10

Hydrologic Regimes under Climate Change in Indo-gangetic Basin and their Impact on Fruit Production

Gopal Krishan and A.K. Lohani

Although India's share in the world's population is 17.5 % but it has approximately 4% of the total available fresh water resources (Kumar and Kumar, 2013). Among these, groundwater resources are depleting at an alarming rate and in the surface water resources, except a few perennial rivers most of the rivers are seasonal and rainfed. Climate change can severely threaten India's water security and India's hydro-climatic regime is expected to alter significantly over the course of the 21st century which will ultimately affect the food security of India. Various researchers have reported a change in the climate of India and alteration in the hydrological regimes.

There is a broad consent that climate change is a current observed fact that will be predictably leading to alterations to the hydrological cycle like change in temperature and precipitation, receding of glaciers, snowfall etc. which will be harmful to man and environment. Majority of the researchers based on their observations and analyses will find that the anthropogenic activity leading to emission of green house gases is the main factor behind the global warming while the researchers believing the natural reason for this are in minority. It is certain that the temperature will rise and warming will be persistent for the coming years causing many changes in the environment including the significant effect on water resources in form of draughts and floods in all over the World. A detailed basin wise understanding of climate change variations in space and time is vital in order for human society to adapt and survive. Here some issues related to climate change on vulnerability and sustainability of water resources for the mankind in context of fruit production are discussed.

Water resource has become a prime concern for any development and planning including food production, flood control and effective water resource management. Studies have demonstrated that global surface warming is occurring at a rate of 0.74 ± 0.18 °C over 1906–2005 (IPCC, 2007). Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, decrease in annual average runoff and availability of water will project up to 10–30% (IPCC, 2007). Various researchers have contributed to the study of climate change with long term data. Study of different time series data has proved that trend is either decreasing or increasing, in case of rainfall. Human interference is also leading to climate change with changing land use from the impact of agricultural and irrigation practices.

The effects of climate change on fruits are considered on the aspects of their reaction to the changing climate variables like increased risks of spring frost, new destructive diseases or pests, hails, floods and droughts for simulating it through the use of a model.

The main focused points in the study of climate change are:

To create scenario over the next century and beyond to find out the amplitude and rate of global climate change; to express the global mean climate in terms of extreme droughts and floods, sea level changes, groundwater recharge, soil degradation, deforestation, loss of biodiversity, and changes in ecosystem functioning, especially in view of the human-induced greenhouse effect; and to assess impact of the complex changes on vulnerability and sustainability of water resources.

Indo-Gangetic Basin (IGB)

The Indo Gangetic Basin (IGB) alluvial aquifer system is one of the world's most important water resources which is formed with sediments eroded from the Himalayas by the Indus, Ganges and Brahmaputra rivers and is spread in a flat fertile plain across Pakistan, northern India, southern Nepal and Bangladesh (Figure 1).

Climate Change Impacts

Kothyari and Singh (1996) investigated the rainfall and temperature trends of the Ganga basin in India. Long-term data on the monsoon and annual rainfall and the average annual temperature and on the monsoon rainfall, number of rainy days and annual maximum temperature of the Ganga basin were analyzed. The trends in these data are detected using non-parametric methods. The results of this study showed that the rainfall variables have a decreasing trend and the temperature has an increasing trend. These trends were observed to have begun around the second half of the 1960s, and have implications for the Indian economy. As the Indian economy continues to be based on agriculture, water resource management for irrigation plays a vital part in its growth.

Nityanand and Sontakke (2002) reported on the climatic fluctuations and environmental changes of the Indo – Gangetic plain region (IGPR) (Geographical area-600000 Km^2) of India is very important for the flood security of South Asia. Literatures provided the detailed documentation of environmental changes due to different factors of importance except climatic parameters like rainfall amounts (1829-1999). Summer monsoon rainfall showed increasing trend (170mm/100-yr) from 1900 while over central IGPR. Analysis suggested westward shift in the occurrence of sever rainstorms. Spatial changes in rainfall activities were attributed to global warming and associated changes in the Indian summer monsoon circulation and the general atmospheric circulation. The annual surface air temperature of the IGPR showed rising trend (0.53^oC /100-yr, significant at 1% level). Meteorological factors like strength and direction of low level winds and spatial shift in rainfall/climatic belt also play a significant role along with tectonic distribution and local sedimentological adjustment in the vagrancy of the river courses over the IGPR.

Some of the impacts of the climate changes in the IGB or in general are summarized below:

Receding glaciers

There are various reports and estimates of the numerous researchers that the glaciers are receding mainly in the western Himalayas which may be possibly as a result of : increase in temperature, change in precipitation and due to excessive snow melt.

Available records suggest that the Gangotri glacier is retreating at about 28 metres per year. However, as the melting of glaciers intensifies their shrinkage will also become more rapid. This rapid glacial recession will reduce the summer and autumn water flow in the river systems in long term (Rajya Sabha Secretariat, 2008). For example, water flow in the river Ganga could drop by two-thirds affecting more than 400 million people who depend on it (Sharma and Sharma, 2008).

