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Review Article

Understanding Integrated Impacts of Climate Change and Pollution on Ganges River System: A Mini Review on Biological Effects, Knowledge Gaps and Research Needs

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Abstract

Clear insights of climate change impacts on river pollution are difficult to predict particularly for big river basins due to huge variations in their hydro-geochemical and ecological complexities. This review is focused towards better understanding of the cause-effect interactions of climate change and river-pollution with special reference to Ganges River system in India which is facing huge ecosystem disturbances since last few decades. It synthesizes the interrelations of nutrient fluxes, their forms and transformations, sediment loads and major river pollutants with climatic variables. It also gives an account of major bio-physical processes and ecological services affected and their impacts on river biota. It tries to reveal the connections and effects of pollution with different levels of temperature variation induced flux shock and consequent altered discharge, changed homeostasis and pollution variance in rivers which may be extrapolated and projected. Based on current understandings and knowledge gaps, some future research approaches have also been suggested to comprehend this issue.

Introduction

Almost all civilizations of the world are inextricably linked with rivers where all civilizations originated and developed [1]. Rivers in any means are enormously cherished and valued by all human communities due to their significant services on which human civilization's survival is dependent [2]. However, nowadays due to many natural and anthropogenic pollution problems, the riverine ecosystems of the world are under great pressure which are affecting the deliverables of the river systems all over the world [3,4] (Table 1). Unplanned urbanization, changing land use patterns, intensified agricultural processes, huge hydroelectric power projects, heavy industrial use of waters, polluted effluent discharge, and contaminated runoffs are major contributing factors of pollution to these fresh water sources [5,6]. With these concerns, the climate change is another colossal crisis which is aggravating the problems of riverine ecosystem by increasing temperatures, altering rainfall-runoff patterns, and disrupting biological communities of river bodies which impart an imbalance to these ecosystems [7-9]. Numerous other indirectly related climate change stressors also increase the extent and magnitude of pollution problems and thus impacts become much wider along different dimensions of a river regime [10,11]. In consequence, many riverine ecosystems may totally collapse under these complex and unidentified impacts of climate change [4,12,13]. In its fifth assessment report, IPCC has projected 1.5-4.5°C increase in average global temperature (IPCC, 2013). The present assessment projects that, the globally averaged combined land and ocean temperature shows a warming of 0.89°C (0.69 to 1.08°C) over the period 1901-2012; with the rate of warming at 0.05°C (–0.05 to +0.15°C) per decade over the past 15 years (1998-2012). This report indicates the freshwater-related risks of climate change has also increased significantly where each degree of warming is projected to decrease renewable water resources by at least 20%. These trends and changes may intensify the problems of raw water quality by increasing water temperature; more loading of sediment, nutrient and pollutant due to abrupt and heavy rainfall; reduced dilution of pollutants during droughts, and unmanageable treatment facilities during floods [14-16].

Interrelation of climate change with river pollution

It is essential to recognize that how climate change and its related impacts may influence water quality by altering its pollution levels; because of diverse and interrelated changes in various climate related phenomena under water. As climate change associated surface air temperature increase is not constant over the globe and varies seasonally across the regions; it characteristically affects the river systems in different climatic zones [6,17,18] (Table 1). The unique properties of turbulence and

Table 1: Some specific pollution problems and their associations with climate change in some major rivers and lakes of Asia including Ganges River.

S No	River/Lake	Country	Climate change impacts	References
1	Paldang Lake	S. Korea	Eearlier ice break-up and shorter time period of ice-cover, increased concentration of suspended solids	[86]
2	Yuanjiang Red River basin	China	Increase in suspended sediment loads	[87]
3	Tarim River Basin	China	Significant increase in evaporation	[88]
4	Yellow River	China	Severe low-flow events causing disrupting pollutant dispersal and self cleaning	[89]
5	Ili River Basin	China	Sudden changes of precipitation and temperature affecting flow patterns	[90]
6	Ganges River	India	Increased nitrogen and phosphorus loading in river	[91]
7	Indian Sunderbans	India	Increase in downstream salinity, decrease in phytoplankton and fish density and diversity	[13]
8	Yamuna River	India	Enhanced chemical weathering rates under high water temperatures	[99]
9	Spiti river	India	Various impacts of temperature and precipitation on snow water equivalent, snowmelt runoff, glacier melt runoff, total streamflow and their distribution	[100]
10	Cauvery River basin	India	Increasing trend for maximum temperature, minimum temperature and rainfall over the basin has impacted rice productivity in a great deal	[101]
11	Mahanadi	India	Observed changes in river flows	[102]
12	Subaranrekha river basin	India	Abrupt rainfall pattern and flooding	[103]
13	Indus river system	Indian subcontinent	Change in rainfall pattern, reduced winter rains	[103]
14	Lower Brahmaputra	Bangladesh	Abrupt changes in mean low and high flow conditions, destructive flood events	[58]
15	Mahaweli River Basin	Sri Lanka	Spatial and temporal changes in climate systems	[92]

