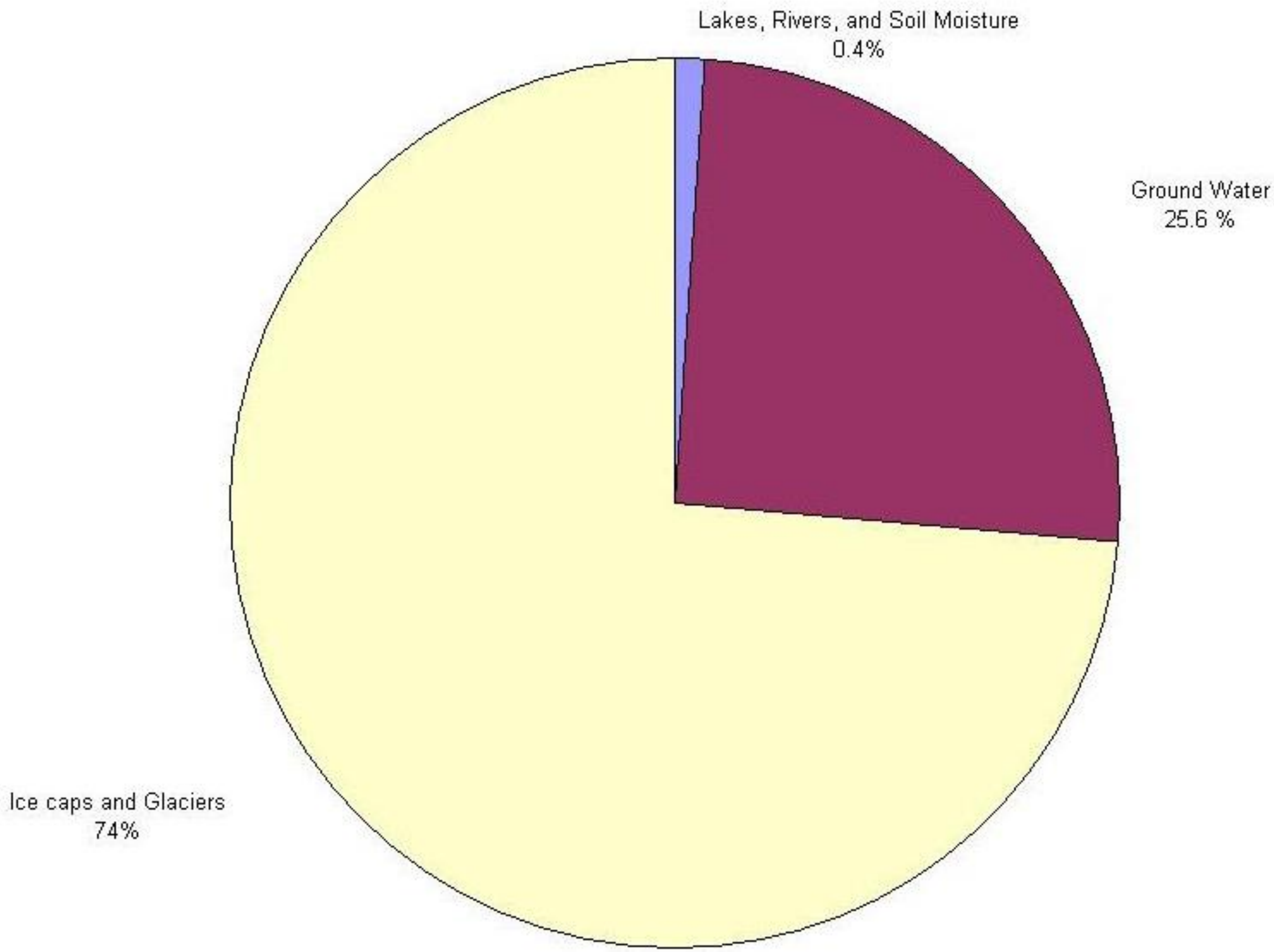
R software

https://www.neonscience.org/resources/learning-hub/tutorials/raster-data-r

Climate change on water resources

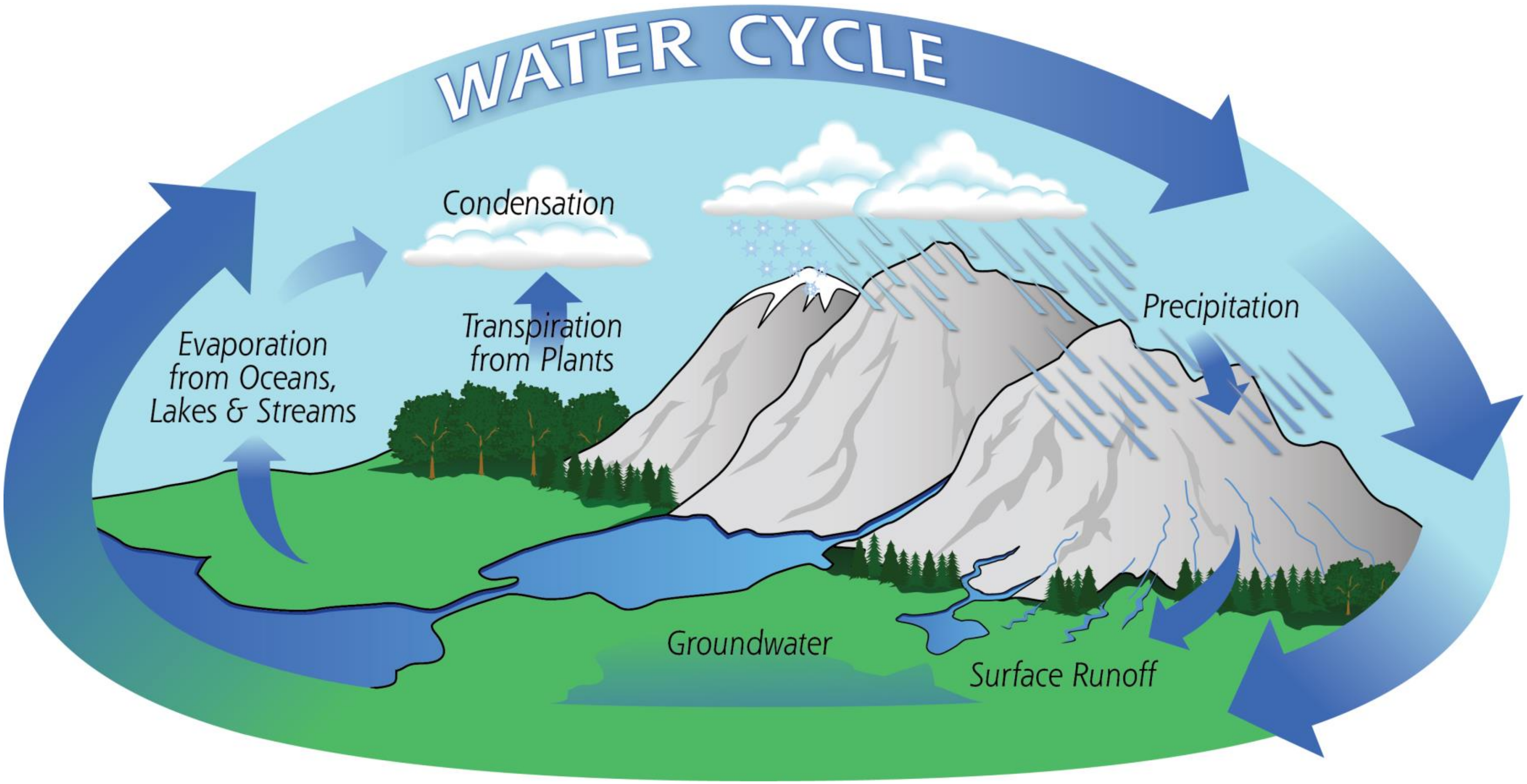


Total global water content



Global fresh water distribution

Introduction-Hydrology