Glacial lake outbursts

Glacial lake outbursts will increase the chances of landslides in the upper regions. INCCA report deals with the projected impact of climate change on the water resources of India in the river basins of four regions namely Himalayan, North-eastern, Western ghat and Coastal regions (on short term basis) in 2030s (Kumar and Kumar, 2013).

Effects on river course

A serious environmental problem has also been witnessed in the Indus-Gangetic plain region where some of the river systems have changed their courses many times (Kumar and Kumar, 2013). For example river Kosi caused heavy flood in Bihar and Nepal when it changed its course (Rajya Sabha, 2008). How the reduced snow cover will affect the water security can simply be deduced from the fact that the Himalayan glaciers provide 30-40% of the water supply of the river Ganga and 70-80% of the Indus water supply (Sharma and Sharma, 2008).

Kumar and Kumar (2013) reported that the initial increase in volume of river waters in the Himalayan region due to enhanced glacial melting and increased precipitation in short term will be followed by decreased water flow in these river basins. This is because as the glaciers disappear, the only source of water for these river systems will be rainfall. Himalayan glaciers provide 30-40% of the water supply of the river Ganga and 70-80% of the Indus water supply. In these scenarios these river systems could also become seasonal which will be a huge catastrophic event.

Temperature variations

Increased temperature will affect the hydrological regime of the Indian subcontinent. As arrival and withdrawal of the monsoon are temperature related events, increased temperature is sure to alter the pattern and distribution of the Indian monsoon. Rainfall is expected to increase in intensity accompanied by decrease in the number of rainy days. Significant changes in rainfall pattern have already been witnessed in India in recent times.

For estimating the change in temperature though, various models have been proposed but it is estimated the increase in average temperature on global level is 1^0C, however the estimates may vary depending on various conditions.

Globally, warming is expected to be the greatest over land and at the highest northern latitudes, and least over the Southern Oceans and parts of the North Atlantic Ocean.

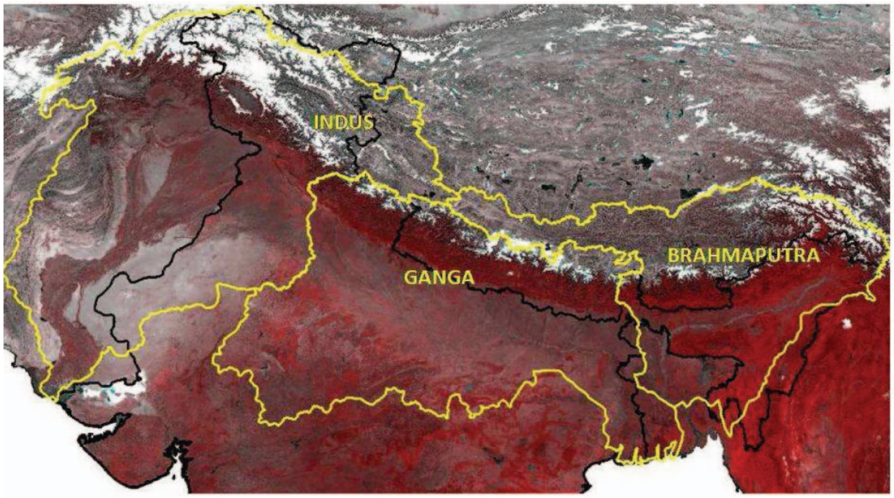

Fig. 1: Indo-Gangetic basin (IGB)

Precipitation variations and extremes

There is a great possibility in continuation and frequent happenings of events like hot extremes, heat waves and heavy precipitation and there will be increased precipitation at high latitudes, which will be decreased in most subtropical land regions.

Though glacial sources make Indus-Ganga-Brahmaputra river systems perennial, monsoonal rainfall is primarily responsible for their large annual volume. More intense rainfall concentrated over a few days along with large glacial melt will increase the chances of flash floods in the river basins in short term (Raj, 2010).

Mark *et al* (2012) reported ensemble mean precipitation anomalies under three emission scenarios, SRESA1B, SRESA2 and SRESB1 relative to 1970-1999 for 2030s, 2050s and 2090s (Fig. 2). It was found by Mark *et al* (2012) that in all three emissions scenarios, the ensemble mean precipitation over each domain increases in pre-monsoon, monsoon and post-monsoon seasons. In all cases, however, the inter-model spread is large, and the inter-model range spans zero, indicating that reductions in rainfall cannot be ruled out. For the winter season, ensemble mean rainfall shows small reductions, while the pre-monsoon, monsoon and post monsoon seasons show increased rainfall. Comparing seasons, the change is less during *rabi* and winter seasons (not more than ±0.06 mm/day) and the greatest during the monsoon season with the three