mixing in rivers are key which respond to changes in atmospheric conditions quite easily and thus river waters become warmer [19,20]. For those rivers in which long term temperature records are available, significant warming trends have been noticed [21,22]. It is now well established that increase of temperature influences physical, chemical and biological properties of aquatic ecosystems [23]. It poses undesirable impacts on the water quality by causing changes in planktons and in turn affects the animal-plant structures at the higher trophic levels [23,24]. Also, in uncertain chemical-to-chemical interactions, some confounding environmental variables may influence biological response to chemical challenge triggered due to any climate related changed in them [25,26]. For example, the increase in temperature may alter pollution degradation, ambient partitioning of pollutants and solvent depletion in river waters [27] (Table 2) which will alter the pollutant chemistry and its behavior and will exacerbate the problem. As the changing temperature of waters will increase salinity, to the alterations in pollutant behavior will enhance the toxicity of pollutants in aquatic biota by changing biotransformation mechanisms impairing homeostasis and affecting physiological responses, reproduction, and development of aquatic organisms [28,29]. These interactions are complex which may prove dangerous for vulnerable species having low physiological tolerance range [28].

The potential of the rising temperature to alter the environmental distribution and characteristics of chemical toxicants have been analyzed and researches focused hydrological characteristics of flood, runoff, sediments, soil erosion and their role in pollution distribution in river waters [30-32]. Under current scenario of climate change and related precipitation pattern; river discharge are expected to change in several regions potentially much faster than their historical rates [19]. This may induce several hydrological changes by fast decrease and increase in discharge of rivers and enhancing pollutant distribution in water and sediments [22] 2013) (Table 2). Increased discharge may add more pollution while decreased discharge may add sediment load by more sedimentation in turn altering self cleaning capacity of the rivers thus resulting in aggravated pollution loads [29,33]. These are the basic tribulations acting as the precursors or enhancers of the various pollution problems in rivers and are augmenting day by day. This must be understood in every river basin in detail by examining range of climatic variables affecting the rivers in terms of both global and regional climate change [23]. Temperature increase in river waters may influences many physical and chemical characteristics

Table 2: Some potential river pollutants found in Ganges River System and their climatic interactions which may affect its biological processes.

S No	Pollutants	Climatic interactions	Major Biological Effects	References
1	Persistent Organic Pollutants	Increase in temperature affects photolysis, biodegradation, oxidation, and surface exchange properties	Reproductive and congenital abnormalities	[93]
2	Heavy metals	Increased levels in post monsoon periods due to increased mobilization and Some metals tend to distribute towards increasing gradients of temperatures	Toxic to phytoplankton, and zooplanktons. Disturb all physiological activities plants and animals	[47,63,94,95]
3	Added fluxes of NPK and other nutrients	Temperature increase induces mobilization of nitrates and phosphates, also increase photo-oxidation and photo-mineralization	Eutrophication and algal blooms, Toxins released by cynobacterial blooms cause Neurotoxicity, liver damage and other dangerous effects in fishes	[66,96]
4	Pesticides	Change in temperature, salinity, pH affects activity of pesticides, its half life, biodegradation etc	Effects on several reproductive and cognitive abilities in fishes	[97]
5	Radionucleoides	Weathering, transportation and depositional changes under climatic influences	Carcinogenic risks to riverine animals	[98]

Table 3: Some case studies of climate change effects on pollution in South Asian Rivers.