The hydrologic cycle consists of four key components

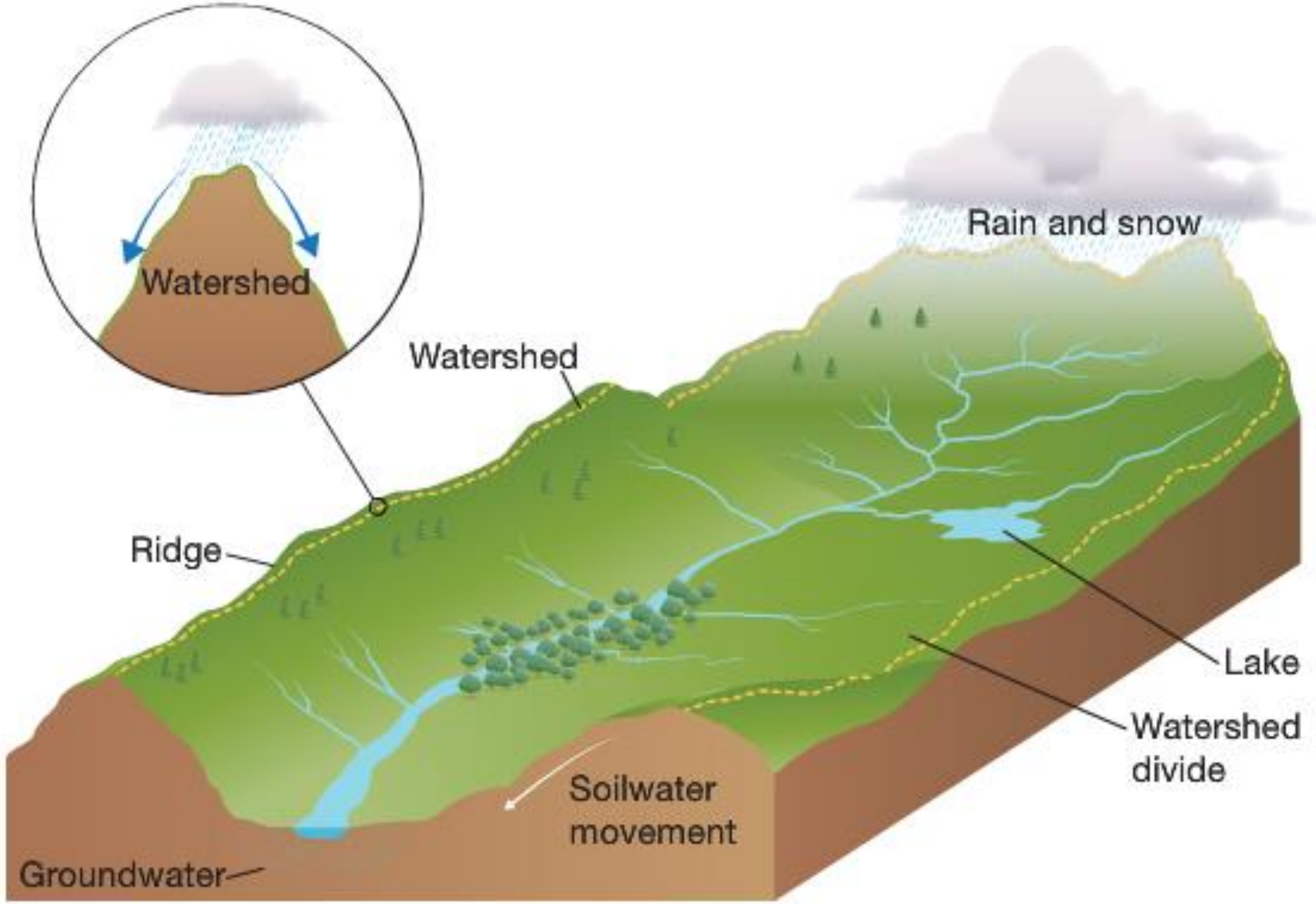
1. Precipitation

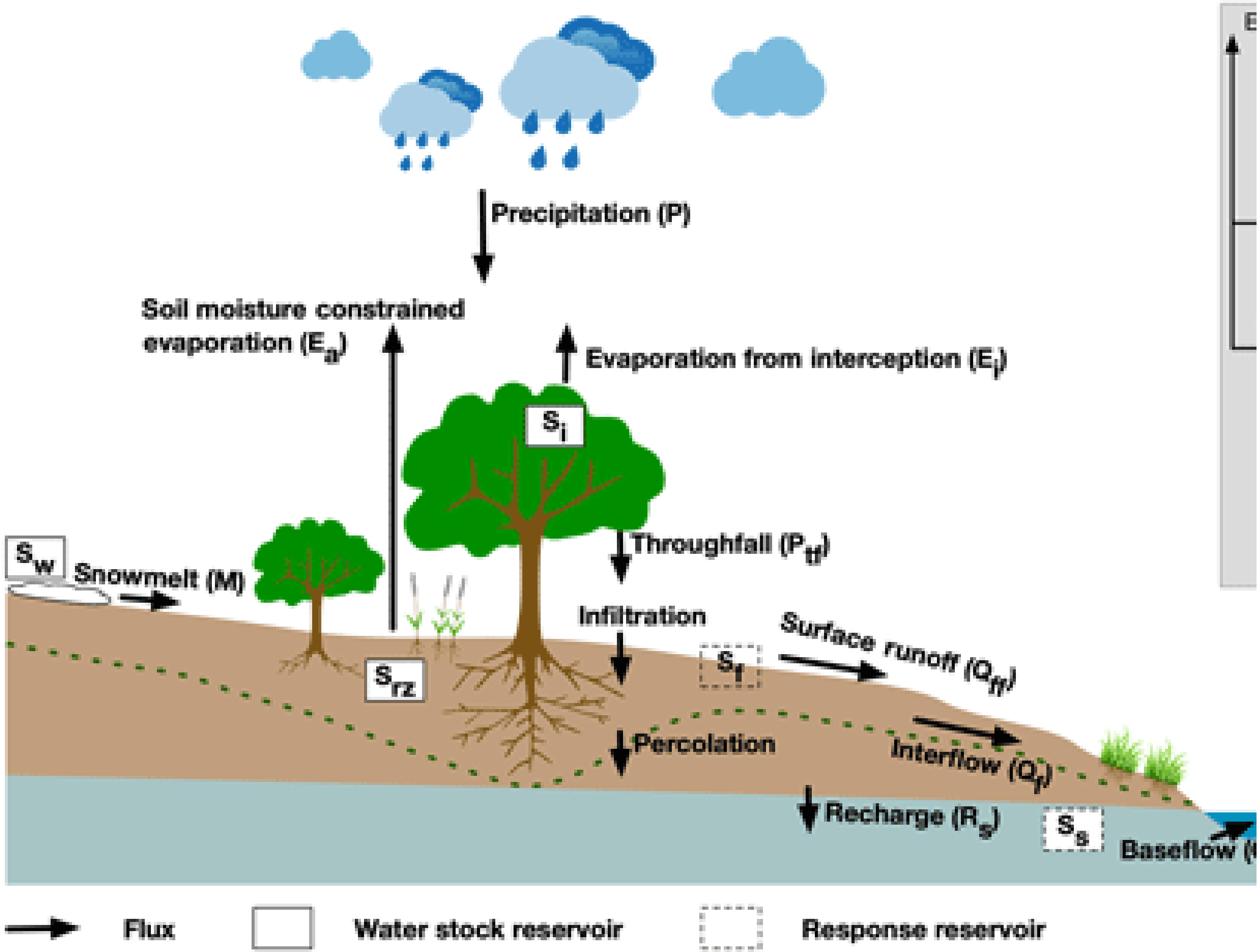
2. Runoff

3. Storage (lake, rivers, ground water)

4. Evapotranspiration

Watershed


Watershed
Rain and snow
Watershed
Ridge
Lake
Watershed divide
Soilwater movement
Groundwater

