East African Journal of Biophysical and Computational Sciences

Journal homepage : https://journals.hu.edu.et/hu-journals/index.php/eajbcs

Climate change, freshwater ecosystems and inland fisheries: implications for the developing nations

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KEYWORDS:

Climate change;
Fisheries;
UNFCC;
Drivers;
Hydrology;
Livelihood

ABSTRACT

Freshwater ecosystems are vital for ensuring drinking water supplies, bio-resources that support livelihood, and a wide array of ecosystem services. Further, they are among the key components in achieving the United Nations Sustainable Development Goals (UN SDGs) set for the year 2030, including poverty reduction, food security, clean water and sanitation, conservation of biodiversity and climate action. The aquatic ecosystems globally are susceptible to the impacts of climate change much more than terrestrial and marine ecosystems, impacting the livelihood of fishers and farmers depending on it. Climate change is expected to adversely affect the sustainable development capabilities of many Asian and African nations by putting more pressures on natural resources and the environment. This article reviews the impact of climate change on freshwater ecosystems and fisheries and addresses the key adaptation, mitigation and management strategies to address the issue of climate change.

INTRODUCTION

Water is inextricably linked to the development of all societies and cultures and is an integral component in all the major pillars of sustainable development including economic, social and environmental. Moreover, healthy freshwater ecosystems provide both direct and indirect services to mankind and serve as key components in achieving the United Nations Sustainable Development Goals (SDG) set for the year 2030. Unsustainable development pathways and anthropogenic interventions such as population growth, urbanization, changing patterns of consumption and climate change have affected the quality and quantity of water availability across the globe, despite the increasing demands for freshwater and the resources therein (WWAP, 2015).

One of the requirements for sustainable development of water resources is to balance the gap between demand and supply, both in terms of quality and quantity. However, climate

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change may affect both sides of the balance, thereby add to the challenges (IPCC, 2014). Global warming and the resultant climate change is occurring at an unrivalled pace in human history (Barros et al., 2014), showing progressive threat to freshwater ecosystems (O'Gorman et al., 2014; Li et al., 2016).

Under current climate projections, most freshwater ecosystems will face ecologically significant climate change impacts by the middle of this century (IPCC, 2014). Most freshwater ecosystems have already begun to feel these effects. These impacts will be largely detrimental to the existing freshwater species and human livelihoods. The impact of climate change may vary in different types of aquatic ecosystems, and also within the same ecosystem such as a river and many impacts remains to be documented in many countries of Asia and Africa.

Considering the world's weather-and climate-related disasters, Asia has encountered the maximum, resulting in colossal economic loss (IPCC, 2012). Freshwater species populations have declined on an average by 50 per cent, when compared to 30 per cent for marine and terrestrial species between 1970 and 2000 (MEA, 2005). Climate change is expected to adversely affect the sustainable development capabilities of most Asian and African countries by aggravating pressures on natural resources and the environment. Owing to the thick population and considerable economic dependence on inland fisheries in Asia, freshwater resources need to be carefully assessed and monitored across the wide range of climates (Pfister et al., 2009). According to the report of the Inter governmental Panel on Climate Change (IPCC), global warming will lead to "changes in all components of the freshwater system". Water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change (Bates et al., 2008). According to Sharma et al. (2015), during 2014-2015 the food production in India declined substantially due to droughts, flood, hailstorms and unseasonal rains. Climate change is expected to adversely affect the sustainable development capabilities of many nations by putting more pressures on natural resources and the environment. India stands second in contributing to the global inland fish production and therefore any impacts of climate change on aquatic ecosystems as well as fisheries should be given due recognition.

Blessed with diversified agro-climatic conditions, Kerala state of India is rich in aquatic resources. It has 44 rivers and their numerous tributaries, canals, lakes, ponds etc. which have the potential to emerge and develop and also to contribute to the livelihood and nutritional support to the country. The rivers in Kerala entirely monsoon-fed, some of them nearly turn into rivulets in summer. The state is a part of Western Ghats Sri Lanka biodiversity hot spot with greater endemism of freshwater fauna. Around 130 species of freshwater-dependent fauna belonging to five taxonomic groups (fish, amphibians, crabs, shrimps and odonates) are endemic to the region, of which 25 per cent have a high risk of extinction (Raghavan et al., 2016). Even though the wetlands in dry environments are considered productive, the biodiversity hotspots areas, their flora and fauna are under threat of extinction as the runoff decreases and wetland dries out (Zacharias and Zamparas, 2010).

Even a very small increase in precipitation will have pronounced effects on freshwater ecosystem. The part of Konkan coast and south Kerala are considered as the most vulnerable stretches by India's Second National Communication to United Nations Framework Convention on Climate Change (UNFCCC) (Anonymous, 2012). The natural resources from lakes, rivers, ponds, wetlands, reservoirs and backwaters of Kerala are depleting due to habitat modification and alterations, pollution, eutrophication, invasive species and climate change. These negative effects definitely have adverse impact on the ecosystem. Being a small coastal state located in the tropical region; the climate of Kerala is not exposed to severe fluctuation in terms of most of the meteorological factors except rainfall (Niyas et al., 2017). The rainfall data from the meteorological department also stipulate the declining pattern of northwest and southeast monsoon especially in the hilly areas of south Kerala during the last 60 years. The state receives adequate rainfall (average 3000mm), most of it is obtained via southwest and northeast monsoons. Kerala is advancing towards water crisis owing to the variability in temporal and spatial distribution of rainfall and the steep slope of the state allows almost 75% of rainwater to flow to sea at a much faster rate before exploitation (Nair, 2016).

Most of the species adapt to environmental changes but even then it leads to local or global extinctions and biodiversity loss (Gallo et al., 2017). Unlike marine ecosystem, inland bodies are markedly vulnerable to the climate change. Rise in water surface temperature, changes in primary production and changes in fish stock distribution disrupts habitat destruction, aquatic flora and fauna and prey predator composition which will have a nugatory influence on the resources leading to depletion of fish stock and will definitely jeopardise the livelihood of fishers. All these points towards the need for better policies and framework for dealing matters related to the impacts climate change on aquatic ecosystems and inland fisheries.

DRIVERS OF CHANGE

The freshwater ecosystems are affected by several stressors, of which climate change is by far more critical (Garner et al., 2017). Climatic drivers are the temperature, precipitation, evaporation, sea level, carbon dioxide concentration etc. whereas economic developments, urbanization, increase in population and land use or natural geomorphic changes form the non-climatic drivers. Of these, the main climatic driver which control freshwater resources are the evaporation and precipitation. More intense extreme precipitation events are expected due to climate change (IPCC, 2012). Such drivers question the sustainability of resources by decreasing water supply or increasing demand (Cisneros et al., 2014). The future of freshwater systems will be hit strongly by demographic, socioeconomic, and technological changes, including lifestyle changes. The details of framework and linkages for considering impacts of climatic and social changes on freshwater systems, and consequent impacts on and risks for humans and freshwater ecosystems are provided in Figure 1.

