

## **Climate Change Impacts on Water Quality of Water Bodies-A Review**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. Authors MPS and RS conceptualized and designed the study. Author ES managed the literature collection, material preparation and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.*

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### **ABSTRACT**

The impacts of climate change on water quality of water bodies are associated with the climatic extreme events (heavy rainfall and flood, heat, drought, wildfires, cyclones, hurricane, super storms) as the major drivers that require knowledge of understanding. Most research studies present the role of climate change in threatening water quality, risks on drinking water and contributions of catchment in water pollution, but less attention has directed to specific sensitive water quality parameters, appropriate methodologies, risks on ecosystem and managerial practice to reduce the impacts. This review highlight the of effect climate change on surface water bodies based on recent literatures on the impacts of climate change on water quality and promote practical opportunity for better management of these impacts. We conclude that consideration of climate change preparedness plan in catchments is the best option to adopt for minimization of climate change impacts on water quality of water bodies.

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## 1. INTRODUCTION

Climate change, a complex phenomenon slowly changing over millennia, is resulting in significant changes observed during the last two decades. The changes in the environment and their impacts on global climates enhance the climate related impacts such as average increase in global temperature, sea level rise, uneven distribution of rains and extreme events causing huge population and property damages. These events affect almost all the components of ecosystem including water, the most important key element of life on the earth [1]. The occurrence of extreme events of deadly heavy rainfalls in drought-stricken India in 2019, the floods, wildfires in Spain, increased heat waves in Europe in 2019 and occurrence of cyclones in various parts of the world are the significant indicators of the climate changes [2]. Further, the world also experienced flooding and unprecedented events of powerful hurricanes that destroyed homes and crops in the Dominican Republic, Haiti, and other areas of Caribbean islands apart from loss of life, degradation of the land surface, air quality as well as increasing water pollution in water bodies [3]. Impacts of debris and sediments from the watershed result in rapid decline in water quality of water bodies either by increasing the concentration or changing the nature of water quality parameters. Globally, the increase in surface and water temperature play important role in affecting the water quality of the water bodies, due to abrupt changes in water catchments, storage reservoirs, the performance of water treatment processes or the integrity of distribution systems [4]. Some authors reported that Global temperature has increased the water surface temperature by 0.2-2°C annually, 0.8-1.1°C by mid-century and 1.6-3.1°C by the century due to climate changes [5,6]. The water quality parameters like water temperature, dissolved organic carbon (DOC), nutrients, Organic pollutant, pathogens, cyanobacteria and cyanotoxins, stream flow and sediments are readily changing with change in climates [4,5,6,7,8]. The nitrate nitrogen ( $\text{NO}_3\text{-N}$ ), total phosphorous (TP), fecal coliform and fecal coliform bacteria also change with the changes in catchment area [9,10]. Wang et al. [11] found that increase stream discharge (Q), total nitrogen (TN) and total phosphorous (TP) also is increased with the increase in global temperature. Other parameters like average

monthly runoff,  $\text{NO}_3^-$  and organic nitrogen loads are decreased by 27, 18 and 13.5% in Golgol River (Iran) waters due to climate change [12]. Apart from water quality impairment, the impacts of climate change influence both physical damage of water structures, disease eruptions, severe pollutions, increase in water hardness, and increased growth of viruses, thereby, causing the chronic diseases like hepatitis, typhoid etc [13,14,15,4]. The risks associated can vary from local area to global level. However, based on the climate change impacts on water quality of water bodies, particularly rivers, the different models and tools like Hydrological models, water quality models, watershed management models, correlation, sensitivity analysis and other statistical multivariate techniques can be employed to show the impacts of climate change on water quality of water bodies.

In view of the above, it is mentioned that climate change has significant changes in water quality of water bodies. The present paper covers the literature review of relations between the changing climates and water quality of water bodies, the methodologies used to analyze the impacts of climate change on water quality and mechanism of pollution of water bodies by the climate changes. However, the risks associated with climate change on water bodies' ecosystem, sensitivity of water quality parameters to climate change (CC) and proposal of managerial measures to the impacts are also addressed in this paper.

## 2. CLIMATE CHANGE IMPACTS ON WATER QUALITY OF WATER BODIES

The concept of climate change effects on water quality of water bodies can easily be based on the impacts of the flow regime of that particular water body [16]. Any change in the patterns of rainfall, increase in the frequency of the rainfall, flood fluctuations and other extreme events results into the change in the flows regimes caused by the change in hydromorphology, chemical reactions and ecological environment of the water bodies [16,17]. The effects of climate change on the chemistry and water ecology of rivers can be known from the relations between the climate change and water quality parameters impacted. Based on the literature, Table 1 summarizes the climate change parameters and their impacts on water quality.

The Table 1 shows that climate change parameters are responsible for the water quality impairment. Each parameter has distinct ultimate impacts on water, water quality and river ecology. Increased water temperature, runoff, sediment, increased greenhouse gases(GHG) emissions and drought-flood fluctuations are found to impact water quality parameter like river discharge, suspended solids and nutrient causing impacts on increasing phytoplankton and disturbances of the self-purification process of the rivers.

### **3. METHODOLOGIES USED TO ASSESS THE IMPACTS OF CLIMATE CHANGE ON WATER QUALITY OF WATER BODIES**

The impacts of climate change on water quality can be assessed using various approaches like, statistical analysis; global climate models (GCMs) and hydrological models. Table 2 summarizes the common approaches used to assess the climate change impacts on water quality. The approaches/ methods differ from one catchment to another depending on the type of impact on water quality.