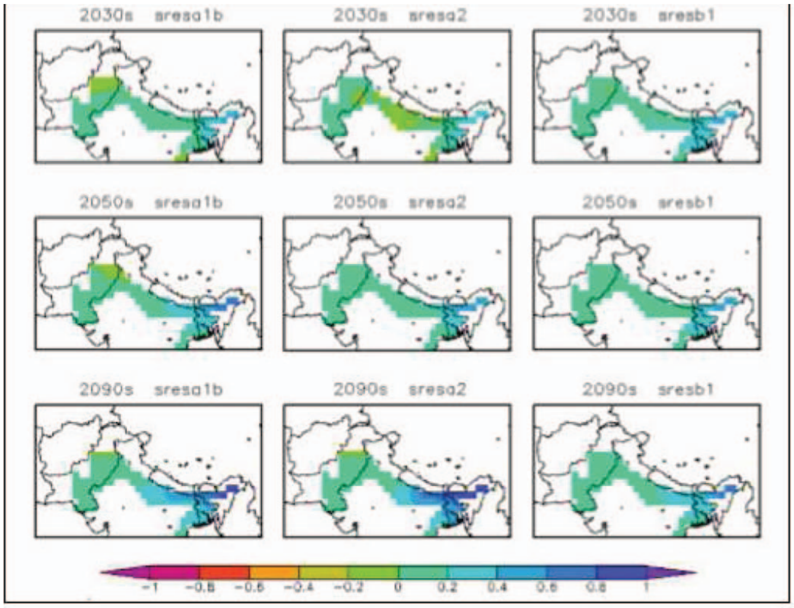

Fig. 2: Ensemble mean precipitation anomalies (mm/day) relative to 1970-1999 for 2030s, 2050s and 2090s under the three emission scenarios. Figures shown are for annual cycle (Mark *et al.,* 2012).

periods registering a change of more than 0.1 mm/day for the three emission scenarios. When the Indus and Ganges are considered separately, the latter shows a larger increase in ensemble mean precipitation change in the monsoon season, with a greater number of models showing increased precipitation. Thus, if the climate model projections are taken at face value, there is a more consistent signal of increased precipitation for the Ganges than the Indus.

Sea level rise

It has been expected that sea levels at the end of the twenty-first century are between 0.18–0.38 m globally but an extreme scenario gives a rise up to 0.59 m.

Evapo-transpiration (ET) variations

On the basis of models developed at IIT-Delhi (http://gisserver.civil.iitd.ac.in/natcom/), it was found that ET is decreasing at the end of century which may be due to the following reasons:

- Runoff is fast, temperature is going up, potential ET is increasing, no soil moisture, actual ET comes down

- Due to carbon mitigation, biomass is increasing
- Variation in huge basin irrigation ET will increase not true for rainfed agriculture
- Gap between rainfall is increasing and temperature is also increasing

Impact on agriculture

Changes in rainfall and other forms of precipitation will be one of the most critical factors determining the overall impact of climate change due to uncertainty in its prediction. In a warmer climate heavy rainfall will increase with more intense events leading higher risk of floods and also to longer dry spells or less rainfall with higher risk of drought. Precipitation, especially rain, has a striking effect on agriculture and a regular rain pattern is usually vital to healthy plants, too much or too little rainfall can be harmful, even devastating to crops. Drought can kill crops and increase erosion, while overly wet weather can cause harmful fungus growth. Plants need varying amounts of water to survive. It main effects may be contamination of water, spread of water-borne diseases, shortage of food crops due to loss of entire harvest.

Although agriculture fulfill the needs for food and clothes, short term effects of climate change can be found on crops and live stocks yet the long-term effects of climate change are still largely unknown. Efforts are being made to predict the changes likely to occur in agriculture due to climate change. Researchers are trying to prove about the future changes but plants are amazingly resilient enough to be productive and can withstand a variety of conditions and factors such as location, soil fertility, crop varieties, and management practices will all affect future yields. The cropping calendar and cropping pattern might change.

Patra *et al.* (2005) suggested that the Indian summer monsoon rainfall interplay coupled dynamics, radiation and cloud microphysics, which has a strong connection to agricultural food production, has been less predictable by conventional models in recent times. Two distinct years 2002 and 2003 with lower and higher July rainfall, respectively, are 5 selected to help understand the natural and anthropogenic influences on ISMR. It showed that the heating gradients along the meridional monsoon circulation are reduced due to aerosol radiative forcing and the Indian Ocean Dipole in 2002. An increase in the dust and biomass-burning component of the aerosols through the zonal monsoon circulation resulted in reduction of cloud droplet growth in July 2002. These conditions were opposite to those in July 2003 which led to an above average

ISMR. In this study, utilized the NCEP/NCAR reanalyzed for meteorological data (e.g. sea-surface temperature, horizontal winds and precipitable water), NOAA interpolated outgoing long-wave radiation, IITM constructed all-India rainfall amounts, aerosol parameters as observed from the TOMS and MODIS satellites, and ATSR fire count maps. Based on this analysis, suggested that monsoon rainfall prediction models should include synoptic as well as interannual variability in both atmospheric dynamics and chemical composition.