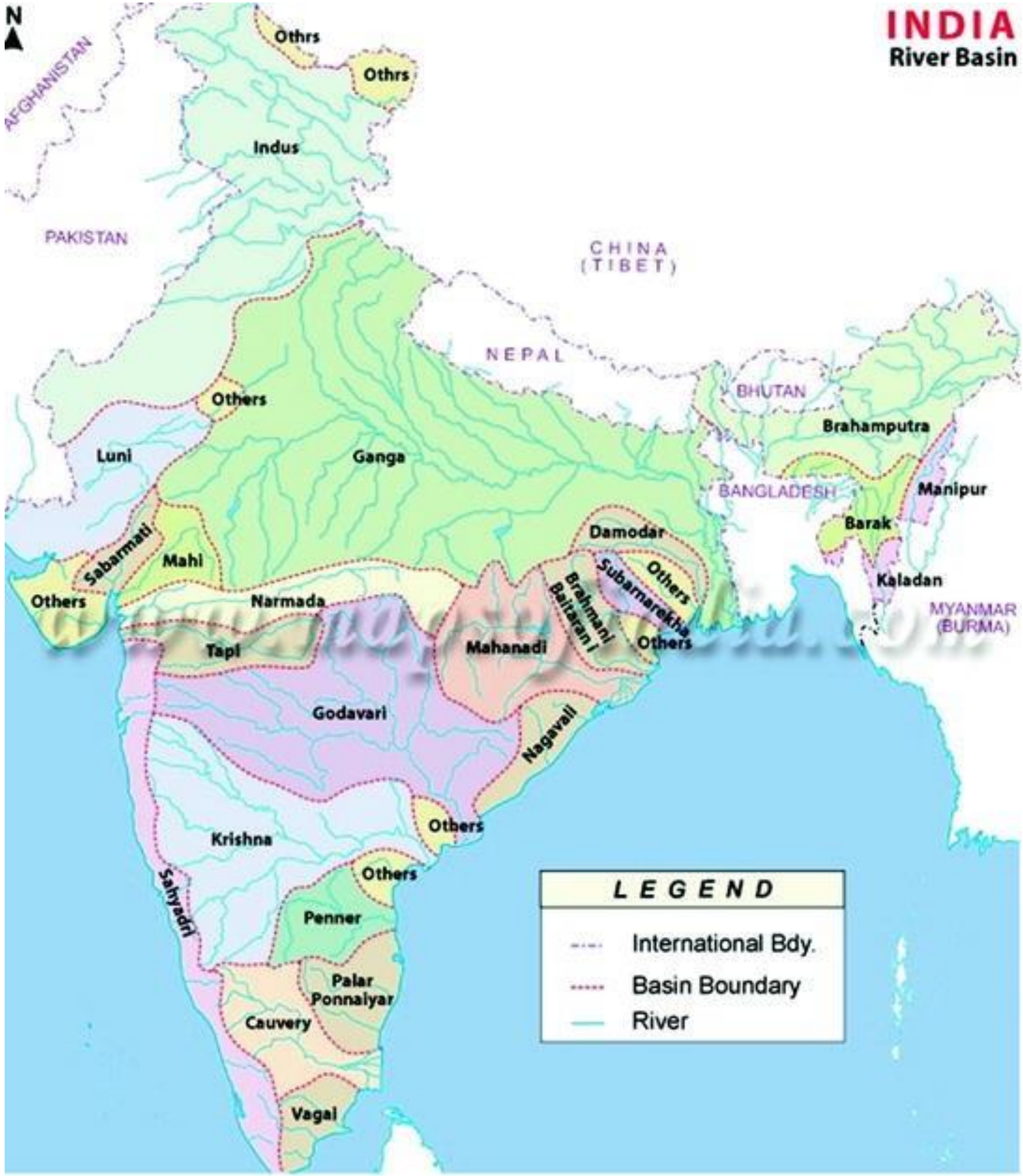

Precipitation (P)
Soil moisture constrained evaporation (E_a)
Evaporation from interception (E_i)
S_i
S_w
Snowmelt (M)
Throughfall (P_{tf})
Infiltration
Surface runoff (Q_{ff})
S_f
S_{rz}
Percolation
Interflow (Q_f)
Recharge (R_s)
S_s
Baseflow
Flux
Water stock reservoir
Response reservoir