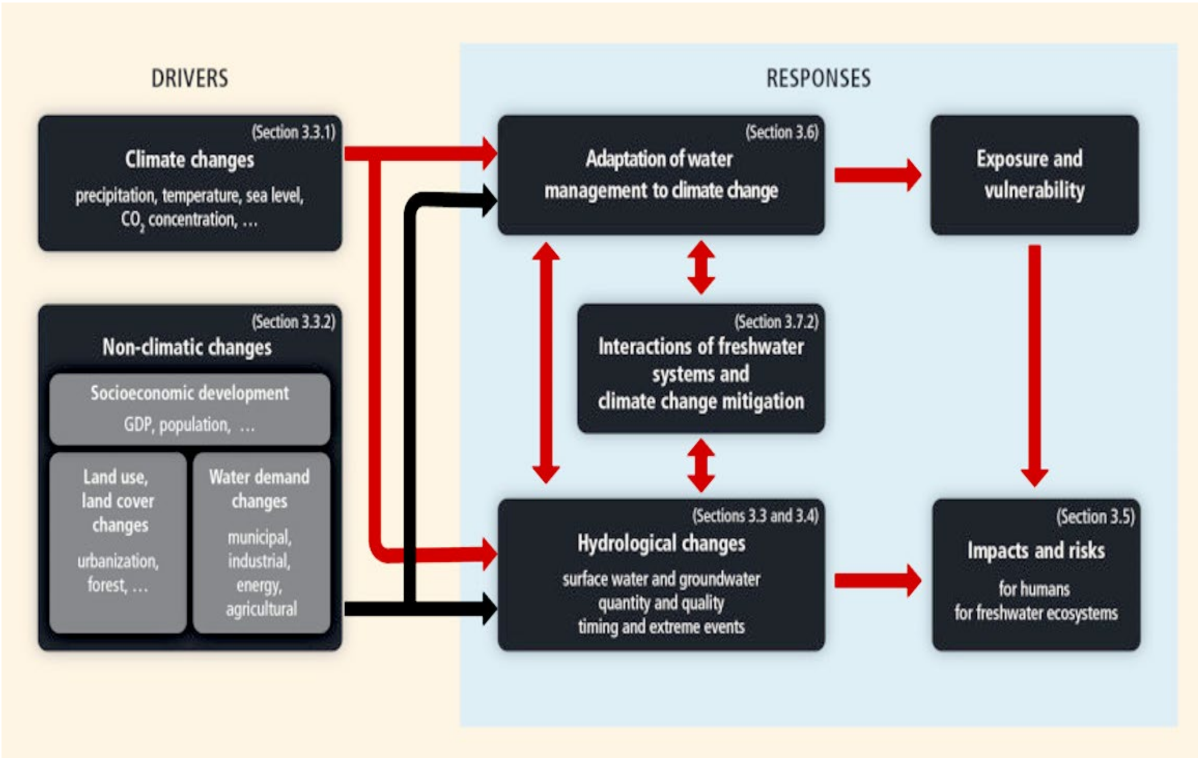

Figure 1. Framework (boxes) and linkages (arrows) for considering impacts of climatic and social changes on freshwater systems, and consequent impacts on and risks for humans and freshwater ecosystems (Source: IPCC report, 2007)

According to VanVuuren et al. (2012) socioeconomic features which include the social, economic, demographic as well as ecological conditions can also create climate changes. Changing land use pattern because of urbanization will also affect freshwater systems strongly. Ninety percent of global water is used for irrigation purpose which will make a severe impact on the freshwater availability to the humans and the ecosystems (Döll, 2009).

Complicated anthropogenic and natural systems working simultaneously influence climate change which affects the quality of water. Water quality projections depends upon climatic and environmental inference, local conditions and also the current state of pollution (Bonte and Zwolsman, 2010; Kundzewicz and Krysanova, 2010; Sahoo et al., 2010; Trolle et al., 2011). Intense effect of climate change includes alteration on hydrological cycle, dried up water resources and thereby its depletion, decline of water table level, saline water intrusion, water logging etc. which causes strain on the availability of drinking water and altered precipitation and unpredictable floods and droughts on inland freshwater wetlands.

The seasonal rainfall in India can be understood from groundwater recharge and the availability of water during summer. Because of increase in population and climate change, per capita availability of freshwater in major river basins is decreasing and degrading at a much faster pace and this will be experienced as water stress in most of the basins by 2030 (Nair, 2016). This will be followed by many serious socio-economic issues like disputes and raising price for water etc. Changes in monsoon patterns cause water stress, decrease in the availability of water in the lakes and rivers of Asia and Africa (IPCC, 2007) causing negative impacts on fish migration, spawning and seed availability for farmers which will also produce less water retention time in non-perennial water bodies (Goswami et al.,2006). In terms of fisheries, African countries are more vulnerable state due to the combined effects of predicted warming, the relative importance of fisheries to regional economy and nutrition coupled with limited societal capacity to adapt to potential impacts and opportunities. Besides, increasing number of extreme climatic events will have serious repercussions on the ecology and biodiversity of inland water bodies, besides the socio-economic losses.

IMPACT, VULNERABILITIES AND RISKS

The impacts of climate change on freshwater ecosystems is always complex, not fully understood and often beyond prediction. However, all these impacts will lead to changes in the quantity, quality, and timing of water. Changes will be driven by shifts in the volume, seasonality, and intensity of precipitation; alteration of surface runoff and ground water recharge patterns; changes in evapotranspiration; increased air and water temperatures; and rising sea levels and other extreme climatic events. In the tropical regions, all these together will lead to a number of key eco-hydrological impacts on freshwater ecosystems including increased low-flow episodes and water stress in some areas; shifts in timing and intensity of floods; increased evaporative losses, especially from shallow water bodies; saltwater intrusion in coastal, deltaic, and low-lying ecosystems, including coastal aquifers; more intense runoff events leading to increased sediment and pollution loads; and increased extremes of water temperatures (WWF, 2010). The possible impacts of climate change in aquatic ecosystems are discussed.

Hydrological cycle

Climate and water cycle are inseparably linked and every change in the climatic system induces a change in the water system, and vice versa. The climate change would impact precipitation, sea level, river flow, soil moisture, evapotranspiration, and ground water, thereby impacting the quantity and quality of freshwater availability (Kundzewicz, 2008). Several studies point towards the impact of climate-driven factors on the recent evolution of the water cycle at large scales (Bindoff et al., 2013), particularly on precipitation (Zhang et al., 2007) or evapotranspiration (Douville et al., 2012). The studies in India also indicate the possible implications of climate change on hydrological cycle (Mehrotra and Mehrotra, 1995), including the Western Ghats biodiversity hotspot (Ramachandra et al., 2013). This points to the research need to enhance the observation network (especially for hydro-meteorological variable such as precipitation, evaporation, snow melt, stream flow, runoff, infiltration) in order to get a quantified estimate of water balance in most of the river and lake basins in Asian and Africa.

Ecosystem Services and biodiversity

Climate change has severe projected substantial impacts on ecosystem services. The impacts happen via changes in the distribution and value of water over space and time. Such proposed effects will be different depending on the extent of the impact of such changes in the distribution of water and the adaptive capacity of the region's biophysical and social system (Chang and Bonnette, 2016). Overview of ecosystem services that are directly and indirectly impacted by climate change and local anthropogenic impacts is given in Figure 2. It show cases the complex, cyclical nature of how the use of ecosystem services can, through direct and indirect mechanisms, affect those same ecosystem services (Liu et al., 2015). Impacts of climate change on ecosystem services is an area not investigated by the research community in India, despite the fact that it is highly important in planning adaptation strategies.