Scientists believe that increasing atmospheric CO_2 results in more plant growth, higher harvestable crop yields depending on the availability of sufficient water and essential nutrients for plant growth but may be with lower nutrient and protein levels.

Some other effects of global warming are that weeds are expected to invade new habitats, herbicides become less effective, insect pests could become more prolific and widespread and there is possibility that they could spread crop diseases into new production areas.

Changes in climate may also impact the water availability and water needs for agriculture. Widespread increased humidity will slow transpiration which is overshadowed by the lack of available water due to increased droughts and heat waves.

To overcome these, scientists need to develop new varieties of crops that are considered to be drought tolerant, and more adaptable to varying levels of temperature and moisture.

Impact on fruit production

The fruit crops change the adaptability as per the climatic conditions which has been seen in phase of dormancy enabling the fruit and nut species to withstand winter temperatures in their original habitat (Hribar and Vidrih, 2015) they further reported that strategies like cultivar selection, dormancy avoidance (defoliation), manipulation of microclimate (irrigation), application of colour sheds and chemicals that trigger dormancy must be examined for overcoming dormancy requirements.

Higher temperature provokes faster tree maturation of fruits resulting in earlier harvest date upto two weeks advance. Fruits are known to mature normally at temperature as high as 35°C, but at higher temperatures ripening processes are blocked. Hribar and Vidrih, (2015) reported that due to the combined effect of elevated temperature and CO_2 level, a decrease in starch, soluble sugars, proteins and majority of minerals and increase in oil content is observed.

The fruits and vegetables grown under elevated temperature and CO_2 level contain more phenols and ascorbic acid.

Venkateshwarlu and Rao (2013) reported a significant decrease in average productivity of apples in Kullu and Simla districts of Himachal Pradesh which is attributed mainly to inadequate chilling required for fruit setting and development. Reduction in cumulative chill units of the coldest months might have caused shift of the apple belt to higher elevations of Lahaul-Spitti and upper reaches of Kinnaur districts of Himachal Pradesh. In general temperature below 7^0C for total 800-1400 hours is taken as chilling requirement of apple; however temperature below 1^0C and above 18^0C is not desired for chill units accumulation.

Impact on groundwater

Groundwater will be vital to improve some of the worst drought situations and for this the hydrogeological research should be focused to mitigate the likely impacts. On the earth the fresh water contribution is only 2-3% and out of which between 13% and 30% is of groundwater, providing 15% of the water used annually. Groundwater is stored in the aquifers which mitigate droughts due to their high storage capacity and are not that much sensitive to climate change than surface water bodies.

Groundwater is the major source of water in India with 85% of the rural population dependent on it (Water aid, 2008). Moreover, 50% of the urban requirements of the fresh water are met through the ground water extraction (CGWB, 2011). Ground water has two components-static and dynamic. The static fresh groundwater reserve i.e. aquifer zones below the zone of groundwater table fluctuation has been estimated at 10,812 BCM. National Water Policy allows only development of dynamic ground water resources and forbids static ground water resources mining (INCCA, 2010).

For irrigation and food production unsustainable abstraction of groundwater continues to be a water resource challenge facing many alluvial aquifer systems globally. Semi-arid terrain of north-west India is the prime example of this which is a major area for wheat, rice and sugarcane cultivation. In this region, the sustained growth in the agricultural sector has only been possible through the use of irrigation from shallow local groundwater sources as well as an extensive canal network redistributing water from the Himalayan watershed to the plains (Rodell *et al.,* 2009; Tiwari *et al.,* 2009; Wada *et al.,* 2012).

***Methods/tools to study groundwater and climate change*:**

Various methods and tools to study the groundwater and climate change are as below:

- Understanding of the geology and hydrogeology of the study system
- Collection of long time reliable, continuous and good database of hydrometeorological data and soil moisture.
- Remote sensing: It provides a convenient way of assessing the spatial and temporal variations in water fluxes in different components of the water cycle. Eg. GRACE (Gravity Recovery And Climate Experiment) satellite is aimed at observing the gravity field to a high accuracy (c. 1 cm in terms of geoid height and a spatial resolution of 200–300 km). Any redistribution of water masses in different parts of water cycle may result in time variation of gravity field.
- Use of robust models: Numerical hydrological and hydrogeological models, in spite of being a simplified representation of reality, are invaluable tools for describing and understanding hydro-geological processes. The model serves both the understanding the system and prediction, once the model is validated and calibrated using historical data. Models should ensure internal consistency, compatibility with uncertainties, compatibility with constraints of data and robust performance.
- Continuous/dedicated monitoring like flow in both the unsaturated zone and the saturated zone and various water quantity and quality issues can be accounted for depending upon the boundary conditions, subsurface properties and various processes.
- Isotope methods (Krishan, 2015g): Tracer techniques can be used to find out oxygen and carbon isotope composition of benthic and planktonic foraminifera; hydrogen and oxygen isotopic ratios of organic matter; ice cores; carbon and oxygen composition of carbonates, cave deposits, lake and groundwater. In addition to these the isotope techniques can be used to find out the recharge sources, zones, source identification and finding the residence times.

Chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6)

Chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6) are important trace gases for finding the groundwater residence time (Darling *et al.*, 2012, Krishan, 2015g). The build-up in the atmosphere of these gases since 1930s from anthropogenic organic compounds ranging from aerosol propellants to refrigerants offers a suitable way of dating waters up to ~60 yrs old. However as a result of various environmental regulations limiting the use of CFCs, current production estimates are less than half of the peak values of the late 1980s.

CFC-11 ($CFCl_3$), CFC-12 (CF_2Cl_2) and CFC-13 ($C_2F_3Cl_3$) have relatively long residence times in the atmosphere (44, 180 and 85 years, respectively), where they undergo equilibration with surface waters as a function of temperature.

Noble gases

The noble gases make a group of chemical elements with similar properties. Under standard conditions, they are all odorless, colourless and monatomic gases with very low chemical reactivity. The six noble gases that occur naturally are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and the radioactive radon (Rn). Noble gases have been measured in seawater, groundwater, ice cores, and rocks to address a variety of important problems in environmental science such as air-sea gas exchange, marine biological production, groundwater temperatures, firn temperature and thickness, surface exposure ages, etc.

Stable isotopes

The atoms of an element which do not decay with time or take infinite time to decay are called stable isotopes. Water stable isotopes ($d^{18}O$ and d^2H) are tracers of physical processes water molecules undergo between evaporation from the ocean and arrival in the aquifer via recharge by rainfall (Clark and Fritz, 1997; Krishan *et al,* 2012a,b; 2013a,b; 2014d,f; 2015e) and are considered powerful tool to trace the origin and movement of water throughout the hydrological cycle. As H_2O molecules travel through hydrological cycle, various isotopic molecular species, having different isotopic combinations of oxygen (^{18}O and ^{16}O) and hydrogen (^1H and ^2H or D) in them are differentially partitioned between vapour, liquid and solid phases, imparting distinguishable isotopic signature to all the three phases. Long-term average amount weighted isotope values for precipitation can be used to compare with groundwater isotope values to understand recharge sources and processes (Lapworth *et al.,* 2014b, 2015).

A water molecule is formed by combination of two hydrogen atoms (any two of the two stable isotopes; ^1H and D) and one oxygen atom (any one of the three stable isotopes ^{16}O, ^{17}O, and ^{18}O). Thus, 9 possible combinations of these 2 isotopes of hydrogen and 3 isotopes of oxygen are possible and the four most abundant isotopic molecules of water are given in Table 1 along with their relative abundance and molecular masses.

Table 1: The four most abundant isotopologues of water and their molecular masses.

Isotopologue	$H_2{}^{16}O$	$H_2{}^{18}O$	$H_2{}^{17}O$	$HD^{16}O$	$D_2{}^{16}O$
Relative natural abundance	99.78%	0.20%	0.03%	0.0149%	0.022 ppm
Molecular mass	18	20	19	19	20

Environmental tritium

Tritium - the radioactive isotope of hydrogen released from thermonuclear explosions in the atmosphere made possible a way for groundwater age dating and recharge estimations. The cosmogenically produced tritium is found entirely in atmospheric vapour and is brought down to earth's surface by precipitation. Before 1952, the tritium concentration in precipitation was low. When thermonuclear tests in the atmosphere began in 1952, tritium concentrations in precipitation suddenly increased and reached a record-high concentration in 1963-64 in the northern hemisphere.

Radioactive isotope of hydrogen, ^3H (tritium or T), originates (as does ^{14}C) from a nuclear reaction between atmospheric nitrogen and thermal neutrons (Libby, 1946):

$$^{14}N \rightarrow {}^{12}C + {}^3H$$

^3H enters the hydrologic cycle after oxidation to $^1H^3HO$ and finally decays according to:

$$^3H \rightarrow {}^3He + ß\text{-}$$

with E_{bmax} = 18 keV and a half-life of 12.430 years (Unterweger *et al.,* 1980).

To clearly understand the residence time of the groundwater in different aquifers the environmental tritium is also a good option where we have to analyse the samples of rain, river and groundwater samples.

These issues can be resolved understanding the following key points:

1. Improving institutional capacity
    - Use of state of art instrumentation techniques
    - Establishment of measurement stations
    - Development of appropriate models
2. Development and management of water resources
    - Identification and selection of site
    - Collection of historical hydro-meteorological data

- Construction of water harvesting structures
- Slope stability
- Precision farming

3. Adaptations to flood and droughts
    - Identifying hotspots of extreme events
    - Adaptation to change in weather pattern
    - Shift in agricultural practices
    - Development of model villages
    - Early warning systems
    - Water conservation
    - Interlinking of rivers
4. Awareness raising
    - People participation
    - Awareness programs for diseases and pest attacks in fruit crops
5. Quality maintenance along with development
    - Environment impact assessment
    - Policy for afforestation/deforestation
    - Water distribution policy

References

Brenninkmeijer, C.A.M. and Morrison, P.D. 1987. An automated system for isotopic equilibration of CO_2 and H_2O for ^{18}O analysis of water. Chem. Geol., 66, 21-26.