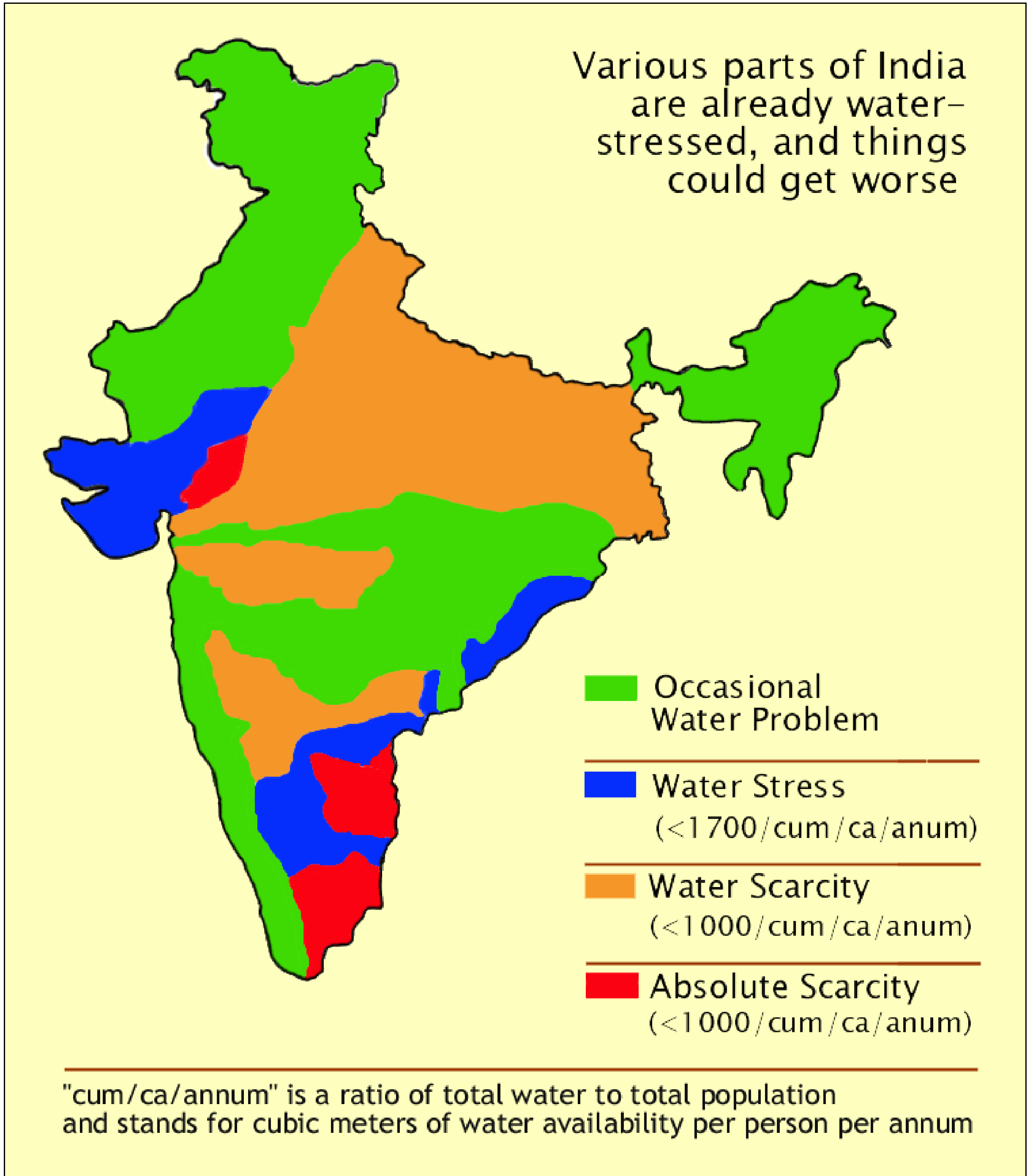
Water Resources – India at a Glance

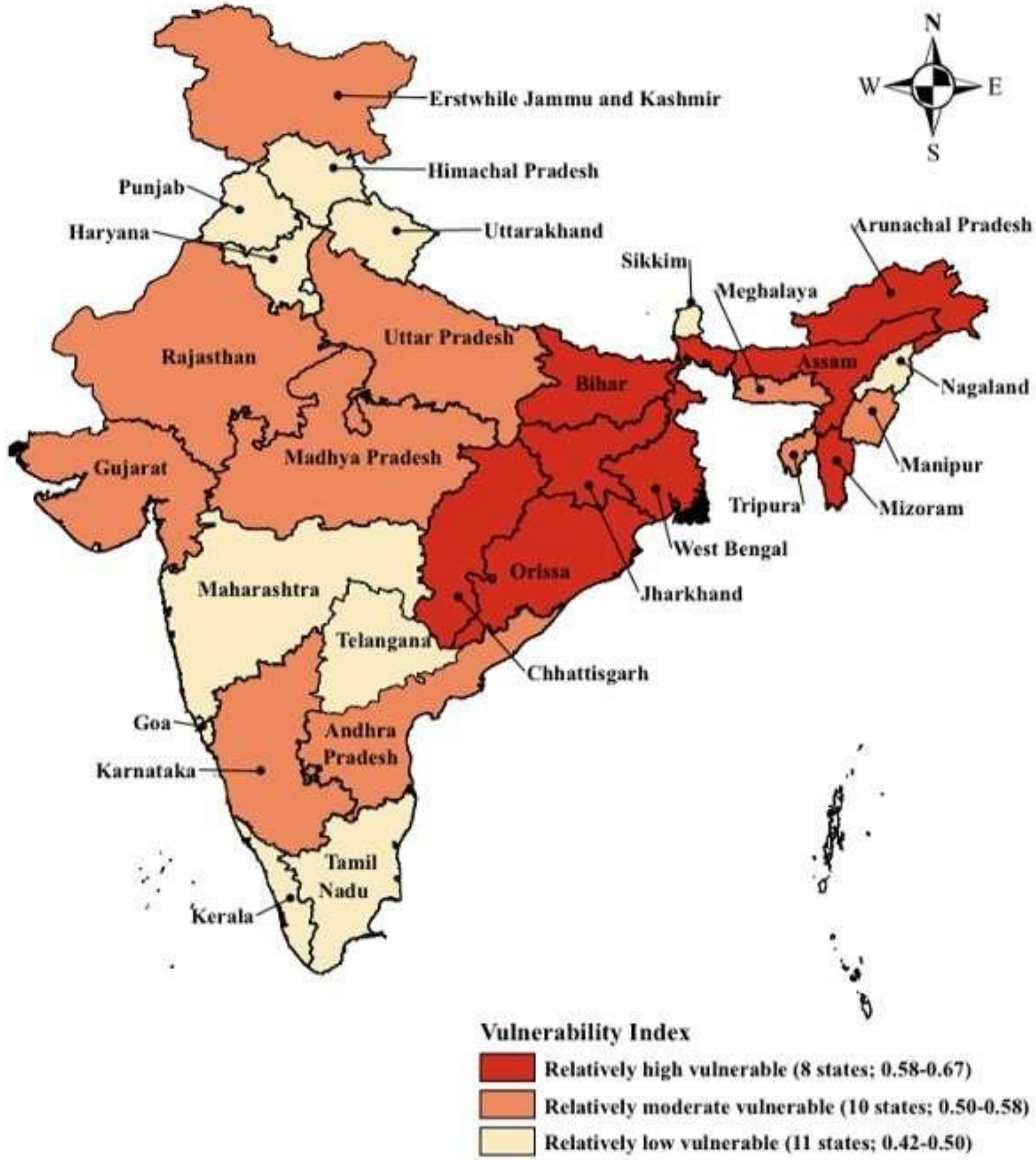
- Area of the country as % of World Area : 2.4%
- Population as % of World population : 17.1%
- Water as % of World Water : 4%
- Rank in per capita availability : 132
- Rank in water quality : 122

Major river basins in India

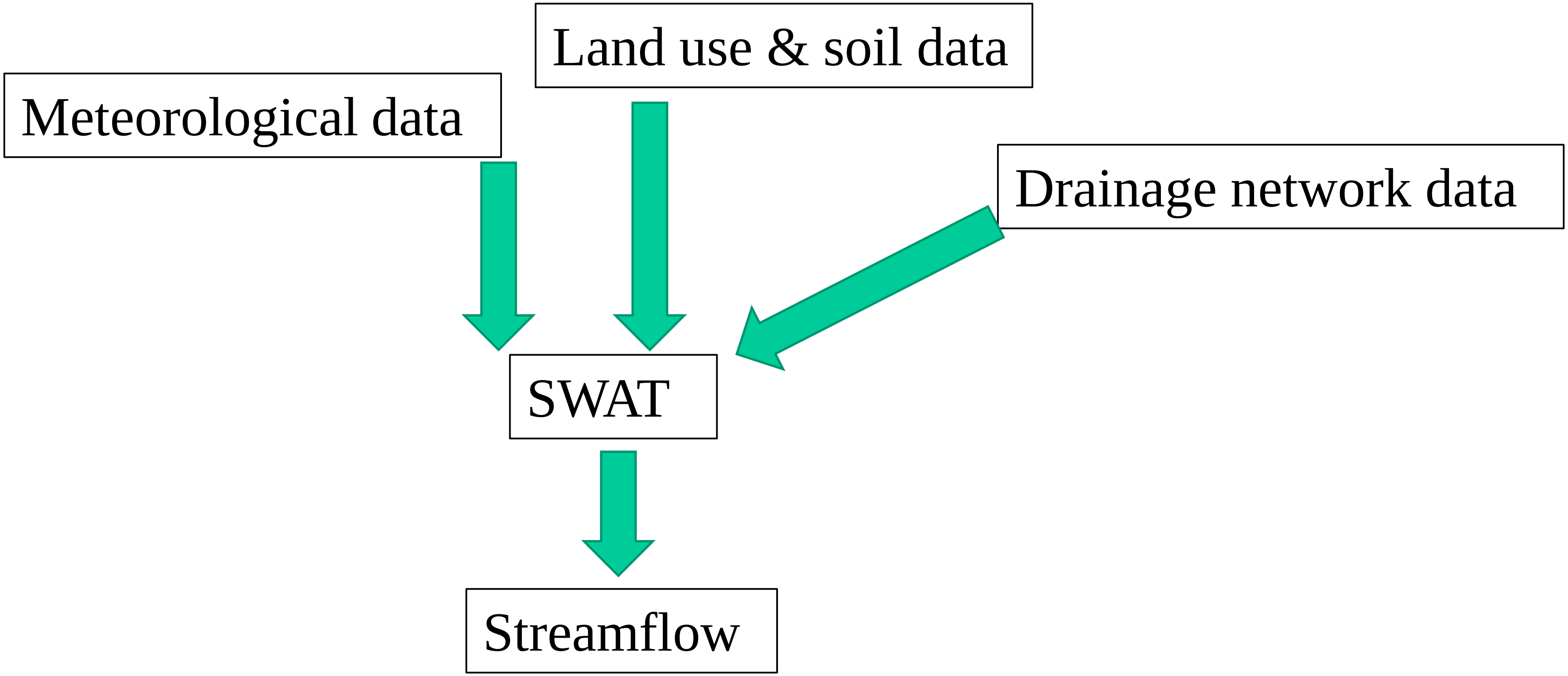
1. Indus
2. Ganges
3. Brahmaputra
4. Krishna
5. Godavari
6. Mahanandi
7. Sabarmati
8. Tapi
9. Brahmani-Baitarani
10. Narmada
11. Pennar
12. Mahi


N
INDIA
River Basin
Othrs
Othrs
AFGHANISTAN
Indus
PAKISTAN
CHINA
(TIBET)
NEPAL
BHUTAN
Others
Luni
Ganga
Brahamputra
BANGLADESH
Manipur
Barak
Damodar
Sabarmati
Mahi
Kaladan
Others
Narmada
Brahmani
Baitarani
Subarnarekha
Others
MYANMAR
(BURMA)
Tapi
Mahanadi
Others
Godavari
Nagavali
Others
Krishna
Others
Sahyadri
Penner
Palar
Ponnaiyar
Cauvery
Vagai
LEGEND
International Bdy.
Basin Boundary
River