S No	Rivers	Case studies
1	Yamuna (Study of New Delhi, India)	The study shows that how temperature and flow variability due to climate change can be affective for some pollution parameters. The effect of change in air temperature on water quality is very minimal however; DO showed to be more prone to climate change effect whereas BOD was vulnerable to drain flow fluctuations. The maximum percentage reduction in DO (39.79%) is observed when the air temperature is increased by +4°C and 100% increase in drain flows. The increase in temperature was also very important for BOD as it increased under increased temperature scenarios (+4°C) and increased drain flows into the river [108].
2	Brahmaputra-Meghna River system (Study of Bangladesh)	The study in various districts of Bangladesh founds that river salinity can increase by about 0.5 to 2 PPT (parts per thousand) under 2°C increase of temperature. Also the duration of river salinity above 1 PPT can double in some locations of these rivers. This increase also has the impacts on river flows, average wet season water level increasing to 0.2 to 0.5 m. At many locations the duration of flood levels above the established danger level can be double which will have impacts on the salinity levels as well [105].
3	Indus basin (Study of Indo-Pak region)	Not only the high flow is bad for the river system but also low runoff conditions are also very dangerous as it concentrates the pollutants at same place. A characteristic study of upper Indus basin shows strong links between temperature and runoff and strong spatial correlation in seasonal temperature across the region. Climate stations in the upper Indus basin show a reduction in mean summer temperature of 1.2°C over the period 1961 to 2000 representing a fall in average summer runoff of 20% on the Hunza and Shyok rivers in Pakistan. Similarly, during the more sensitive spring months a 40-yr mean temperature reduction of 0.3°C yields a fall in spring runoff of 15% to 20%. These trend are dangerous for the availability of the water in this region and also for the restriction of the pollutant mobility in downstream in turn increasing sediment pollutant loads [109].

of water such as solubility of gases, chemical reaction rates, toxicity, and microbial activity [23,28]. Increase in water temperature will enhance the volatility of POPs and other pesticides from water to the atmosphere, will augment their solubility making them more pertinent to be retained in water and will also increase the hydrolysis of pesticides to less or more bioactive degradates in water bodies [27,28] [Table 2]. These effects will alter the pollutant level and its behaviour as changes in climate attributes (especially temperature) will alter the fundamental mechanisms of solvent switching and solvent depletion and consequently will also enhance contaminant degradation [27,104]. Solvent switching involves contaminants partitioning into different chemical phases (solid, liquid, gas) while solvent depletion requires energy and increases contaminant concentrations exceeding the thermodynamic equilibrium [28,104]. Climate change will also influence the environmental fate and behaviour of pesticides by altering fundamental mechanisms of environmental partitioning primarily through mechanisms of increased volatility, wet deposition, and enhanced degradation [6,23,27,28] [Table 2].

Therefore, it is imperative to understand that how climate change is impacting hydrology and water resource systems by enhancing the level of pollution and its distribution in different aspects [34-36]. However, it is still a complex task to understand and link climate change and pollution in rivers and understanding major driving forces of climate change altering hydro-biological properties and indirectly enhancing pollution levels of many rivers along with anthropogenic sources of pollution [37,38]. While free flowing protected rivers seem to be somewhat resistant for these changes but glacial fed rivers like Ganges are much sensitive and vulnerable to any climatic shift or change [39]. Although rivers represent rather dynamic systems adjusting with their native environmental conditions by changing its hydro-ecological settings; unpredictable and quick changes in climatic conditions in river basins are affecting the river sustenance in a great deal [39,40]. All major rivers of the world are facing problems of ecosystem degradation due to changing climate where pollution enhanced by climate change is acting whether as a cause or effect or both; and complex interactions are causing various pollution associated problems affecting river biota and in turn human beings as well [38,40]. Some case studies have been given here for some other rivers of south Asia where climate change has impacted the riverine ecosystem and their pollution levels which will enable us to understand the problem in a large scale and to compare it on regional basis [Table 3].

Since it is expected that climate change is likely to affect the nature, their fate and transport of contaminants in fresh water systems; potential risks therefore are very unusual and are different from those of today. Consequently, the purpose of this review is to give a brief overview to understand the interrelations between climate change and pollution and their direct/indirect effects in one of the biggest trans-boundary river of Asia i.e. Ganges. Wide spread literatures related to climate change have been synthesizes to illustrate the linkage between climate change and pollution in this important river of India and South Asia. Specifically, it focuses the climate induced pollution loads; their environmental distribution; and consequently their effects on aquatic flora and fauna. How climate change may alter and attenuate risks from various pollutions has been discussed here. Based on the current understanding from studies this review suggests

Table 4: Some ecosystem services of Ganges River and the consequences of loss due to climate change effects.