Declines in river flows, increased drought and extreme flooding events, and salt-water intrusion are all very likely to result in changes to the composition, structure and function of freshwater ecosystems. In addition, existing stresses on freshwater ecosystems of Kerala (e.g. habitat degradation and alterations, habitat loss, altered hydrology, pollution, habitat loss, invasive species, etc) will be aggravated by climate change, increasing the risk of species extinctions and shifts in the provision of ecosystem services.

Biodiversity in backwaters is disappearing at a much faster pace as a consequence of developmental projects which promote vigorous use of resources and environment and also the ample reclamation of these water bodies result in irretrievable loss of habitat. These backwaters exert serious impact on the coastal fisheries as they serves as nursery and breeding grounds for a variety of coastal fish and shellfish species. Encroachment into diverse sections of water bodies including wetlands, paddy fields, lakes etc. are encroached upon in different parts of the state for constructing buildings, houses and resorts violating the laws (Nair, 2016).

The heavy rain and floods could impact the ecosystem and ecosystem services considerably. In the freshwater ecosystems along the Western Ghats, the impacts would be much more pronounced. Floods may trigger a major shift in the diversity of flora, with invasive species taking over from endemic varieties. The floods also aid in the escape of exotic fish species cultivated in the flood plains to the natural water bodies. It could enhance the threat to Rare, Endangered and Threatened (RET) species, leaving them more vulnerable.

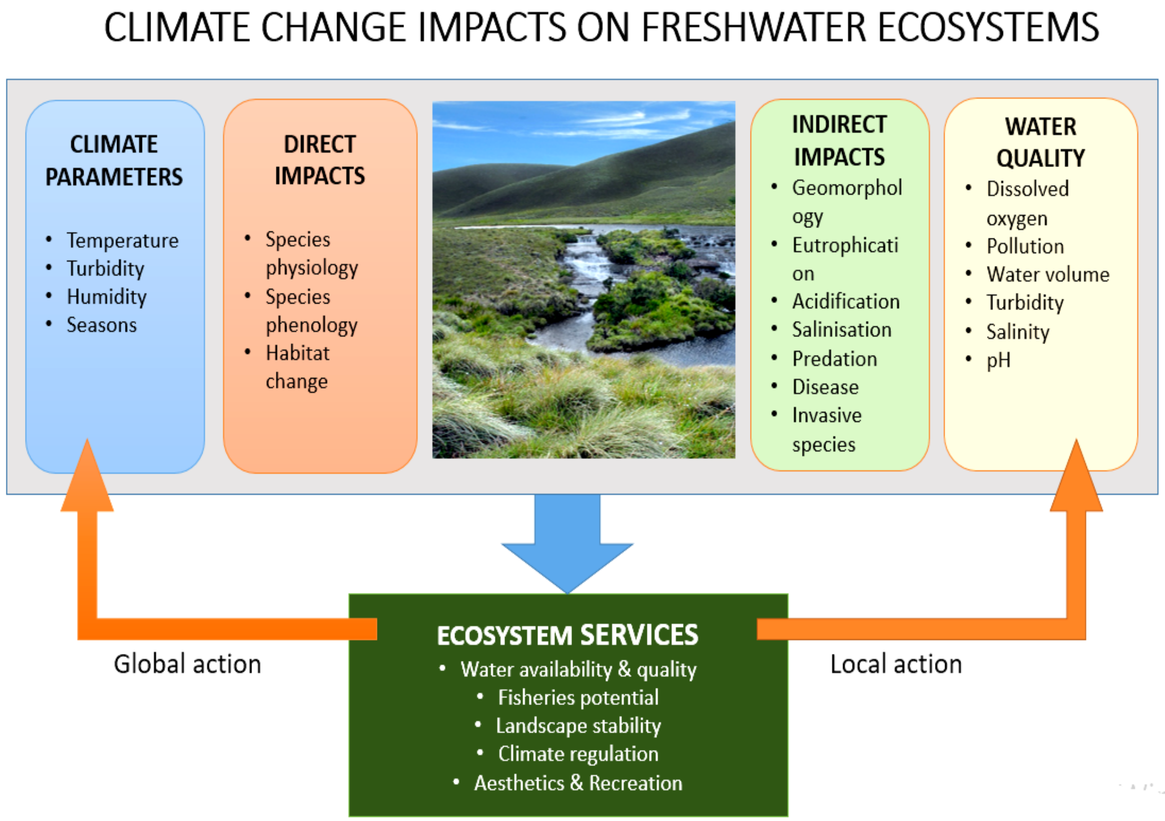

Figure 2. Overview of ecosystem services that are directly and indirectly impacted by climate change and local anthropogenic impacts (adapted from Liu et al., 2015).

Agriculture and animal husbandry

India is home to more than 16 per cent of the world population, at the same time harbours only 4 per cent of the world water resources. Agriculture is directly dependent on climate and water is a critical component of agricultural vulnerability in India where agricultural production depends on availability of rainwater and water available through irrigation. A warmer climate will accelerate the hydrologic cycle, altering rainfall, magnitude and timing of run-off. Warm air holds more moisture and it will result in an increase in evaporation of surface moisture. Climate change has a direct impact on crop evapotranspiration, thereby affecting the soil moisture, groundwater recharge, and frequency of flood or drought, and finally groundwater level in different areas. The observed and predicted vagaries of monsoon and the climate driven changes in soil quality would ultimately impact regional agriculture. The multiple impacts of climate change on agriculture are summarised in Figure 3. The earlier-anticipated potential benefits of climate change from carbon dioxide would be offset by pollution, serious related climate effects as well as nutrition limitation.

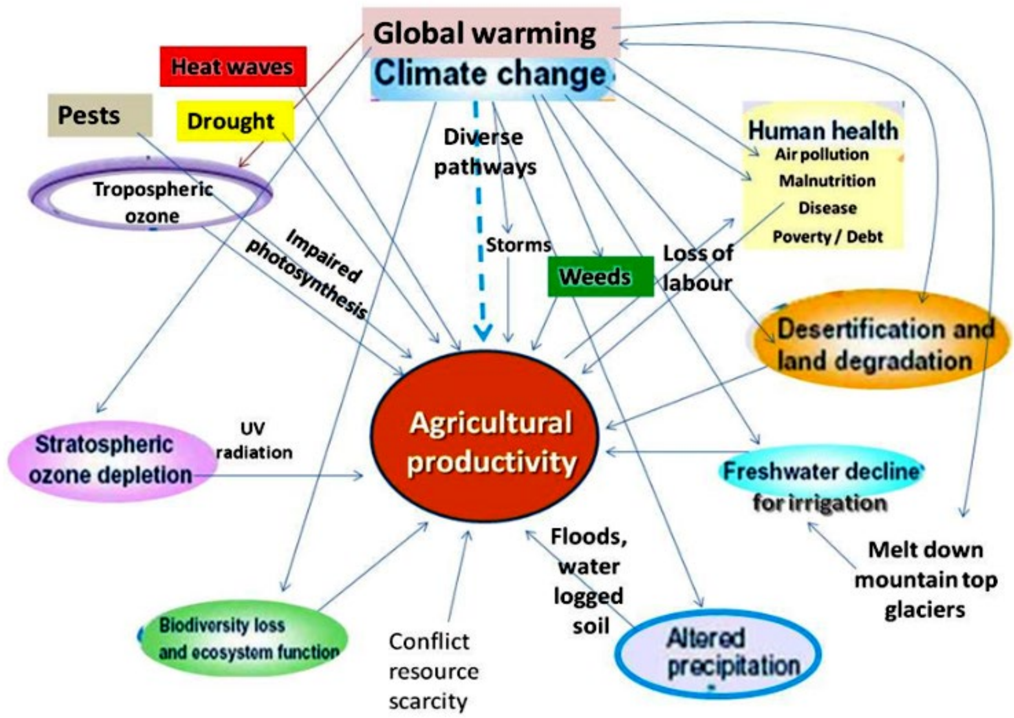

Figure 3. Schematic representation of multiple impacts of climate change on agriculture

Dev (2011) pointed out that agriculture was less sustainable in the past because of less yields, soil erosion and natural calamities, water and land related problems which made the rural livelihoods susceptible to climate change vulnerability. In addition, rise in sea level will increase the risk of permanent or seasonal saline intrusion into ground water and rivers which will have an impact on quality of water and the agricultural productivity, particularly in below-sea level farming systems in various regions of the world.