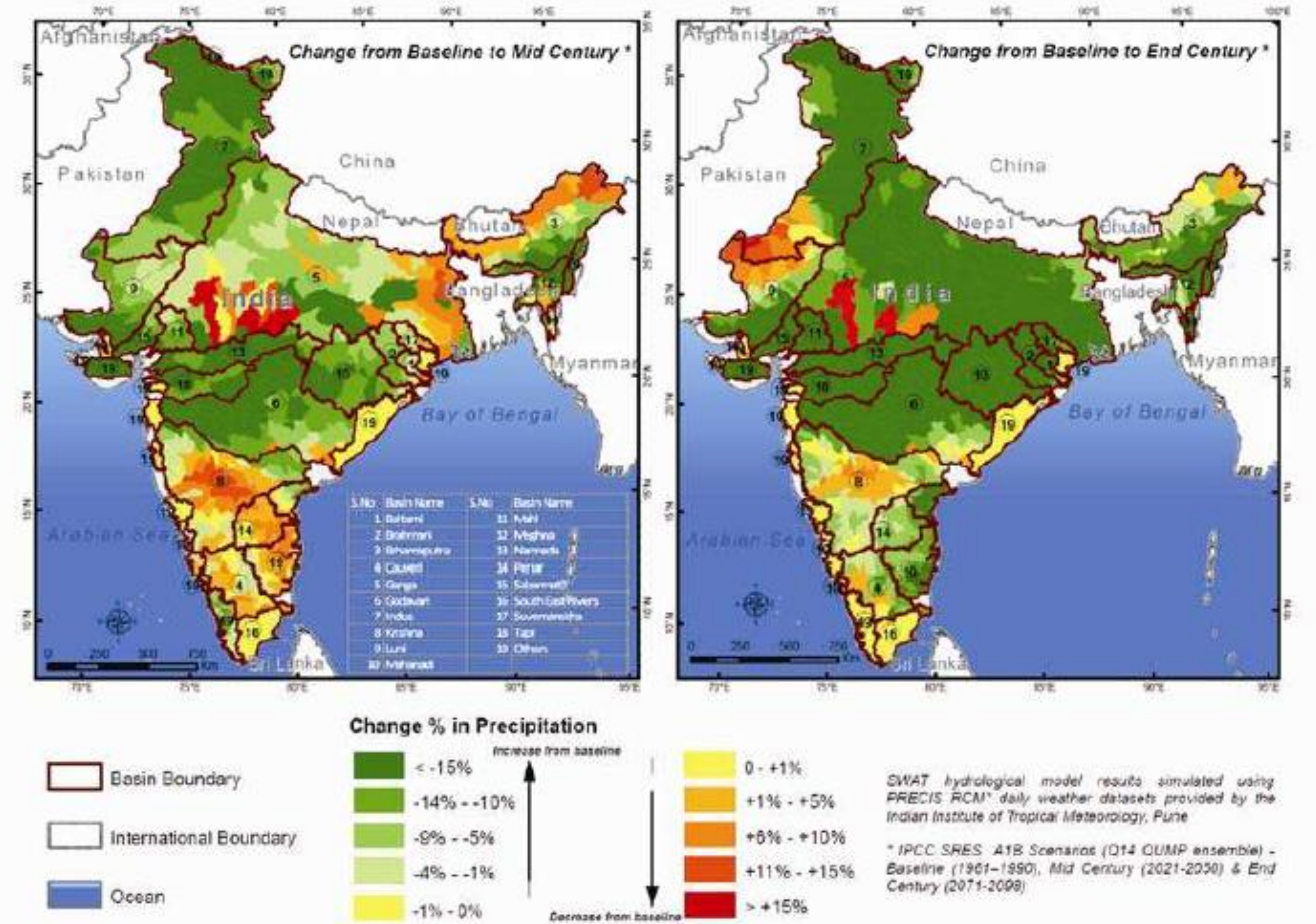

Various parts of India are already water-stressed, and things could get worse
Occasional Water Problem
Water Stress
(<1700/cum/ca/anum)
Water Scarcity
(<1000/cum/ca/anum)
Absolute Scarcity
(<1000/cum/ca/anum)
"cum/ca/annum" is a ratio of total water to total population
and stands for cubic meters of water availability per person per annum


N
W
E
S
Erstwhile Jammu and Kashmir
Himachal Pradesh
Punjab
Haryana
Uttarakhand
Arunachal Pradesh
Sikkim
Meghalaya
Uttar Pradesh
Rajasthan
Bihar
Assam
Nagaland
Gujarat
Madhya Pradesh
Manipur
Tripura
Mizoram
West Bengal
Orissa
Maharashtra
Jharkhand
Telangana
Chhattisgarh
Goa
Andhra Pradesh
Karnataka
Tamil Nadu
Kerala
Vulnerability Index
Relatively high vulnerable (8 states; 0.58-0.67)
Relatively moderate vulnerable (10 states; 0.50-0.58)
Relatively low vulnerable (11 states; 0.42-0.50)