S No	Ecosystem services	Consequences of loss triggered by changing climate
1	Water purification through nutrient recycling and control of pollutants and contaminants	In extreme temperature and varied flow conditions retention, storage and removal of excess N_2 and P and decomposition of organic matter is affected. Sediment and pollutant transport to the downstream is also affected. This may cause increased BOD loads, algal bloom and toxic conditions leading to anoxic condition and death of biotic communities. Fisheries are affected in a great deal.
2	Control of flood and disasters	Due to loss in the riparian wetlands and vegetations, dried soils of the catchment and floodplain, and changing land use; physical slowing and temporary storage of water is affected. This increases the flood vulnerability as well as low ground water recharge which in turn leads in drought conditions.
3	Carbon sequestration.	Loss in vegetation (algae and plants) due to extreme water temperature and low or high flow events CO_2 build up takes place in river waters,
4	Provisioning services (food sources)	Reduction in food sources derived from aquatic plants (algae, plants, rice etc). Loss in fisheries due to invasion, thermal intolerance, and habitat destruction due to varied flow conditions.
5	Regulatory services (temperature and erosion control)	Excessive water temperature creates thermal intolerance in aquatic biota leading to death and decay. High erosion leads in excess downstream transport of the contaminants. Decrease depth of the channel which affects deep water animals. High erosion due to dried catchment soils impart high turbidity, TSS and TDS values

some future research approaches which could contribute to increase the perceptive acquaintance and knowledge base to fill the knowledge gap of exact know-how related to this issue for this very important river basin of the Asia (Table 4).

Ganges River Basin: An important river basin of Indian subcontinent

The Ganges River, the third largest river by discharge and second largest river of the world after Amazon by its total drainage area of 1.75 million km^2, is a much important, sacred and ecologically sensitive river system. The Ganges basin is the part of the combined Ganga-Brahmputra-Meghna basin spread across China, Nepal, India and Bangladesh (Figure 1). Out of the total drainage basin area roughly 80%, is located in India covering around one-fourth of the country's total geographical area and thus is biggest river basin of India. It has much complicated hydrology with peak discharge between 70000 m^3/s to 180 m^3/s; highly seasonal stream flow with average dry season to monsoon discharge ratio of 1:6, causing both drought and flood in this river basin. It is bounded by the Himalayas in north, in south by the Vindhyas and Chhotanagpur Plateau, by the Aravalli in west and in the east by the Brahmaputra ridge [41]. In India this basin covers nine states out of 29 states. In the upper stretch of the river the natural flow is affected due to hydroelectric dams. While due to typical patterns of rainfall being restricted to only about 3 months during a year in the basin, the dry season flow in downstream has been seriously affected in conjugation with over-abstraction of groundwater in the basin. Marked variation in rainfall and temperature patterns have been reported in the basin indicating insistent climatic abruptions and weather shifts [42-45].

It has been the cradle of the Indian civilization since ages where around 40% of the population of India lives. Together associated with population explosion the rapacious and indiscriminate urban-industrial growth in this river basin, has resulted in massive fluxes of nutrients and other contaminants along its 2525 km length from its origin in Gangotri to the end in Bay of Bengal. Consequently it is witnessing huge concerns for its increasing pollution levels and associated ecological crisis [2]. Increased temperature and irregular rainfall patterns over this basin in recent decades has stimulated climate change stressors causing threat of ecological as well socio-economical crisis to it [44,46]. Global warming associated melting glaciers will not only increase flood events but also reduce water supplies in long run in this basin and thus both increased and decreased flow will definitely affect pollutant distribution in its long course. Therefore, it is imperative to view the status of pollution and other ecological problems associated with this river in the context of global and regional climatic change to understand the complex relations among pollution problems and climatic stressors acting in this river basin [45,47,48].

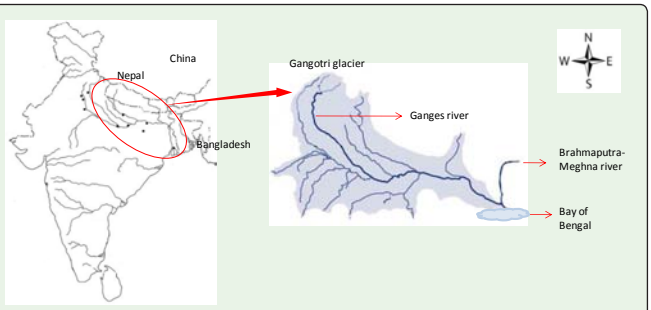

Figure 1: Location map representing Ganges River Basin and its drainage area in Indian subcontinent. Map not to scale.