Due to deforestation and increase in sea surface temperature, the temperature across the high ranges and low lands have increased considerably (Rao, 2017). Vagaries in monsoon may impact the production of economically valuable crops like pepper, coffee, tea, cardamom, banana, ginger and tuber crops. By 2050, the food production is supposed to increase by 60 per cent to meet the increase in demand and therefore any substantial changes in climate would ultimately impact local agricultural productivity (Alexandratos and Bruinsma,2012) and livelihood. Wayanad district experiences low water yield and increasing water stress because of decrease in precipitation and increase in temperature and evapotranspiration due to climate change which is supposed to affect the crops in the district causing reduction in yields and changes in cropping patterns (Dinesan, 2017).

Climate change poses formidable challenge to the development of livestock sector in India. Livestock production will be limited by climate variability as animal water consumption is expected to increase by a factor of three, demand for agricultural lands increase due to need for 70% growth in production, and food security concern since about one-third of the global cereal harvest is used for livestock feed (Rojas-Downing et al., 2017).

According to Sirohi and Michaelowa (2007), "the anticipated rise in temperature between 2.3 and 4.8°C over the entire country together with increased precipitation resulting from climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their productive and reproductive performance, and hence reducing the total area where high yielding dairy cattle can be economically reared. Given the vulnerability of India to rise in sea level, the impact of increased intensity of extreme events on the livestock sector would be large and devastating for the low-income rural areas. The predicted negative impact of climate change on Indian agriculture would also adversely affect livestock production by aggravating the feed and fodder shortages". The locally adapted indigenous breeds in India therefore would play a critical role in future towards climate change adaptation.

Impacts on Wetlands

Wetlands including swamps, mangroves, lakes and marshes play an important role in carbon cycle. While wetland sediments are the long-term stores of carbon, short-term stores are in wetland existing biomass and dissolved components in the surface and groundwater (Wylynko, 1999). Though wetlands contribute about 40 per cent of the global methane (CH_4) emissions, they have the highest carbon (C) density among terrestrial ecosystems and relatively greater capacities to sequester additional carbon dioxide (CO_2) (Pant et al., 2003).

In India, coastal wetlands are playing a major role in carbon sequestration. The total extent of coastal ecosystems (including mangroves) in India is around 43,000 km^2 (Kathiresan and Thakur, 2008). Overall, mangroves are able to sequester about 1.5 metric tonne of carbon per hectare per year, and the upper layers of mangrove sediments have high carbon content, with conservative estimates indicating the levels of 10% (Kathiresan and Thakur, 2008).

Limited analysis on the impact of climate change on wetlands in India suggests that high altitude wetlands and coastal wetlands (including mangroves and coral reefs) are some of the most sensitive classes that will be affected by climate change (Patel et al., 2009). In case of the coastal wetlands such as Indian part of Sundarbans mangrove, rising sea surface temperature and sea level rise due to thermal expansion, could affect the fish distribution and lead to the destruction of significant portion of mangrove ecosystem. Further destruction of the Sundarbans mangroves would diminish their critical role as natural buffers against tropical cyclones resulting in loss of lives and livelihoods (UNESCO, 2007; CSE, 2012).

Climate change induced rising temperature and declining rainfall pattern presents a potential danger to the already disappearing lakes in the Gangetic plains (Sinha, 2011). Decreased precipitation will exacerbate problems associated with already growing demands for water and hence alter the freshwater inflows to wetland ecosystems (Bates et al., 2008; Erwin, 2009), whereas, rise in temperature can aggravate the problem of eutrophication, leading to algal blooms, fish kills, and dead zones in the surface water (Gopal et al., 2010). Also, seasonality of runoff in river basins such as Ganges will increase along with global warming, that is, wet seasons will become wetter and dry seasons will become drier (World Bank, 2012). This would have severe adverse impact on affected populations, especially if the seasonality of runoff change would be out of phase with that of demand.

Impacts on fisheries and aquaculture

Climate change may affect the hydrology and fisheries of inland waters through increased precipitation, air temperature, and decrease in water quality. The health and productivity of the ecosystems depend upon the fisheries which they are based and are vulnerable to physical and chemical changes in temperature, salinity, acidity and water levels and flows (IPCC, 2007; Bindoff et al., 2018). Climate change impact pathways in fisheries and aquaculture are detailed in Fig. 3. The recent report of Food and Agriculture Organization (FAO) indicate that climate change will affect the productivity of the world's freshwater and marine fisheries, and the impacts on inland sector will be connected to the scarcity and quality of water of natural water bodies. In the aquaculture sector, the short-term climate change can include losses of production and infrastructure arising from extreme events such as floods, increased risks of diseases, parasites and harmful algal blooms, and the long-term impacts can include reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater (Barange et al., 2018).

Fisheries in lakes, rivers, dams and wetlands are affected by changes in rainfall and run-off, rise in temperature, drought, evaporation, intense storms, river flow and several other hydrological parameters which results in water level variations, habitat loss, disease and mortality, alteration of productivity, invasive alien species and species loss. Fisheries and aquaculture too contribute to climate change by altering mangroves and coastal wetland ecosystems, and also consume energy required for the production of processed feeds and also to pump water.

The outcome of extreme weather events and changes in monsoon pattern storms and floods are huge losses in cage culture systems in rivers and lakes causing large fin fishes to escape (Soto et al., 2001).Rise in temperature generated by humans on lakes and rivers cause grave threats to various fish species and fish culture production (Cheung et al., 2010; Fickeet al., 2007) as recognised by the report of Intergovernmental Panel on Climate Change (IPCC 2007). According to Katikiro and Macusi (2012) and Xenopoulos et al. (2005) inland fisheries which are artisanal fisheries will be extremely affected by changing water levels and increasing occurrence of dry spells as well as flooding. Climate change also causes increase in vaporization, turbidity, reduced solar radiation reaching water bodies resulting in plankton blooms leading to water pollution, run-off due to flooding creating damages to cages and loss of livelihood of fish farmers (Anyanwu et al., 2014). Rise in temperature due to climate change cause stress in fish and cause diseases.