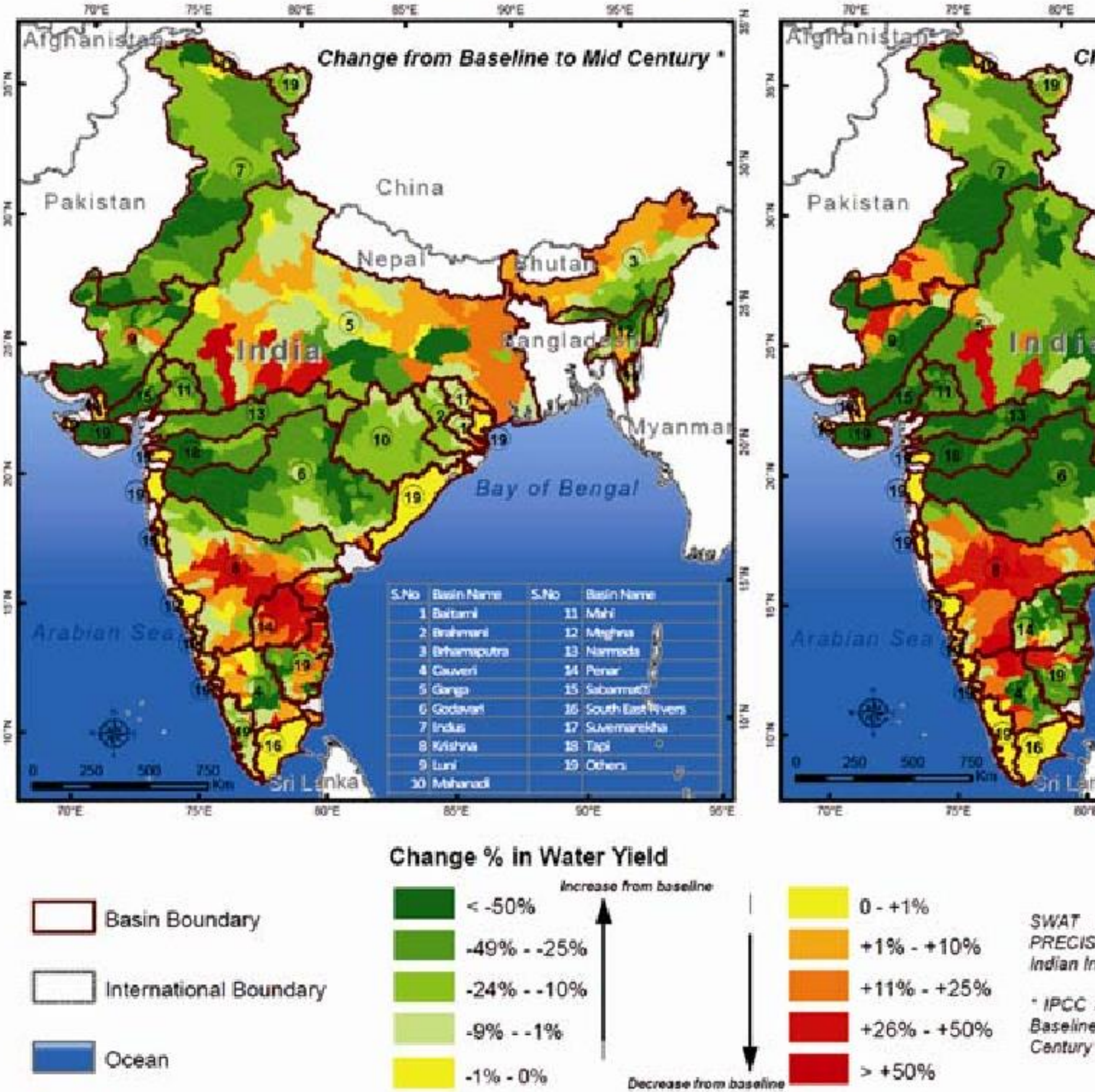
Impact analysis



Per cent Change in Precipitation across India

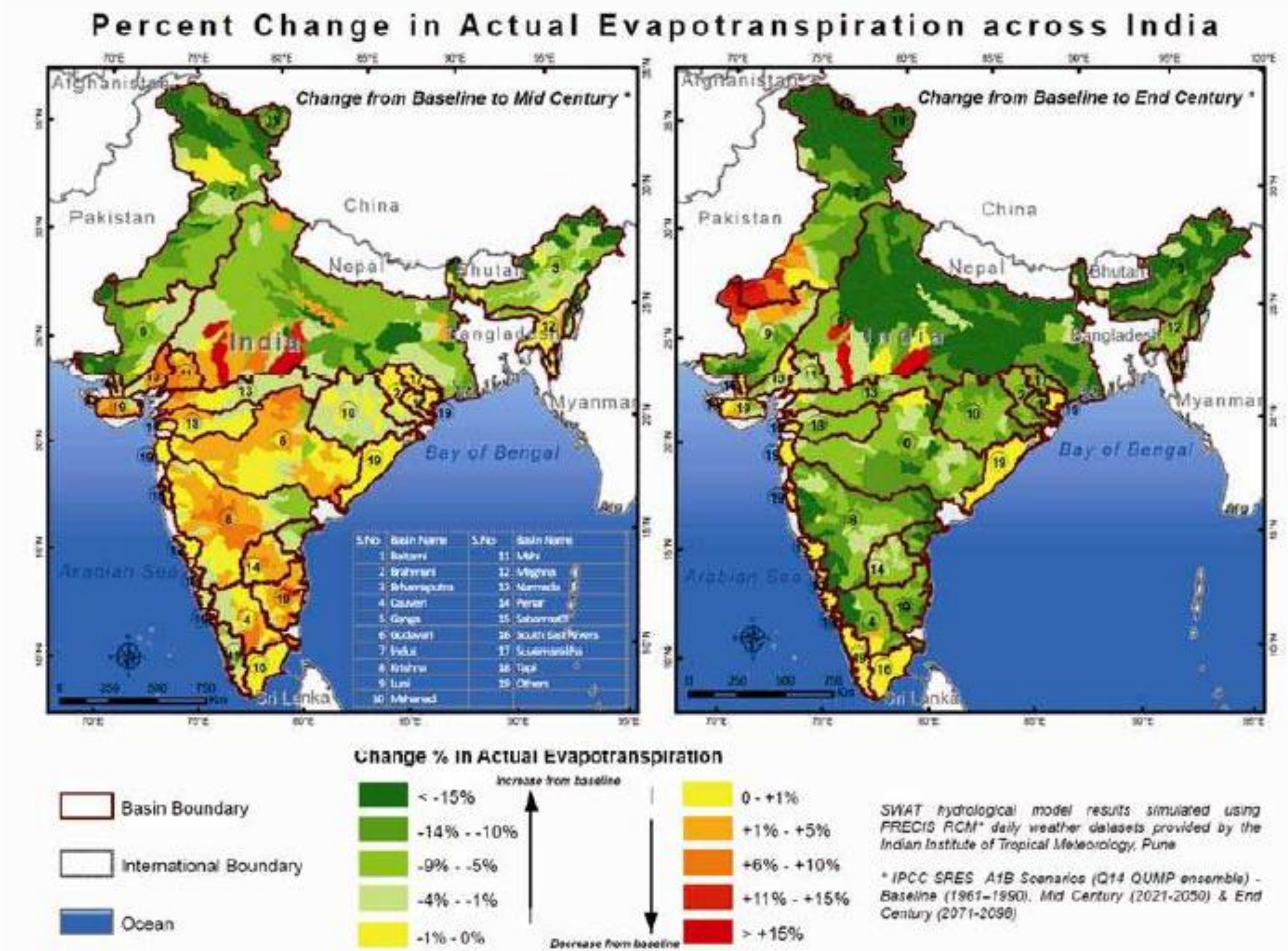


Per cent Change in Water Yield across India



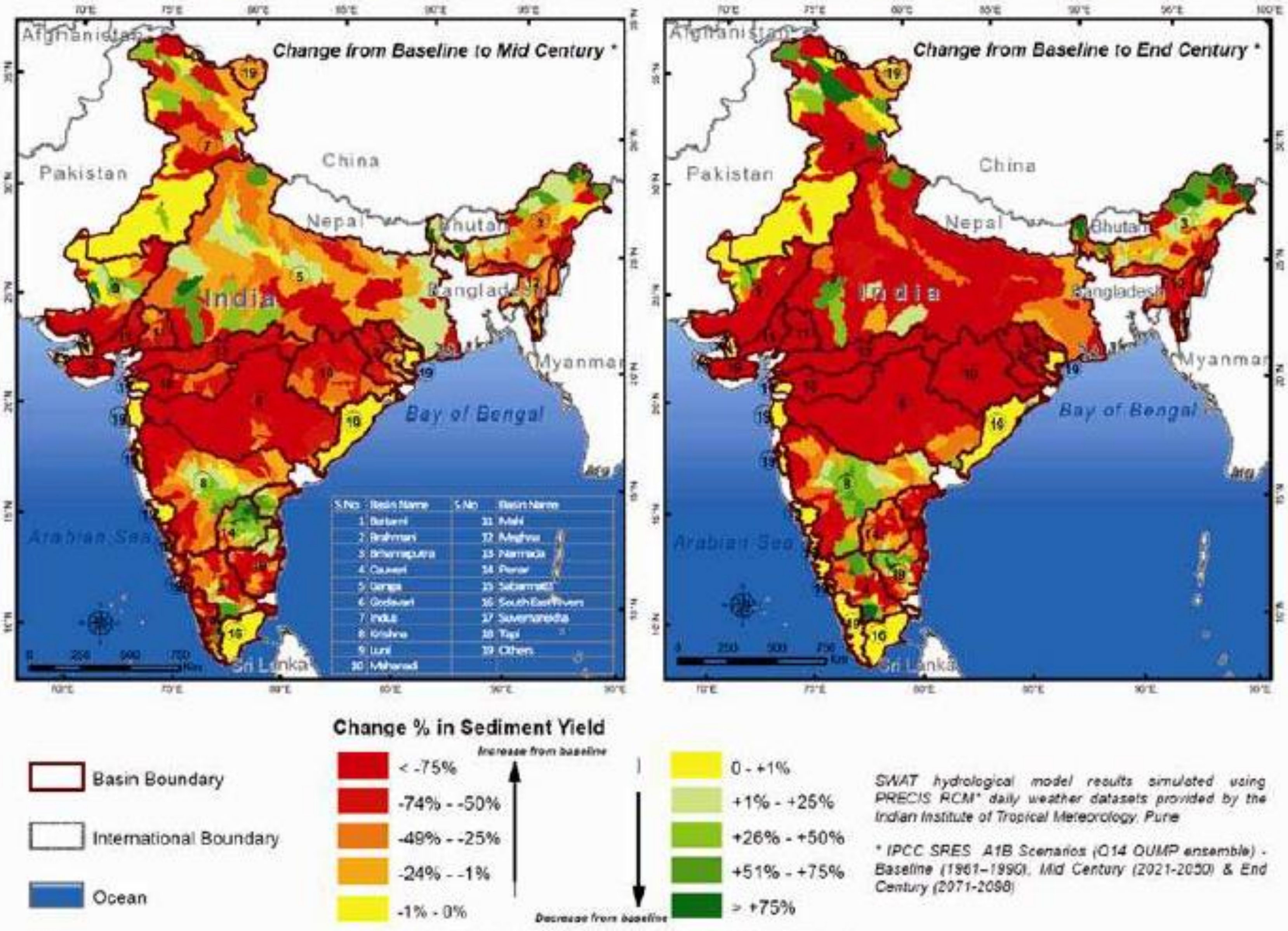
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune

* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)



Percent Change in Actual Evapotranspiration across India
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
Bangladesh
India
Myanmar
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name
1 Baitarni
2 Brahmani
3 Brahmaputra
4 Cauveri
5 Ganga
6 Godavari
7 Indus
8 Krishna
9 Luni
10 Mahanadi
11 Mahi
12 Meghna
13 Narmada
14 Pennar
15 Sabarmati
16 South East Rivers
17 Subarnarekha
18 Tapi
19 Others
Change % in Actual Evapotranspiration
Basin Boundary
International Boundary
Ocean
Increase from baseline
Decrease from baseline
< -15%
-14% - -10%
-9% - -5%
-4% - -1%
-1% - 0%
0 - +1%
+1% - +5%
+6% - +10%
+11% - +15%
> +15%
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)

Percent Change in Sediment Yield across India



- In northern India, a declining trend in 41 years (1970–2010) of daily streamflow records for Sutlej River has been observed at three gauging locations (Kasol, Sunni, and Rampur)

- The basin has importance in the high potential for hydroelectricity power generation and agricultural practices (Singh et al. 2014a)

- A significantly declining trend in mean annual streamflow in the Beas River and a decreasing but insignificant trend for the Ravi River is observed, while winter streamflow in the Chenab River showed a statistically significant increase during 1961–1995 attributed to variability in snow and glacier melting (Bhutiyani et al. 2008)