Climate Change Related Impacts on Ganges River: What Needs to Fill the Knowledge Gaps?

There are many sources of pollution in Ganges basin such as, domestic waste discharges, industrial effluents and agriculture runoff; affecting its water quality which may be exacerbated under climatic influences [43]. Under the influence of climate change induced erratic rainfall creating high and low flow conditions; the organic matter and nutrients load of this river may interact with many environmental factors changing its physiological properties [49]. Though the climate change related impacts are important issues for this river basin, there are very few studies about the climate change related impacts on this river system [50-52]. Most of these studies are limited to assessing temperature and rainfall analysis over this basin or to identify and understand spatial-temporal effects temperature change on the species distribution in this river [50-54] (Table 1). Some studies report that there is marked change and shift in weather patterns over some Indo Gangetic regions which can be noticed by increasing mean annual maximum and minimum temperature range and decline in total monsoonal rainfall and no of rainy days in past few decades [44,55]. Trends in annual mean maximum and minimum temperature and total rainfall in last 50-55 years over one of the most polluted segment of the Ganges River clearly shows the variation and increase in temperature and corresponding decrease in total rainfall (Figure 2). This points out towards a possible change in climatic regime of the Ganges basin in the future as well. Few studies have also taken into account the impact of climate change on river hydrology and hydro-geochemical dynamics of Ganges basin [56,57] and have shown marked changes. For example, in Hooghly estuary, the lowermost part of river Ganges, a detailed study evaluates the spatio-temporal changes in selected physico-chemical parameters (temperature, transparency, pH, free CO_2, dissolved oxygen, specific conductivity, total alkalinity, total hardness, salinity, available nutrients like nitrate, phosphate and silicate) and founds that the

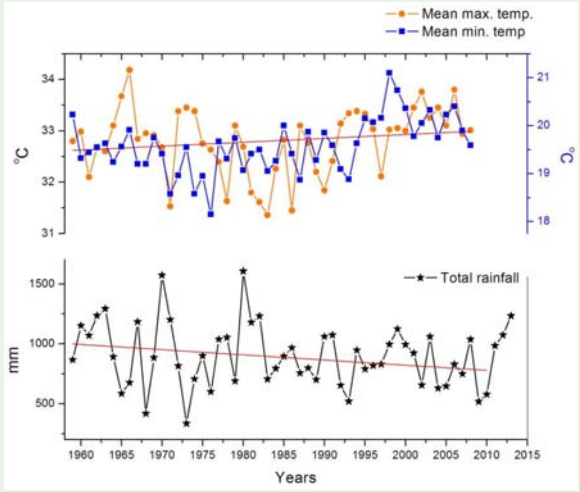

Figure 2: The mean maximum and minimum temperature and rainfall (1959-2014) pattern over Allahabad region of the Gangetic Basin.

salinity based zonation for biotic communities are modified now with a downward shift of freshwater zone with enhanced level of various water quality parameters [57]. Various simulation studies on extreme temperature over Gangetic basin show considerable seasonal and spatial variations due to warming with increasing numbers of warm nights/days as compared to cold ones [50,58,59]. Some individual as well as ensemble RCM models project possible extremes in Ganges basin but the efforts to explore their interaction with climate change and increasing level of pollution are spars [59,60]. These studies provide us an idea that this basin is experiencing growing seasonal temperature, seasonal high and low flows due to climatic extremes. However, changing future climatic extremes in the basin remain unexplored.

Variety of pollutants arising out due to climate change interactions is important to understand as they causing danger to Gangetic ecosystem [13]. Erosion features, salinity increase and more sedimentation in these river systems are prominent which may exacerbate under extreme vents triggered due to climate change [30,61] (Figure 3). A recent analysis on the future changes in temperature and precipitation scheme in the Ganges River basin projects the increase in the extreme events in the basin which could lead more pollution load in Ganges River [62]. Nutrient loading (such as, N, P, K, and Si) in Ganges River basin is also a big problem nowadays and it has also been discussed in studies however, only sporadic evidences are available where model projections and scenario developments have been used to estimate future projections [63,64] (Figure 3). There is a general lack to link their relations to the changes in climate regime such as with high temperature and irregular rainfall patterns which are clearly prevailing over this basin [44]. Although, distribution and transport of carbon, nitrogen, phosphorus and silicon in Ganges basin have been discussed in studies [5,65,66]; their fate and interactions under changing climate is still very complex which should be unveiled (Figure 3).There are some good attempts to link the drivers of climate change to pollution in rivers Ganges by providing insights on changing state of atmospheric land water transfer and associated shift in dissolved organic carbon build up on river [66]. Recently a changing state of atmosphere–land–water transfer and associated shift in Dissolved Organic Carbon (DOC) in Ganga River (India) has been reported [66]. A 1.5 to 1.8 fold increase was observed in atmospherically deposited organic carbon in water indicating a variable but strong linkage between atmospheric deposition and hydrological control of terrestrial carbon to this river. This may be an important link to understand carbon linkage in river water system by analyzing the interaction among variables of land-atmosphere inputs such as nitrate and phosphate runoff (Figure 3).