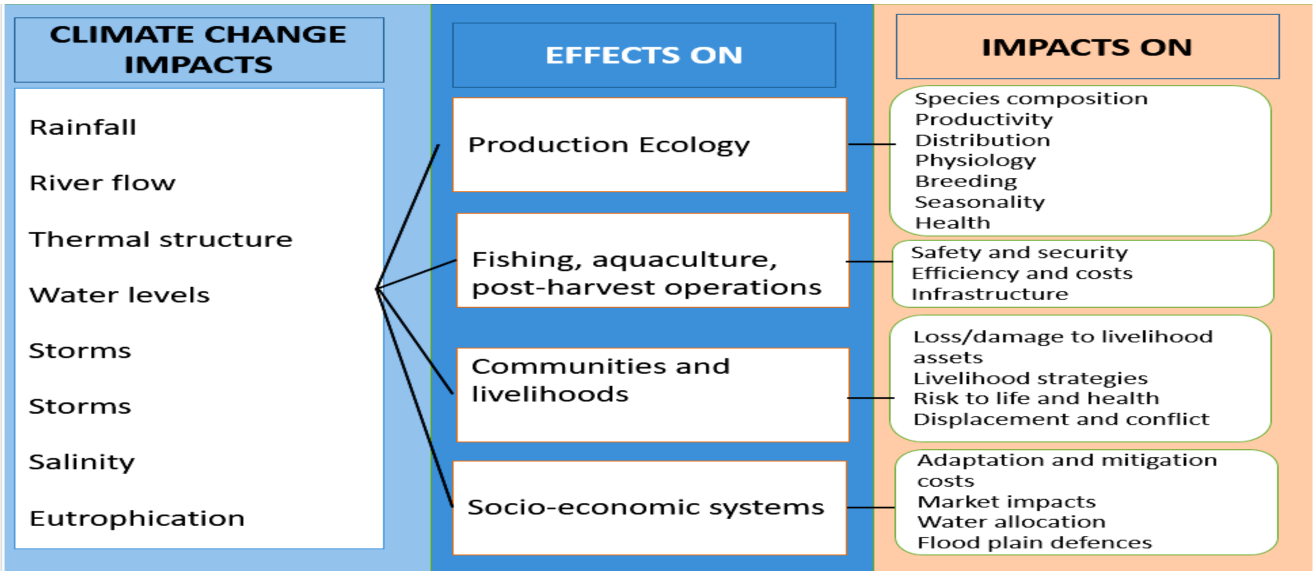

Figure 3. Climate change impact pathways in fisheries and aquaculture (adapted from Badjeck et al., 2010)

Human health

In addition to threats to water supplies for drinking and hygiene, the extent of mosquito-borne diseases may expand due to the impacts of fewer but heavier rainfall events on mosquito breeding. Projected changes to surface water hydrology may also lead to more frequent and prolonged toxic algae blooms. Reports indicate that in India climate change poses serious threat to public health from extreme weather-related disasters to wider spread of such vector-borne diseases as malaria and dengue (Majra and Gur, 2009). Higher temperature and contaminated water would trigger disease outbreaks and spread of pathogens. Vaccine preventable Japanese encephalitis epidemic due to rainfall has been reported from Himalayan region by Partridge et al. (2007) and Bhattachan et al. (2009) and to rainfall and temperature in South and East Asia (Bi et al., 2007; Murty et al., 2010). Similarly, Devi and Jauhari (2006), Dev and Dash (2007), Dahal, (2008) and Laneri et al. (2010) showed correlations of frequent occurrence of malaria with rainfall which otherwise is influenced by non-climatic variables. Increases in heavy rain and temperature will raise the risk of diarrheal diseases, dengue fever and malaria (IPCC, 2014).

Research linking temperature and health effects in tropical countries is sparse. However, understanding of the current impact of weather and climate variability on population health is the first step for assessing the effects of temperature, rainfall, infectious diseases and extreme weather.

Socio-economic and other impacts

Responding to the growing imbalance between water supply and demand has driven changes in water governance, in particular water allocation, in many parts of the world. With a growing population and people living under water stress, particularly for drinking water, there is also likely to be further pressure on individuals and organisations to alter their water use patterns and accept significant changes to the quality and quantity of water provided for different purposes. Policy, infrastructure and social changes are likely to be necessary to facilitate adaptation to water scarcity in both rural and urban areas. Further, there will be more demands for more desalination plants and recycling and reuse of water from the effluents (IPCC, 2012).

Changes in the structure and function of rivers, estuaries and wetlands will affect the ecosystem services they provide, with far-reaching social and economic implications. For example, in rural areas, declines in agricultural productivity and shifts in farming are very likely. Moreover, salt-water intrusion into estuaries and wetlands may affect coastal fisheries and tourism. Water related conflicts may occur regionally due to higher demands for water and scarcity.

ADAPTATION, MITIGATION AND MANAGEMENT

Protection of biological diversity of aquatic ecosystems and integrity are important activities to improve the resiliency of aquatic ecosystems so that they continue to provide important services under changed climatic conditions. Appropriate adaptation and mitigation strategies would bring community empowerment in the face of climate change vulnerability.

Global warming, rapid urbanization, industrialization and economic development are the key factors which cause stress and will intensify climate change (reference??). Attention among policy-makers is divided about how to minimize the change, how to mitigate its effects, how to maintain the aquatic ecosystems and biodiversity on which societies depend and how to adapt human societies to the changes. Maintenance and rehabilitation of ecological integrity of the aquatic ecosystems will inevitably include restoration of health of the ecosystems and the biological resources, not to speak of sustainability of ecosystem services.

The ecosystems in good health may remain in few protected areas in Kerala, through a long tradition of conservation management that is largely species-based, as amenable to adaptive management. In many cases it may be perceived as the richness of plant and vertebrate communities and this often forms a focus for planning. The need of the hour is preparation of a data base on impacts of climate change on each specific kind of aquatic ecosystem and prioritize its management.

In the case of freshwater biodiversity, adaptation strategies that maintain well-functioning ecosystems are pivotal. This is achieved through enhancing resilience, removing or managing existing stressors, and maintaining diverse and well-connected mosaics of ecosystems (i.e. aquatic, riparian and terrestrial components) across the landscape. Surface and groundwater resources are essential to freshwater biodiversity and aquatic ecosystem processes. Appropriate management is critical. Over-allocation of water resources represents a major obstacle to implementing suitable adaptation strategies for protecting freshwater biodiversity.

Mitigation measures include efforts to develop integrated water management strategies along with water saving technologies, increasing water productivity and water reuse to adapt to climate change (IPCC, 2014). However, most of these efforts in developing countries are land-based and therefore fresh efforts are required for mitigating impacts of climate change. Negative repercussion arises in natural ecosystems and carbon sequestration when we prevent nature to take its own course to changing conditions as we build sea walls, channels, bunds and dams for agriculture and human settlement (IPCC, 2014). The freshwater areas under protected area network are comparatively less in tropical countries and there is an urgent need to conserve highly threatened ecosystems, especially all the remaining mangrove ecosystems. Further, the afforestation initiatives in the ecologically sensitive areas along with integrated watershed management programmes will go a long way in adaptation process. Beyond the intrinsic value of wild species and ecosystems, ecosystem-based approaches to adaptation aim to use the resilience of natural systems to buffer human systems against climate change, with potential social, economic, and cultural co-benefits for local communities (IPCC, 2014).