Burnett WC. and Dulaiova H., 2003. Estimating Sekulic the dynamics of groundwater input into the coastal zone via continuous radon-222 measurements. J Environ Radio act 69, 21–35.

Central Ground Water Board (CGWB). 2011. Dynamic Ground water Resources of India (As on 31 March, 2009), Ministry of Water Resources, Government of India.

Chopra, R.P.S. and Krishan, Gopal. 2014a. Analysis of aquifer characteristics and groundwater quality in southwest Punjab, India. Journal of Earth Science and Engineering. 4(10): 597-604.

Chopra, R.P.S. and Krishan, Gopal. 2014b. Assessment of groundwater quality in Punjab. Journal of Earth Science and Climate Change. 5(10):243.

Clark, I.D and Fritz, P. 1997. Environmental Isotopes in Hydrogeology. Lewis Publishers, Boca Raton.

Darling, W G, Gooddy, D C, MacDonald, A M and Morrris, B L . 2012. The practicalities of using CFCs and SF_6 for groundwater dating and tracing. Applied Geochemistry. 27(9):1688-1697.

Dragoni, W and Sukhija, B.S. 2008. Climate change and groundwater-a short review. Geological society London, 288 (1-12).

Edmunds, W.M., Guendouz, A.H., Mamou, A., Moulla, A., Shand, P., and Zouari, K. 2003. Groundwater evolution in the Continental Intercalaire aquifer of southern Algeria and Tunisia: trace element and isotopic indicators. Applied Geochemistry, 18(6), 805-822.

Epstein S. and Mayeda T. 1953. Variations of the 18O/16O ratio in natural waters. Geochimica et Cosmochimica Acta, 4, 213-224.

Hribar, J. and Vidrih, R. 2015. Impacts of climate change on fruit physiology and quality. (In) Proceedings of 50th Croatian and 10th International Symposium on Agriculture . Opatija . Croatia. 42–45 pp.

IAEA (International Atomic Energy Agency), 2006. Use of Chlorofluorocarbons in Hydrology: A Guidebook, STI/PUB/1238, 277 pp. Obtainable from http://www-pub.iaea.org/MTCD/publications/PDF/Pub1238_web.pdf.

Indian Network for Climate Change Assessment (INCCA). 2010. Report # 2., Climate Change and India: A 4X4 Assessment, A Sectoral and Regional Analysis for 2030s, Ministry of Environment and Forests, Government of India.

IPCC-TGICA. 2007. General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 2. Prepared by T.R. Carter on behalf of the Intergovernmental Panel on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assessment.

Kothyari, U.C. and Singh, V. P. 1996. Rainfall and Temperature Trends in India, Journal of Hydrological Processes, 10: 357-372.

Krishan, Gopal, Rao, M.S., and Kumar Bhishm. 2012a. Study of climatological conditions using isotopic signature of air moisture at Roorkee, Uttarakhand, India. NDC-WWC Journal. 1 (2):5-9.

Krishan, Gopal, Rao, M.S. and Kumar, Bhishm. 2012b. Application of Isotopic Signature of Atmospheric Vapor for Identifying the Source of Air Moisture-An Example from Roorkee, Uttarakhand, India. Journal of Earth Science and Climate Change 3:126. doi:10.4172/2157-7617.1000126

Krishan, Gopal, Rao, M.S., Jaiswal, R.K., Kumar, Bhishm and Kumar, C.P. 2013a. Southwest (SW) monsoon dynamics study in Indo-Gangetic plains using isotopic techniques. Journal of Geology and Geosciences. 2:119. http://dx.doi.org/10.4172/jgg.1000119

Krishan, Gopal, Lohani, A.K., Rao, M.S., Kumar, C.P., Kumar, Bhishm, Rao, Y.R.S, Jaiswal, R.K., Thayyen, J., Renoj and Tripathi, Shivam 2013b. Studying Dynamics of the South West Monsoon in Indian Sub-Continent through Geospatial Correlation of Isotopes in Air Moisture. Journal of Geology and Geosciences 3:139.

Krishan, Gopal, Lohani, A.K., Rao, M.S. and Kumar, C.P. 2014a. Prioritization of groundwater monitoring sites using cross-correlation analysis. NDC-WWC Journal. 3 (1): 28-31.

Krishan, Gopal, Rao, M.S., Loyal, R.S., Lohani, A.K., Tuli, N.K., Takshi, K.S., Kumar, C.P., Semwal, P and Kumar Sandeep. 2014b. Groundwater level analyses of Punjab, India: A quantitative approach. Octa Journal of Environmental Research. 2(3): 221-226.