Some reports also indicate the huge amount of potassium in the Ganges River and its tributaries but attempts to understand the impacts of climate change on this aspect are also lacking from this region [5,67]. In recent decades, increase of arsenic and fluoride concentration and salinity in Ganges River basin has been reported and is of greater concern [13,61]; however, it has not been viewed under climate related aspects though the geogenic origin of these elements are related with the increase in atmospheric and water temperature. Since arsenic and fluoride is mainly derived from weathering which is directly affected by changes in pH, temperature and solubility product of chemical, the variation in climate would have interrelations with fluoride and as leaching in water in this basin which should be explored [68]. Also, it is predicted that the increase in temperature and decrease in precipitation can reduce groundwater recharge by 50% [69] which can raise the salinity of soils and waters

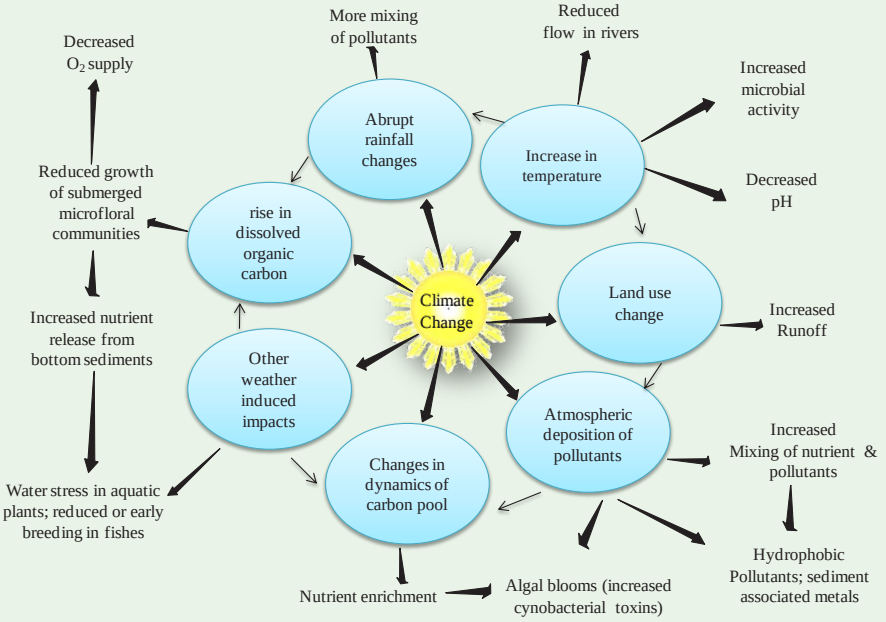

Figure 3: A schematic of the effects of climate change on various aspects of river biology. This represents a chain of interactions and their associated impacts on a river regime including Ganges River System. Various direct effects of the climate change induce other indirect effects on a river system posing many changes in the pollutant's chemistry and directly and indirectly affect river biology in many aspects.

in catchments [61,70]. Hence, proper and elaborative studies are demanded to understand the climatic interaction with these factors in Ganges basin. Impact studies on increased monsoon flow and flux on the concentration and dispersion pattern of metal pollutants in sediments of Ganges Rivers have also been carried out [30,47,64]. The response of the Ganges dispersal system to climate change is an important aspect which has been clearly evaluated by Goodbred [110]. According to his study the altered precipitation patterns under climate change, have forced system-wide responses ranging from glacier advance/retreat to sediment fluxes to the margin and deep-sea fan in this river basin. The study indicates that the immense dispersal system responds to multimillennial-scale (<104 years) climate change and that major sedimentary signals can be transferred rapidly from source to sink with little noticeable attenuation. Furthermore, these acute responses to climate change have produced sedimentary/stratigraphic features that diverge from traditional sequence models in their nature and timing in this river basin.