Various downscaled tools to support, formulate, and implement climate change adaptation policy for local governments are under development. One of the major tools is vulnerability assessment and policy option identification with Geographical Information Systems (GIS). These tools are expected to be of assistance in assessing ecosystem based adaptation options by examining estimated impacts and identified vulnerability for aquatic ecosystems.

While top-down approaches provide scientific knowledge to local actors, community-based approaches are built on existing knowledge and expertise to strengthen coping and adaptive capacity by involving local actors (van Aalst et al., 2008). At the same time community-based approaches may have a limitation in that they place greater responsibility on the shoulders of local people without necessarily increasing their capacity proportionately (Allen, 2006). More community reserves and community-managed watersheds and ecosystems would not only ensure sustainability, but also provide avenues for adaptation for the stake holders.

In the fisheries sector, some of the impacts of climate change are likely to be positive. For example, increased precipitation could reduce current water stress in some regions and also lead to the expansion of habitats available to fish, leading to higher abundances and potential yields. Taking advantage of new opportunities could require investment in infrastructure and equipment, for which external support may be required. In cases of both new opportunities and negative impacts, a key requirement for nearly all countries and regions will be to ensure flexibility (within the limits of sustainable use) in policies, laws and regulations. This flexibility will then allow fishers to switch between target species and adjust their fishing practices in response to changes in the ecosystems they utilize for fishing. Adaptation in post harvest processes will also be important through, for example, the development or improvement of storage and processing equipment. The implemented post harvest processes can increase the capacity and implementation of robust biosecurity systems in order to ensure the quality of fish and fish products through to the consumers, as well as facilitating possible access to higher value markets (Barange et al., 2018).

The options for adaptation and building resilience in aquaculture should be applied in accordance with an ecosystem approach to aquaculture. They include: (i) improved management of farms and choice of farmed species; (ii) improved spatial planning of farms that takes climate-related risks into account; and (iii) improved environmental monitoring involving users. Alternate livelihood options should be provided to the fishermen to adapt to the changing climate scenarios.

In addition to emissions reductions from the fisheries and aquaculture sector, there is the potential to store carbon in some coastal ecosystems such as mangroves, sea weed ecosystems, sea grass beds, etc. These ecosystems have the potential to remove and store atmospheric carbon at much greater rates than terrestrial ecosystems (McLeod et al., 2011). Some of these systems, such as mangroves also provide additional benefits to communities through flood control, buffering coastlines from storms, water quality, and provide habitat for juvenile fish. Therefore, adaptation may address issues not specifically focused on fisheries or aquaculture, such as mangrove restoration for the primary purpose of buffering coastal communities from storm surge and coastal erosion (Shelton, 2014).

In short, ecosystem-based adaptation recognizes the critical nature of the services that biodiversity and ecosystems provide to human communities and that help build resilience to climate change. Incorporating ecosystem-based adaptation into an integrated approach to climate change adaptation can provide longer term, more effective and more cost efficient solutions that support human well-being and a healthy environment. This approach is particularly relevant to the inland water bodies due to the complex and dynamic nature of these systems.

KNOWLEDGE GAP

Climate change research is at its infancy in the state, and one of the major handicap in arriving at better conclusions on the impact is the lack of data over a time scale with regard to the inland ecosystems. Sustain and expand existing monitoring networks and data collection on hydrologic and meteorological conditions and water demand is one of the priority areas. Similarly there is a need for stronger data on precipitation and river discharge systematically, and management of water flow from dams. A comprehensive bio-monitoring network with clearly defined goals for the State is necessary to fill the gaps in climate change. Long-term climate change monitoring datasets are vital and often useful for research on climate change and the information must be shared across the regions. Due importance should be given to research with improvised models and other methods to explore and foretell the interactions between climate change, invasive species, habitat fragmentation and ecosystem dynamics and also to identify the stressors and threats which will create an impact on climate change.

Urgent actions need to be executed at the local (community involvement), regional and national level and for short and long term involving a multi-disciplinary team. Information on significant variables like soil moisture, groundwater depth, water quality, water demand (including water budget of aquatic ecosystems), rates of surface water and groundwater withdrawal by each sector, long-range diversions etc. are particularly limited in India which result in limited assessment capability.

Engaging stakeholders will definitely leads to the success of the programme and proper public awareness should be propagated regarding environmental and health issues. Further, ecosystem based conservation plans involving local communities is yet another priority programme to be implemented, together with declaration of more protected areas including fish sanctuaries, which may serve as 'climate refugia'.

In many Asian and African countries where tourism is projected as a source for improving economic benefits, maintenance of inland aquatic ecosystems in good health and promotion of responsible tourism would help in sustainable management in the era of climate change. Carbon sequestration capacity of the countries should be increased by promoting public transportation, replacement of old machinery with new energy efficient ones, afforestation, reduction of CO_2 emission from households etc. Another challenge is to increase the food productivity using low emission pathway to reduce the impact of climate change.

Since fisheries is considered as a major source of food while policy formulation, fisheries should come to the forefront but the benefits gained from the sector are often ignored and continue to lack sufficient attention by decision makers in both adaptation to climate change and food security policy formulation. It is also endorsed upon that to minimize the impacts of climate change on fisheries and also to increase the flexibility of the farmers, investments are needed for sustainable artisanal fisheries and market infrastructure to tackle post- harvest losses and also to provide economic incentives. Top priority should be given for the conservation of existing wetlands and restoration of all freshwater bodies should be undertaken as a major measure to fight against climate change. Also science and policy should communicate and interact together to pursue climate change.

More studies with state-specific scientific or modelling studies on climate change are needed, especially in a tropical countries, to study the impacts for effective adaptation strategies and policy framework for the region. Inland fisheries sector has to be boosted by adapting a suitable technology which is eco-friendly and less hostile. Moreover, while taking policy formulations, fisheries and aquaculture sectors need to be directly linked to food security and employment of the rural population.

To enhance the development of young professionals in the field of climate change adaptation, the topic could be included in higher education, especially in formal education programs. Shaw et al. (2011) mentioned that higher education in adaptation and disaster risk reduction in the Asia-Pacific region can be done through environment disaster linkage, focus on hydro-meteorological disasters, and emphasizing synergy issues between adaptation and risk reduction.

Overall, it may be noted that the climate change impacts on inland aquatic ecosystems, though very important in ensuring food security and ecosystem services, they have not received considerable attention by the researchers, planners, policy makers and practitioners. This warrants a critical review of existing management plans for watershed conservation, flood mitigation, environment and biodiversity regulations, covering potential implications of climate change in regional perspective, besides following an ecosystem approach in conservation and mitigation.

References

Alexandratos N. and Bruinsma J. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Work.Pap.12-03.FAO Agricultural Development Economics Division, Rome. ⟨http://www.fao.org/docrep/016/ap106e/ap106e.pdf⟩.

Allen K.M. 2006. Community-based disaster preparedness and climate adaptation: local capacity-building in the Philippines. *Disasters*. **30**(1):,81–101.

Anonymous 2010. National Wetland Atlas Kerala. National Wetland Inventory and Assessment (NWIA)and Space Applications Centre (ISRO), Ahmedabad and Kerala State Remote Sensing & Environment Centre, Thiruvananthapuram.

Anonymous 2012. India: Second National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment and Forests, Government of India, New Delhi.

Anyanwu C.N., Osuigwe D.I. and Adaka G.S. 2014. Climate change : Impacts and threats on Freshwater Aquaculture. *J. Fish. Aquat. Sci.* **9** (5): 419-424.