Krishan Gopal, Lapworth D. J., Rao M. S., Kumar C. P., Smilovic M. and Semwal P. 2014c. Natural (Baseline) Groundwater Quality In The Bist-Doab Catchment, Punjab, India: A Pilot Study Comparing Shallow and Deep Aquifers. International Journal of Earth Sciences and Engineering, 7 (01): 16-26.

Krishan, G, Rao, M.S., Kumar, B., Kumar, C.P., Kumar, S., Jaiswal, R.K., Rao, Y.R.S., Tripathi, S., Kumar, M., Garg, P.K. and Kumar, P. 2014d. Monitoring of Southwest Monsoon using isotope analysis of ground level vapour (Glv) in Indian Sub-Continent. Journal of Earth Science and Climate Change. 5:224. http://dx.doi.org/10.4172/2157-7617.1000224

Krishan Gopal. Rao, M.S. and Kumar C.P. 2014e. Estimation of Radon concentration in groundwater of coastal area in Baleshwar district of Odisha, India. Indoor and Built Environment. DOI: 10.1177/1420326X14549979

Krishan, Gopal, Rao, M.S. and Kumar, C.P. 2014f. Isotopes analysis of air moisture and its application in hydrology. Journal of Climatology and Weather Forecasting. 2:106. http://dx.doi.org/10.4172/2332-2594.1000106

Krishan Gopal, Singh, R.P. and Takshi, K.S. 2015a. Water Level Fluctuation as the Sum of Environmental and Anthropogenic Activities in Southeast, Punjab (India). Journal of Environmental and Analytical Toxicology. 5: 298.

Krishan, G., Saini, R., Tuli, N.K. and Kaur, G. 2015b. Assessment of groundwater quality in Baddi catchment, Solan, Himachal Pradesh, India. IWRA (India) Journal. 4(2): 25-30.

Krishan, Gopal, Lohani, A.K., Rao, M.S., Kumar, Sudhir and Takshi, KS. 2015c. Spatiotemporal Variability Analysis of Groundwater Level for Water Resources Development and Management in Northern Punjab, India. Journal of Environmental and Analytical Toxicology. 5(4):279.

Krishan, Gopal, Rao, M.S., Kumar, C.P., Kumar, Sudhir, Rao and M. Ravi, Anand. 2015d. A study on identification of submarine groundwater discharge in northern east coast of India. Aquatic Procedia. 4: 3-10.

Krishan, Gopal, Rao, M.S., Kumar, Bhishm and Kumar, C.P.2015e. Possibility of using isotopic composition of ground level vapour (Glv) for monitoring arrival and withdrawal of southwest monsoon. Current Science. 108 (5):784-786.

Krishan Gopal. Rao, M.S. and Kumar C.P. 2015f. Radon Concentration in Groundwater of East Coast of West Bengal, India. Journal of Radioanalytical and Nuclear Chemistry. 303(3): 2.

Krishan, Gopal. 2015. Environmental tracer techniques in groundwater investigations. Water and Energy International. 58 (7): 57-63.

Kumar, M and Kumar, P.P. 2013. Climate Change, Water Resources and Food Production: Some Highlights from India's Standpoint. International Research Journal of Environment Sciences. 2(1): 79-87.

Lapworth, D.J., Krishan, G., Macdonald, A.M., Rao, M.S., Gooddy, D.C. and Darling, W.G. 2014a. Using Environmental Tracers to Understand the Response of Groundwater Resources in Nw India to Sustained Abstraction. In Proc. of 41st International Conf. of International Association of Hydro-geologist (IAH-2014) on Groundwater: Challenges and Strategies during Sep. 18-19, 2014. at Marrakech Morocco.

Lapworth, Dan, Krishan, Gopal, Rao, MS and MacDonald, Alan, 2014b. Intensive Groundwater Exploitation in the Punjab – an Evaluation of Resource and Quality Trends. Technical Report. NERC Open Research Archive, BGS-UK, OR-14-068, 34pp

Lapworth DJ, MacDonald AM, Krishan G, Rao MS, Gooddy DC and Darling WG. 2015. Groundwater recharge and age-depth profiles of intensively exploited groundwater resources in northwest India. Geophys. Res. Lett., 42

Lee J.M. and Kim G., 2006. A simple and rapid method for analyzing radon in coastal and ground waters using a radon-in-air monitor. J Environ Radioact 89:219–228

Libby W.F. 1946. Atmospheric Helium Three and Radiocarbon from Cosmic Radiation. Physical Review 69 (11–12): 671–672.