Notably, most monsoonal discharge has been notified to add the elevated levels of some radioactive elements such as Ba, Ra and Sr in Ganges River basin basically due to increased chemical weathering in Himalayas region and subsequent changes during transportation and deposition process which would be somewhere indirectly linked with increase in temperature in this region [71,72] (Table 2). Various other attempt have also been made to assess the pollution types and levels in river Ganges and its tributaries and most of them are sources and type specific and are not linked with impact of climatic variations on them [30,45]. The microbial pollution in this river system is most dangerous for the sustenance of this vital ecosystem as coliform pollution is increasing day by day in this river system [73]. The urbanization and discharge of untreated sewage along the course of the Ganges has degraded its pristine nature and polluted the water which have many bad health effects to the nearby populations. Although many studies have explored the nature and types of the microbes and microbial pollution in this river system [74,75], the studies regarding the impact of high temperature events and other climatic variables on the status of microbial pollution is very sparse and thus needed.

From careful observations and synthesis of available knowledge on various aspects of Ganges River pollution and its climate change linkages; it is quite evident that there are sporadic studies elaborating various pollution aspects of this river basin under various stressors of the climate change. There are scanty attempts to search a specific cause-effect interaction between climate change and pollution problems in this important river basin because climate change directly and indirectly affects many biophysical and chemical processes which are related with the river and their sustenance.

Biological Impacts on Ganges River

The climate change induced increased temperature and erratic rainfall may induce variable flow patterns this river regime, which after interacting with various pollutants may affect its biota by changing pollutant behavior and distribution pattern [49]. Although some efforts have been made to understand the interaction of climate change stressors and pollution in Ganges, species specifics microcosm studies with regards to climate change and its impact to are still sporadic [52]. Few studies have shown heavy metal and organic chlorine compounds accumulation in fish and prawn in Ganges River [52,76-78] however, these effects are not deliberated under significant experimental setup which could possibly explain the impact's causes and effects of different climatic variables (Table 2). This river basin is witnessing the alteration in fish population dynamics, diversity and community structures for which climate change induced sedimentation and species invasion were thought to be the major cause [52,79]. Downstream sediment transport by the river under increased flood conditions has also caused much danger to fish biodiversity in this basin and for which erratic rainfall patterns are responsible [52]. A recent investigation reports 0.99°C increase in minimum water temperature in the upper stretch of river Ganges and 0-1.4°C increase in aquaculture waters of some Gangetic plains impacting breeding in native fishes and increasing the assemblages of non native fishes in polluted upstream [79]. The shift in minimum air temperature coupled with increase in post monsoonal rainfall is clearly evident in this basin which has impacted the warm water fish migration and spawning in great deal [49,80]. Notably, the changes in thermal stratification in water columns may also impact the prey-predator relationship of this river causing manifold damages to this ecosystem [80,81].

Descriptions of biodiversity spatial patterns in structure and distribution of benthic diatoms, macro invertebrates and ichthyofauna in Ganges are available however they relatively lack to provide an insight to understand the effects of pollution levels on the distribution and abundance of above floral and faunal communities [82]. Furthermore, not only zooplanktons, but also the phytoplanktons have also declined in last few decades in Ganges River basically due to rise in water temperatures [82]. This seems an important observation and link as temperature has been is an important influencing factor controlling the occurrence of different phytoplankton in water bodies [80]. Thus this link may provide to understand many other related aspects where changes in climatic variables may be impacting phytoplanktons and their eco-physiological activities. Variability in pre and post monsoonal flow have been an important factor to assess the pollution variance in this river systems and many water quality parameters such as turbidity, transparency, DO, pH, free CO_2, specific conductivity, salinity, hardness, silicate silica were tested under this which remarkably affect the distribution of biotic communities signifying climatic impact on this river basin [57].

The properties of the Ganges water were unputrefying since ancient times that it has been used for daily uses and remedial purposes even after long periods of storage [83]. The presence of noticeable antibacterial activity against Vibrio cholera in Ganges water in India was observed long back in 1896 by Ernest Hankin [84]. Based on this instance, latter D'Herelle termed 'bacteriophage' to some invisible antibacterial agents [83]. This is an important aspect for this river which needs elaborative studies to identify different groups of phages and their role in microbial pollution abatement. Now it is utmost important to understand the changes in bacteriophages and their activity under increased temperature regimes of water columns and under other climatic stressors. As various forms of bacteriophage are now being assessed to be used in pollution source tracking as well as attacking on various coliforms to clean the waters it's the relation between climate change impacts and activities of bacteriophages in Ganges River, requires great attention [85]. It is important to understand that how temperature increases, low and high flow conditions and other associated impacts may affect the occurrence and survival of these phage communities in Ganges

waters. This could lead to an important research solution if climate resistant phage strains can be developed and used for the cleaning of microbial polluted waters of this river basin.