Badjeck M., Allison E.H., Halls A.S. and Dulvy N.K. 2010: Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy* **34**(3): 375-383.

Barange M., Bahri T., Beveridge M., Cochrane K., Funge-Smith S. and Poulain F. 2018. Impacts of climate change on fisheries and aquaculture - Synthesis of current knowledge, adaptation and mitigation options. Fisheries and Aquaculture Technical Paper. No. 627. Rome, FAO.

Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R. and White L.L. 2014. Climate Change: Impacts, Adaptation, and Vulnerability. USA.

Bates B.C., Kundzewicz Z.W., Wu S. and Palutikof J.P. 2008. Climate Change and Water. Technical Paper VI, Intergovernmental Panel on Climate Change, Geneva.

Bhattachan A., Amatya S., Sedai T.R., Upreti S.R. and Partridge J. 2009. Japanese encephalitis in hill and mountain districts, Nepal. *Emerg. Infect. Dis*. **15** (10): 1691-1692.

Bi P., Zhang Y. and Parton K.A. 2007. Weather variables and Japanese encephalitis in the metropolitan area of Jinan city, China. *J. Infect.* **55** (6): 551-556.

Bindoff N., Stott P., Achuta Rao K., Allen M., Gillett N., Gutzler D., Hansingo K., Hegerl G., Hu Y., Jain S., Mokhov I., Overland J., Perlwitz J., Sebbari R. and Zhang X. 2013. Detection and attribution of climate change: from global to regional. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 867–952.

Bonte M. and Zwolsman J.J.G. 2010: Climate change induced salinisation of artificial lakes in the Netherlands and consequences for drinking water production. *Water Res*. **44**(15): 4411-4424.

Chandrashekara U.M. 2015. Climate Change Mitigation Strategies in the Forestry Sector of Kerala, India. International Journal of Advancement in Remote Sensing, GIS and Geography. Special issue on Forest and Climate Change. *Int. J. Adv. Remote Sens. GIS Geogr.* **3** (1): 29-37. ISSN 2321–835.

Chang H. and Bonnette M.R. 2016. Climate change and water-related ecosystem services: impacts of drought in California, USA. Ecosystem Health and Sustainability. 2(12):e01254. 10.1002/ehs2.1254

Cheung W.W.L.; Lam V.W.Y.; Sarmiento J.L.; Kearney K.; Watson R.; Zeller D. and Pauly D. 2010. Large scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Glob. Change Biol*. **16**:24-35.

Cisneros J.B.E., Oki T., Arnell N.W., Benito G., Cogley J.G., Döll P., Jiang T. and Mwakalila S.S. 2014. Freshwater resources. In: Field C.B., Barros V.R., Dokken D.J., et al. (Eds). *Climate Change 2014:* Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269.

CSE (Centre for Science and Environment) 2012. Living With Changing Climate: Impact, Vulnerability and Adaptation Challenges in Indian Sundarbans Centre for Science and Environment, New Delhi.

Dahal S. 2008. Climatic Determinants of Malaria and Kala-Azar in Nepal. Regional Health Forum, pp 32-37.

Dev V. and Dash A. 2007: Rainfall and malaria transmission in north–eastern India. *Annals Trop. Med. Parasitol*. **101** (5): 457-459.

Devi N.P. and Jauhari R. 2006: Climatic variables and malaria incidence in Dehradun, Uttaranchal, India. *J. Vector Borne Dis*. **43** (1), 21.

Dinesan V.P. 2017. Impact of climate change on water and land resources in Wayanad district. Climate variability in Kerala in recent years: Climate change perspectives. Published by Institute of climate change studies (ICCS).

Döll P. 2009. Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment. Environmental Research Letters, 4: 035006.

Douville H., Ribes A., Decharme B., Alkama R. and Sheffield J. 2012. Anthropogenic influence on multidecadal changes in reconstructed global evapotranspiration. *Nat. Clim. Change* **3** (1): 59–62.

Erwin K.L. 2009. Wetlands and global climate change: the role of wetland restoration in a changing world. Wetl. Ecol. Manage.**17**: 71-84.

Ficke A.D.; Myrick C.A.; Hansen L.J. 2007. Potential impacts of global climate change on freshwater fisheries. *Rev Fish Biol Fisher*. **17**:581-613.

FSI (Forest Survey of India) 2015. India State of forest report. Forest Survey of India, Dehradun, 288 pp.

Gallo B, Jackson M.C., O'Gorman E. and Woodward G. 2017. Adaptation of freshwater species to climate change. Grantham Institute, Imperial College, London. Briefing note No 8.

Garner G., Hannah D.M. and Watts G. 2017. Climate change and water in the UK: Recent scientific evidence for past and future change. *Prog. Phys. Geog.: Earth and Environment*. **41**: 154-170.

Gopal B., Shilpakar R. and Sharma E. 2010. Functions and Services of Wetlands in the Eastern Himalayas: Impacts of Climate Change. Technical Report 3, International Centre for Integrated Mountain Development, Kathmandu, Nepal.

Goswami B.N., Venugopal V., Sengupta D., Madhusoodanan M.S. and Xavier P.K. 2006. Increasing Trend of Extreme Rain Events Over India in a Warming Environment. *SCIENCE* Vol 314 1 December 2006. www.sciencemag.org

IPCC (Intergovernmental Panel on Climate Change) 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B., Barros V., Stocker T.F., Dahe Q., Dokken D.J., Ebi K.L., Mastrandrea M.D., Mach K.J., Plattner G.-K., Allen S.K., Tignor M. and Midgley P.M. (eds.). Cambridge University Press, Cambridge, UK, and New York, USA, p. 582.

IPCC (Intergovernmental Panel on Climate Change) 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge , UK New York, NY.

IPCC (Intergovernmental Panel on Climate Change) 2014. Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

Katikiro E. and Macusi E.D. 2012. Impacts of Climate Change on West African Fisheries and its Implications on Food Production. *J. Environ. Sci. Manag*. **15**:83-95.

Kundzewicz Z.W. 2008. Climate change impacts on the hydrological cycle. *Ecohydrol. Hydrobiol.* **8**: 195-203.

Kundzewicz Z.W. and Krysanova V. 2010. Climate change and stream water quality in the multi-factor context. *Clim. Change*. **103**(3): 353-362.

Laneri K., Bhadra A., Ionides E.L., Bouma M., Dhiman R.C., Yadav R.S. and Pascual M. 2010: Forcing Versus Feedback: Epidemic Malaria and Monsoon Rains in Northwest India. *PLoS Comput. Biol*. **6** (9): e1000898.

Li W., Xu X., Fujibayashi M., Niu Q., Tanaka N. and Nishimura O. 2016. Response of microalgae to elevated CO2 and temperature: impact of climate change on freshwater ecosystems. *Environ. Sci. Pollut. Res*. .**23**: 19847-19860.

Liu J., Hull V., Luo J., Yang W., Liu W., Viña A., Vogt C., Xu Z., Yang H., Zhang J., An L., Chen X., Li S., Ouyang Z., Xu W. and Zhang H. 2015. Multiple telecouplings and their complex interrelationships. *Ecol. Soc*. **20** (3): 4. http://www.ecologyandsociety.org/vol20/iss3/art44/

Majra J.P. and Gur A. 2009. Climate change and health: Why should India be concerned? *Indian J. Occup Environ Med*. **13**(1): 11–16.