Macdonald, Alan, Bonsor, Helen, Rao, M. Someshwar, Krishan, Gopal , Steenburgen, Frank Van, Ahmed, Kazi, Shamsudduha, Mohammad, Dixit, Ajaya and Moench, Marcus. 2013 Groundwater Topologies In the Indo Gangetic Basin, In Proc. of International Conf. on Advances in Water Resources Development and Mangement held at PU, Chandigarh during Oct. 23-27, 2013. P: 2

Macdonald, A. M., Bonsor, H. C., Krishan, Gopal , Rao, M. S., Ahmed, K.M., Taylor, R.G., Shamsudduha, M., Steenburgen, F Van, Mackenzie, A.A., Dixit, A, Moench, M and Tucker, J. 2014. Groundwater in the Indo Gangetic Basin: Evolution of Groundwater Typologies. In Proc. of 41st International Conf. of International Association of Hydrogeologist (IAH-2014) on Groundwater: Challenges and Strategies during Sep. 18-19, 2014. at Marrakech Morocco.

MacDonald AM, Bonsor HC, Taylor R, Shamsudduha M, Burgess WG, Ahmed KM, Mukherjee A, Zahid A, Lapworth D, Gopal K, Rao MS, Moench M, Bricker SH, Yadav SK, Satyal Y, Smith L, Dixit A, Bell R, van Steenburgen F, Basharat M, Gohar MS, Tucker J, and Maurice L. 2015. Groundwater Resources in the Indo-Gangetic basin- Resilience to climate change and abstraction. British Geological Survey Open Report, OR/15/047, 63pp

Mark New, Muhammad Rahiz and Jagadishwor Karmacharya. 2012. Climate Change in Indo-Gangetic Agriculture: Recent Trends, Current Projections, Crop-climate Suitability, and Prospects for Improved Climate Model Information. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark.

Moore, W.S, 1996. Large groundwater inputs to coastal waters revealed by Ra-226 enrichments. Nature 380, 612–614.

Oster, H .1994. Dating groundwater using CFCs: conditions, possibilities and limitations (Datierung von Grundwasser mittels FCKW: Voraussetzungen, Möglichkeiten und Grenzen). Dissertation, Universität Heidelberg

Patra, P.K., Maksyutov, S., Ishizawa, M., Nakazawa, T., Takahashi, T. and Ukita, J. 2005. Interannual and decadal changes in the sea-air CO_2 flux from atmospheric CO_2 inverse modeling. Global Biogeochemical Cycles 19.

Raj A. 2010. Water security in India: The Coming Challenge, Future Directions International, http://www. futuredirections.org.au /files/......,

Rajya Sabha Secretariat. 2008. Climate Change: Challenges to Sustainable Development in Inda, Occasional Paper Series (3), New Delhi, India.

Rao, M. S., P. Purushothaman, G. Krishan, Y.S. Rawat, and Kumar, C.P. 2014. Hydrochemical and isotopic investigation of groundwater regime in Jalandhar and Kapurthala districts, Punjab, India. Int. J. Earth Sci. Eng., 7 (1): 6-15.

Rodell, M., I. Velicogna, and Famiglietti, J.S. 2009. Satellite-based estimates of groundwater depletion in India. Nature, 460(7258): 999-1002.

Sekulic B and Vertacnik A. 1996. Balance of average annual fresh water inflow into the Adriatic Sea. Water Resour. Development 12: 89-97.

Sharma B.R. and Sharma D. 2008. Impact of Climate Change on Water Resources and Glacier Melt and Potential Adaptations for Indian Agriculture, Keynote Address at 33rd Indian Agricultural Universities Association Vice Chancellors' Annual Convention on "Climate Change and its Effect on Agriculture",; Anand Agricultural University, Anand (Gujarat), India (Convention Proceedings Page 86101, IAUA, NASC Complex, Pusa, NewDelhi, India)

Singh, Nityanand and Sontakke, N.A. 2002. On Climatic Fluctuations and Environmental Changes of the Indo-Gangetic Plains, India, Climatic Change, 52: 287-313.

Stute, M., J. F. Clark, P. Schlosser, W. S. Broecker, and Bonani, G. 1995. A 30,000 yr continental paleotemperature record derived from noble gases dissolved in groundwater from the San Juan Basin, New Mexico, Quat. Res., 43(2), 209-220.

Tiwari, V. M., J. Wahr, and S. Swenson. 2009. Dwindling groundwater resources in northern India, from satellite gravity observations, Geophys. Res. Lett., 36(18).

Unterweger, M.P., B.M. Coursey, F.J. Schima and W.B. Mann 1980 Preparation and calibration of the 1978 National Bureau of Standards tritiated-water standards. Int. J. Appl. Radiat. Isotopes, 31, 611-614.

Wada, Y., L. Beek, and M.F. Bierkens. 2012. Non-sustainable groundwater sustaining irrigation: A global assessment. Water Resour. Res., 48(6).

Water Aid. 2008. Drinking Water Quality in Rural India: Issues and Approaches, http://www.wateraid.org/.....water.pdf, Accessed on 05.04.2010.

Venkateswarlu, B. and Rao, V. 2013. Climate Change and Its Impact on Indian Agriculture. Climate Change Modeling, Mitigation, and Adaptation: pp. 419-453.