Future Research Approaches to Comprehend Climate Change Interactions with River Pollution

Based on the rigorous literature survey and synthesis; subsequent broad areas of the research are required to be undertaken for linking and understanding climate change effects on river pollution in Ganges River basin. These significant research approaches would be able to fill the knowledge gaps by determining and establishing cause and effect relationship between climate change and pollution in rivers.

1. There is a need to produce accurate and integrated process based prediction models for microbial pollutants and their interactions with increasing temperatures and increased flow of nutrients in rivers since microbes has deciding roles in mineralization and transformation of major nutrients coming into this river system
2. Estimating and understanding the sediment pollutant release ratios under increased temperature, in dry weather flow and peak flow in river Ganges would help to assess the magnitudes of the effects.
3. Microcosm studies are needed to understand the combined effects of salinity, pH and temperature in conjugation with chemical pollutants in Ganges River system; and consequently their potential impacts on river biota,
4. Transfer, transport and cycling of major nutrients and pollutants; their interactions with floral and faunal communities should be examined under enhanced surface temperatures and other climatic variables to assess their fate and impacts.
5. Social behavior and neurobehavioral change studies in fishes and other invertebrates in response to pollutions aggravated by climatic change are needed to have clear understandings of community functioning in such conditions in any riverine ecosystem.
6. Detailed explorations are needed in Ganges basin to completely assess the complex interrelations of climate change and process of N fixation, quantifying phosphorus fluxes, characteristics of phosphorus transformations and their direction of change at the sediment–water interface.

Scientific Methods to Cope Up With the Existing Climatic Stress

There is a strong need to employ scientific and effective river basin management actions to cope up with the existing problems and to be adaptable to future problems. River management authorities should plan and act on following things to reduce the chances of devastations in a river regime: (a) There is a need to develop precise forecasts and enhanced level of monitoring system for the air and water temperature status, precipitation, river discharge, amount of flow and fluxes of nutrients to become prepare for the upcoming happenings in the river regime. This should be done at local levels by improving the technical skills of local planners and workers. (b) There is a need to increasing the flood plain areas along the rivers where more plantations should be done. This will increase the watershed catchment zone, moisture content of catchment soil thereby reducing the flow velocities of runoffs, and root filtration zone. This will also enhance storm-water control, wetland creation, floodplain management, increased infiltration and water storage which in turn greatly minimize the flood risks. (c) Sustaining environmental flows, habitat rehabilitation in river channels, biological monitoring for early detection of changes in reproductive output are the options which may reduce the impacts of climate change related pollution problems in river regime.

Conclusion

It is quite evident that the impact of climate change pertaining to cause-effect relation to pollution in this river system will not only depend on high flow, discharge and fluxes of pollutants but also on the rate and magnitude of changes in flow regime associated with temperature, pH and other such factors which get influenced by the climatic extremes. These may have far reaching consequences for this river basin. Increasing temperatures and lowering pH are one of the major precursors, enhancers and modifiers of physico-chemical and biological systems of the rivers for which more interactive studies are still needed to completely understand the associations. Abundant knowledge is available on various pollution problems of this river basin; however, attempts to link it with changes in climate related variables and yet to understand and specify.

Pollution problems in river Ganges are now being viewed under broader aspects and with various dimensions of the climate change. However, there is still a huge need to establish various interactive experimental evidences by intriguing climate variables and pollutant interactions to understand pollutant dispersion and transformation and their effects not only in waters but also in sediments and in biota. In view of these facts the there is need to acquire adequate baseline information on water flows and related water quality disturbances interacting with climate change to develop comprehensive scenarios of the likely impacts of climate change in this river basin. Also, there is a strong need for strapping management actions to restore the ecosystem functioning of this river in conjugation with scientific research outputs establishing climate interactions with pollutions. Therefore, to evolve and restore riverine ecosystems of this important basin; climate change must be integrated in all research activities and policies to emphasize the cause effect relationship for a better and precise understanding of exact know-how and to plan accordingly for the adaptation and abatement of the effects.

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