Mcleod E., Chmura G.L., Bouillon S., Salm R., Björk M., Duarte C.M., Lovelock C., Schlesinger W. and Silliman B. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front. Ecol. Environ*. **9**: 552–560.

MEA (Millennium Ecosystem Assessment) 2005. Ecosystems and Human Well-being: Wetlands and Water: Synthesis. A Report of the Millennium Ecosystem Assessment, World Resources Institute, Washington DC, USA, 68 pp.

Mehrotra D. and Mehrotra R. 1995. Climate change and hydrology with emphasis on the Indian subcontinent. *Hydrol. Sci. J.* **40**: 231-242.

Murty U.S., Rao M.S. and Arunachalam N. 2010. The effects of climatic factors on the distribution and abundance of Japanese encephalitis vectors in Kurnool district of Andhra Pradesh, India. *J. Vector Borne Dis.* **47** (1): 26-32.

Nair K.S. 2016. Impact of climate change and anthropogenic pressure on the water resources of India: challenges in management. Proc. IAHS. **374**: 63–67.

Niyas N.T., Mini V.K and Sudevan S. 2017. Study on temperature features and its trend over Kerala.

Climate variability in Kerala in recent years: Climate change perspectives. Published by Institute of climate change studies (ICCS).

O'Gorman E.J., Benstead J.P., Cross W.F., Friberg N., Hood J.M., Johnson P.W. and Woodward G. 2014. Climate change and geothermal ecosystems: natural laboratories, sentinel systems, and future refugia. *Glob. Chang. Biol.* **20** (11): 3291-3299,

Pant H.K., Rechcigl J.E. and Adjei M.B. 2003. Carbon sequestration in wetlands: Concept and estimation. *J. Food Agric. Environ*. **1**: 308-313.

Partridge J., Ghimire P., Sedai T., Bista M.B. and Banerjee M. 2007. Endemic Japanese encephalitis in the Kathmandu Valley, Nepal. *Am. J. Trop. Med. Hyg*. **77**: 1146–1149.

Patel J.G., Murthy T.V.R., Singh T.S. and Panigrahy S. 2009. Analysis of the distribution pattern of wetlands in India in relation to climate change. In: Panigrahy S., Shankar Ray S. and Parihar J.S. (Eds.), Proceedings of the Workshop on Impact of Climate Change on Agriculture. Ahmedabad, India, 17–18 December. International Society for Photogrammetry and Remote Sensing.

Pfister S., Koehler A. and Hellweg S. 2009. Assessing the environmental impacts of freshwater consumption in Asia. *Environ. Sci. Technol*. **43**: 4098-4104.

Raghavan R., Das S., Nameer P.O., Kumar B.A. and Dahanukar N. 2016. Protected areas and imperilled endemic freshwater biodiversity in the Western Ghats Hotspot. *Aquatic Conservation: Marine And Freshwater Ecosystems* **26** (Suppl. 1): 78–90.

Ramachandra T.V., Anjali Nair, B. and Vinay S. 2013. Hydrologic regime alterations in the Western Ghats due to changes in the climate. http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/Issue61/article/index.html

Rojas-Downing M.M., Nejadhashemi P.A., Harrigan T. and Woznicki S.A. 2017. Climate change and livestock: Impacts, adaptation, and mitigation. *Clim. Risk Manag.* **16**: 145–163.

Sahoo G.B., Schladow S.G., Reuter J.E. and Coats R. 2010. Effects of climate change on thermal properties of lakes and reservoirs, and possible implications. *Stoch. Env. Res. Risk A*. **25**(4): 445-456.

Sannadurgappa D., Abita R. and Soniya S. 2011. Vulnerability of freshwater fisheries and impacts of climate change in south Indian states economies. *Interdiscip. Environ. Rev.* **12**(4): 283-297.

Sharma A.P., Joshi K.D., Naskar M. and Das M.K. 2015. Inland fisheries and climate Change: Vulnerability and Adaptation options. ICAR-CIFRI Special Publication, Policy Paper No.: NICRA/Policy/2015-16/1, Central Inland Fisheries Research Institute, Barrackpore, Kolkata.

Shaw R., Mallick F. and Takeuchi Y. 2011: Essentials of higher education in disaster risk reduction: prospects and challenges. In: Shaw R., Shiwaku K. and Takeuchi Y. (eds.). Disaster Education, Community, Environment and Disaster Risk Management, Vol. 7 Emerald Group Publishing, Ltd., Bingley, UK, pp. 95-113.

Shelton C. 2014. Climate change adaptation in fisheries and aquaculture – compilation of initial examples. FAO Fisheries and Aquaculture Circular No. 1088. Rome, FAO. 34 pp.

Sinha C.P. 2011. Climate change and its impacts on the wetlands of North Bihar, India. *Lakes and Reservoirs: Resarch and Management* **16**: 109-111.

Sirohi S. and Michaelowa A. 2007. Sufferer and cause: Indian livestock and climate change. *Clim. Change* **85**: 285–298.

Soto D., Jara F. and Moreno C. 2001. Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. *Ecol. Appl*. **11** (6): 1750–1762.

Trolle D., Hamilton D.P., Pilditch C.A., Duggan I.C. and Jeppesen E. 2011. Predicting the effects of climate change on trophic status of three morphologically varying lakes: implications for lake restoration and management. *Environ. Modell. Softw*. **26**(4): 354-370.

UNESCO (United Nations Educational, Scientific and Cultural Organization) 2007. Case Studies on Climate Change and World Heritage, UNESCO World Heritage Centre, France.

van Aalst M.K., Cannonb T. and Burtonc I. 2008. Community level adaptation to climate change: The potential role of participatory community risk assessment. *Glob. Environ. Change.* **18**: 165–179.

Van Vuuren D.P., Kok M.T.J., Girod B., Lucas P.L. and de Vries B. 2012. Scenarios in global environmental assessments: key characteristics and lessons for future use. *Glob. Environ. Change* **22**:884–895

Ward R.D., Friess D.A., Day R.H. and MacKenzie R.A. 2016. Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosystem Health and Sustainability 2(4):e01211. doi:10.1002/ehs2.1211

World Bank, 2012. Turn Down the Heat: Why a 4 °C Warmer World Must Be Avoided. The World Bank, Washington, DC.

WWAP (World Water Assessment Programme) 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO.

WWF 2010. Flowing forward: Freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation. Water Working Notes, No. 28, World Wildlife Fund (WWF) and World Bank.

Wylynko D. 1999. Prairie Wetlands and Carbon Sequestration: Assessing Sinks Under the Kyoto Protocol, International Institute for Sustainable Development, Manitoba, Canada.

Xenopoulos M.A., Lodge D.M., Alcamo J.A.; Marker M., Schulze K., Van Vuuren D.P. 2005. Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Glob. Change Biol.* **11**:1557-1564.

Zacharias I. and Zamparas M. 2010. Mediterranean temporary ponds. A disappearing ecosystem. *Biodivers. Conserv.* **19**: 3827–3834.

Zhang X., Zwiers F.W., Hegerl G.C., Lambert F.H., Gillett N.P., Solomon S., Stott P.A. and Nozawa T. 2007. Detection of human influence on twentieth-century precipitation trends. *Nature* **448** (7152): 461–465.