- A declining trend in the historical annual streamflow data (1982–2012) of Gomti River (total area of 30,437 km2), a tributary of the Ganges River in northern India, has been observed at four gauging stations (Neemsar, Sultanpur, Jaunpur, and Maighat) and is attributed to a high dependency on the monsoon rainfall (Abeysingha et al. 2016)

- In the Upper Cauvery basin of southern India (catchment area of 36,682 km^2), no significant trend has been observed in the monthly streamflow data of a 30-year period (1981–2010) for four gauging stations except one (T. Narasipur), where an annual decrease of 0.778 m^3/s in the period 2001–2010 has been observed (Raju and Nandagiri 2017)

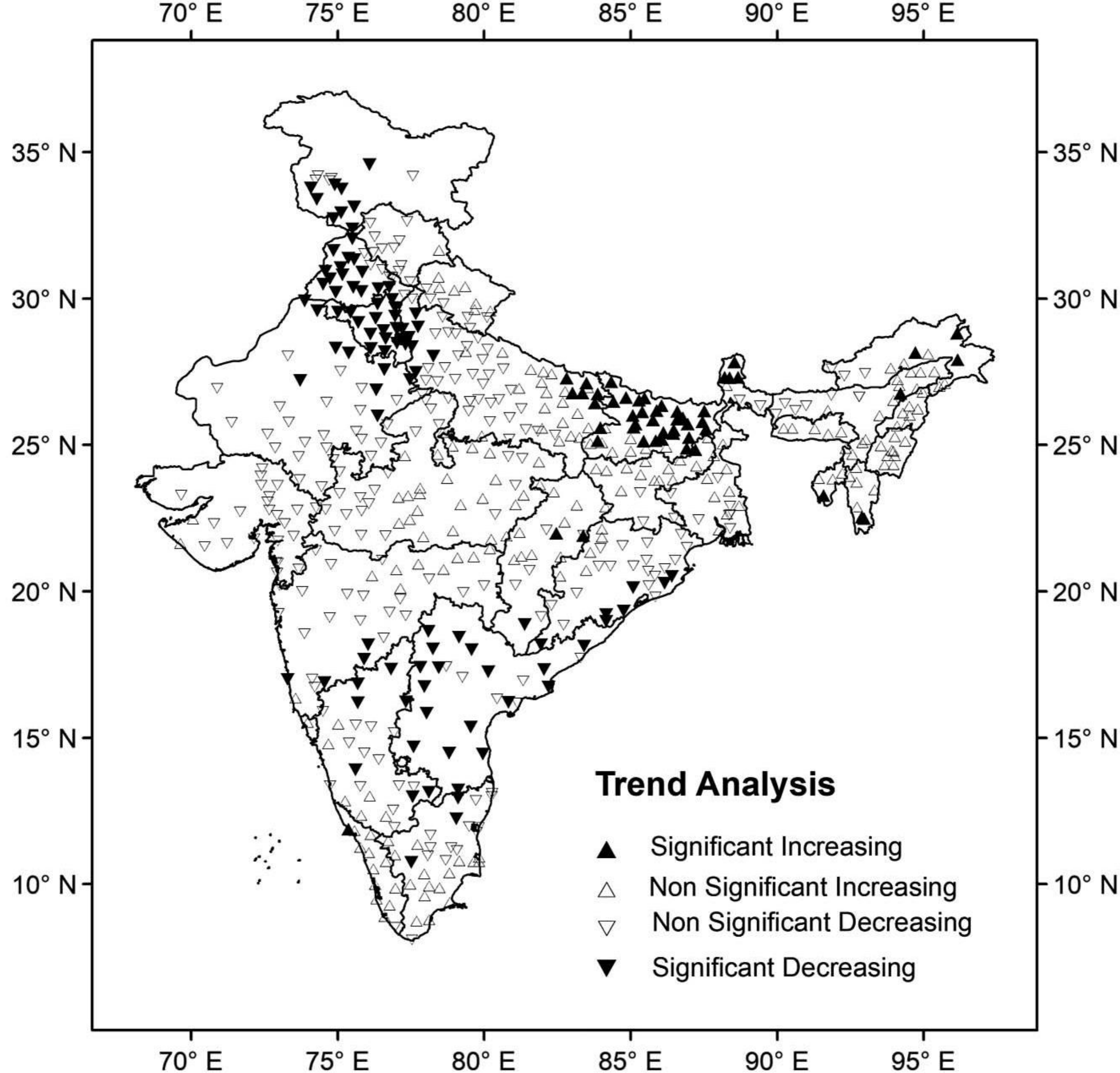
- In peninsular India, the streamflow at the outlet (Tikerpara) of the Mahanadi River basin (catchment area of 141,589 km^2) declined at a rate of 3,388 million cubic meters per decade for the period of 1972–2007 (Panda et al. 2013)

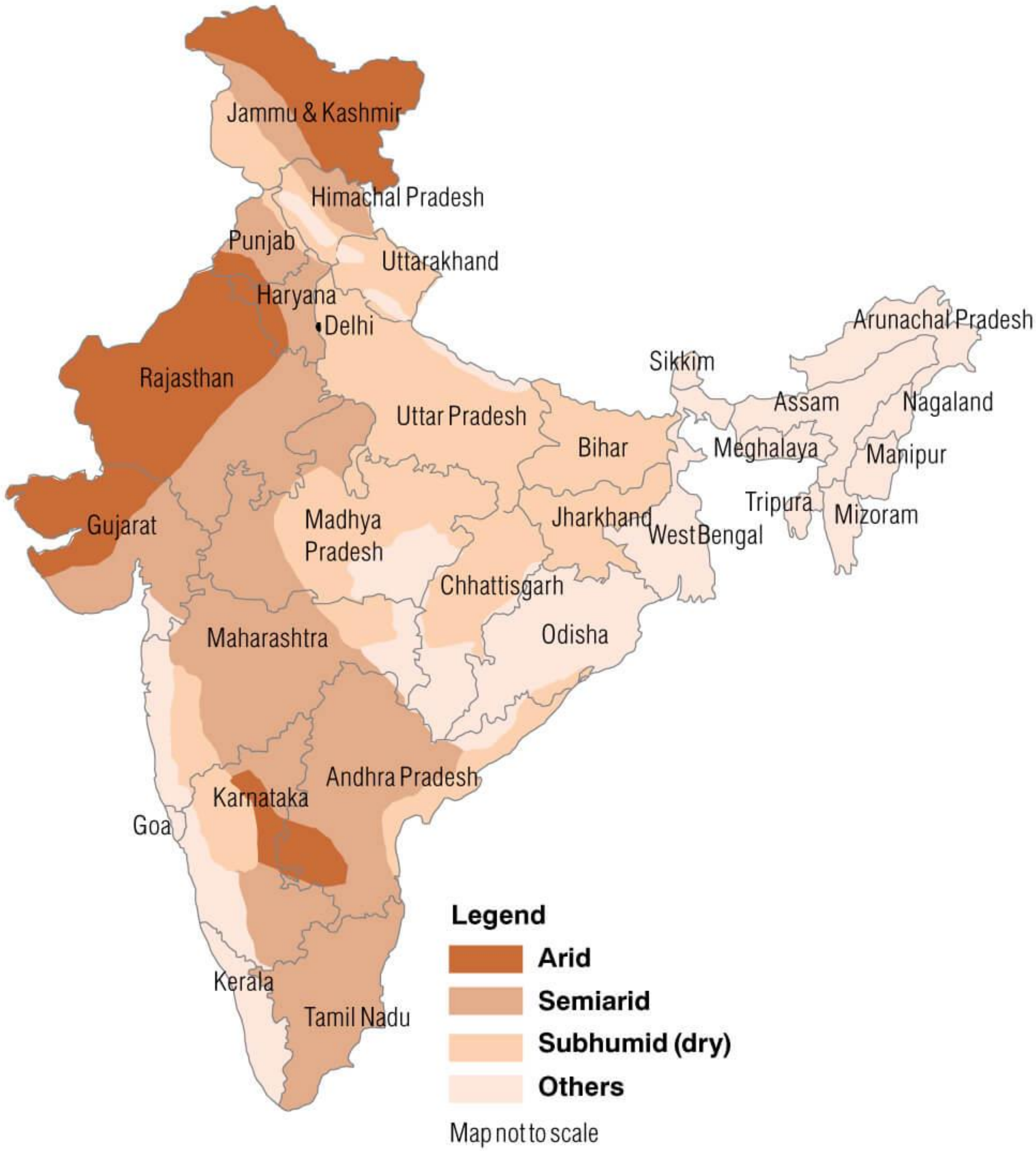
- An increase during 1956–2007 in the number of particular flood occurrences in Bahadurabad in the Brahmaputra River has been recorded (Climate Change Cell 2009).

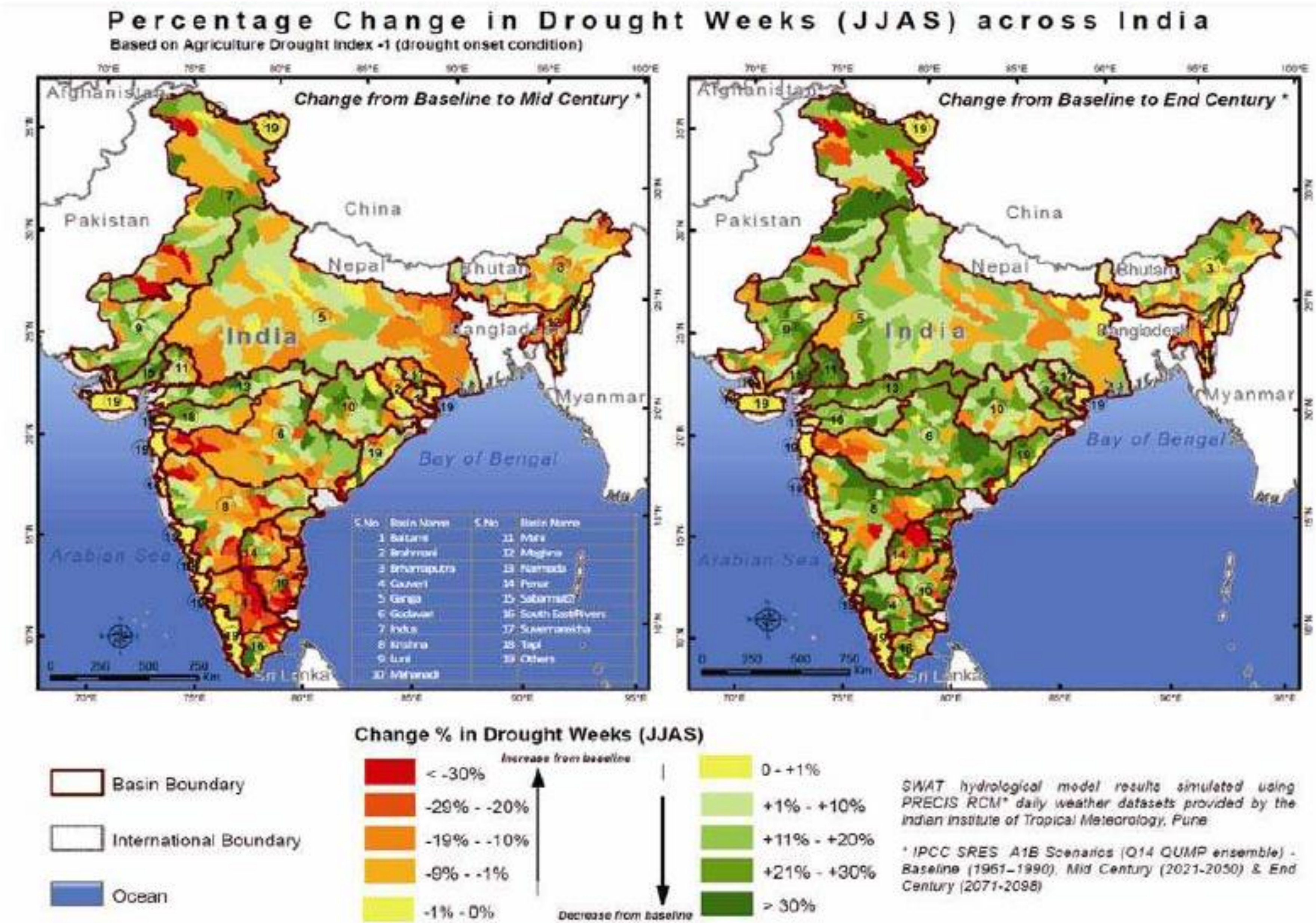
- Dadhwal et al. (2010) reported an increase by 4.53% in the annual stream flow at the Mundali outlet in the Mahanadi basin attributed to a reduction in forest cover by 5.71% for the period 1972–2003

- For the Ganges-Brahmaputra-Meghna (GBM) basin, the longterm mean runoff is projected to increase by 33.1, 16.2, and 39.7% in the Ganges, Brahmaputra, and Meghna basins, respectively (Masood et al. 2015), by the end of the 21st century

Trend analysis of annual drought severity (ADS) across 566 stations in India over 1901–2002


70° E
75° E
80° E
85° E
90° E
95° E
35° N
30° N
25° N
20° N
15° N
10° N
Trend Analysis
Significant Increasing
Non Significant Increasing
Non Significant Decreasing
Significant Decreasing


Jammu & Kashmir
Himachal Pradesh
Punjab
Uttarakhand
Haryana
Delhi
Arunachal Pradesh
Sikkim
Rajasthan
Assam
Nagaland
Uttar Pradesh
Bihar
Meghalaya
Manipur
Tripura
Mizoram
Gujarat
Madhya Pradesh
Jharkhand
West Bengal
Chhattisgarh
Odisha
Maharashtra
Andhra Pradesh
Karnataka
Goa
Kerala
Tamil Nadu
Legend
Arid
Semiarid
Subhumid (dry)
Others
Map not to scale



Percentage Change in Drought Weeks (JJAS) across India
Based on Agriculture Drought Index -1 (drought onset condition)
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
India
Bangladesh
Myanmar
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name S.No Basin Name
1 Baitarni 11 Mahi
2 Brahmani 12 Meghna
3 Brahmaputra 13 Narmada
4 Cauveri 14 Penar
5 Ganga 15 Sabarmati
6 Godavari 16 South EastRivers
7 Indus 17 Suvarnarekha
8 Krishna 18 Tapi
9 Luni 19 Others
10 Mahanadi
Change % in Drought Weeks (JJAS)
Basin Boundary
International Boundary
Ocean
Increase from baseline
< -30%
-29% - -20%
-19% - -10%
-9% - -1%
-1% - 0%
Decrease from baseline
0 - +1%
+1% - +10%
+11% - +20%
+21% - +30%
> 30%
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)

Initiatives taken for drought management

- Enhancement of the capabilities of long-range forecasts to climate modelling and weather forecasting

- In 1989, the National Centre for Medium Range Weather Forecasting started to forecast weather on a medium-term basis (3-10 days in advance)

- Monitoring of storage position of reservoirs: 76 important reservoirs of the country having a total live storage capacity of 131.22 billion m3 are being monitored

- A further 49 have also been identified for inclusion in the monitoring system, which will increase storage capacity of the monitored reservoirs to 156.69 billion m3, i.e. about 74 per cent of the total capacity of 213 billion m3 created so far

- Efforts are under way to improve the efficiency of the irrigation system

- The National Agricultural Drought Assessment and Monitoring System became operational in 1989

- The National Centre for Disaster Management was set up in 1995 to undertake human-resource development, research, building a database and providing information services and documentation on disaster management

- Setting-up of a National Data Bank under the All India Co-ordinated Project on Agrometeorology at the Crop Research Institute for Dry Land Agriculture, Hyderabad

- Setting-up of a National Disaster Management Authority

Approach to flood management

- Attempts to modify the flood
- Attempts to modify the sus-ceptibility to flood damage
- Attempts to modify the loss burden
- Bearing the loss.

The following structural measures are generally adopted for flood protection:

- Embankments, flood walls, sea walls
- Dams and reservoirs
- Natural detention basins
- Channel improvement
- Drainage improvement
- Diversion of flood waters.

Non-structural measures include:

- Flood forecasting and warning
- Floodplain zoning
- Flood fighting
- Flood proofing
- Flood insurance.


Higher rates of evapotranspiration from forests, rangeland and cropland
Glacier melting and change in snowmelt regime
Increased evaporation from reservoirs, water bodies and wetlands
Increased variability in precipitation more extreme weather events
More frequent floods affecting human settlements and cropland
Sea level rise and salt water intrusion
More pressure on groundwater to compensate for more variable surface water supply
More frequent and longer periods of soil moisture deficit affecting crops
Increased demand for irrigation water
Longer periods of low flow affecting water users including industries, electricity generation and irrigation