The Table 2 shows that Soil and Water Assessment Tool (SWAT) and Global Circulation Models (GCM) are more applied tools to analyze the climate change impacts on water quality. Next, the combinations of SWAT with GCM and other models like water evaluation and planning system (WEAP), multi-model ensemble simulations (MMES), Shared Socio-economic Pathways (SSP) and HEC-ReSim etc. are also used to analyze the impacts of climate change on water quality and other purposes such as water availability and distribution(WEAP), transportation of fecal coliform bacteria from catchment to water bodies (MMES), socio-economic impacts(SSP) and future dam capacity by Reservoir System Simulation (HEC-ReSim) respectively. The Commonwealth Scientific and Industrial Research Organization Mark3 (CSIRO-Mk3.0) and TANK model performed better in evaluating the changes in stream flow, SS, and TN in Byonseong stream (South Korea) with change in precipitation [29]. However, the statistical analysis methods (Mann-Kendall, Seasonal Kendall and the paired t tests) are found to be rarely useful in assessing the climate change impacts on water quality. The use of both hydrological and climate models together are found to perform better in assessing climate

change impacts on water quality compared to other methods.

### **4. IMPACTS OF CLIMATE CHANGE ON WATER QUALITY OF RIVERS**

The degradation of Water Quality of rivers due to climate change can be by direct or indirect processes involving hydrological response of the river i.e stream discharge, runoffs, drought and temperature rise etc. as shown in Fig. 1.

The Fig. 1 shows that the climate change is mostly driven by natural processes, anthropogenic activities and population growth. All these factors influence the Green House Gases (GHG) concentrations, which lead to global temperature increase and climate extreme events like heavy rainfall, extreme heat, drought, wildfires, cyclone, hurricane and any super storms with high risks on water quality in the form of increased water turbidity, total suspended solids (TSS), total solids (TS) and pathogens in water, thereby, changing the water quality of rivers/water bodies. Other impacts include fluctuations in river flow, fecal coliform, water temperature and destabilizations of microbial activities. Almost all water quality parameters are impacted by the climate change but dissolved oxygen (DO), suspended solids (TSS), and dissolved solids (TDS), organic matter (OM), nutrients, fecal coliform and other bacteria are more prone to changes in daily weather conditions and last for longer period of time.

### **5. IMPACTS OF CLIMATE CHANGE ON WATERSHED RESULTING TO SURFACE WATER POLLUTION**

The hydrological responses of water bodies are related to the changes in the watershed which decides the water quality of a water body (rivers/streams, reservoirs /lakes as well as oceans). The water quality, most often, changes abruptly or gradually depending on the processes involved and the type and source of the contaminants. The pollutants inherent in sediments at the bed of the water bodies tend to dissolve in water column due to changes in water temperature. Table 3 lists some of the impacts of climate changes on water quality of water bodies.

Table 3 shows the impact of climate change on the watershed processes and type of pollution impacting the water quality. Watershed processes like soil erosion and soil washout, due

to runoffs, contribute to the deposition of soil particles into water bodies leading to alteration of water quality parameter like TSS, TDS, nutrient loadings pathogen contaminant concentrations [26,27]. Presence of decayed living organisms in watershed, overheating, land degradation and excessive agricultural practices also contribute to effective flash flood, excessive evaporations, river sedimentations and depositions of more nitrogen and phosphorous resulting in the increase in organic matter fluxes, heavy metals, eutrophication processes in water bodies and decrease in DO. In this way the climate change impacts alters the physical, chemical and biological compositions of water in water bodies.

### **5.1 Risks Associated With Climate Change Impacts on Water Quality**

The multidimensional risks associated with climate change on water quality include risk to ecological system of rivers, aquatic organisms, human and other terrestrial organisms [13,14,15]. The magnitude of the risks depends on the duration of the event, nature of the pollutants induced into water, water quality parameters affected, extent (spreading level) of the impacts on the aquatic organisms, people, wildlife and the life span of the pollutant in water. One study showed that increased chlorophyll-a, Turbidity, Color, TSS and TDS support the risk to water quality but extreme heat, heavy rainfall and flood, increased global temperature, drought are found more effective climate events affecting the water quality of a given water body [5,7,8,9,11,12]. Table 4 lists the risks that are classified on the basis of extent loss/in general level of predominance.

High<sup>\*</sup>: Loss of life of aquatic organisms and disappearance of some species.

High<sup>\*\*</sup>: Long term DO depressions, suffocations to river health organisms and aquatic organisms.

High<sup>\*\*\*</sup>: Increased level of water toxicity that may result in hormone disruption in living organisms including people, wildlife and aquatic organisms.

High<sup>\*\*\*\*</sup>: Pandemic diseases (cholera, diarrhea), skin rashes, respiratory infections and viral hepatitis.

Medium the effects that exists only for one season.

Low: Pollutions, that persists for short time in water like bad smell, taste, color etc. The risks are summarized in Table 3.

The Table 4 highlights the consequences of the impaired water quality to the ecosystem under the influence of climate change extreme events. Extreme heat and increased air temperature cause death to aquatic organisms due to reduction in DO leading to the disappearance of some micro species in water bodies [6-9]. Heavy rainfall and flood, hurricane, wildfires, drought cyclones and super storms accelerate the sedimentation processes in rivers making it a storage for dissolved organic carbon (DOC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), natural organic matter (NOM) and other pollutants affecting the water through dissolution processes, which pose difficulties in drinking water treatment resulting in waterborne diseases. However, such extreme climate change events can cause more nutrient loading in water which when consumed without proper treatment can result into diseases like cancer [5,7,8,9,11,12]. *E. coli*, Coliform and pathogenic bacteria may also cause the human health in terms of epidemic and endemic diseases [15,10].

### **5.2 Collective Measures to Reduce the Impacts of Climate Change on Water Quality**

The above climate change impacts can be minimized by adopting the best watershed management practice to improve the water quality of water bodies. Further, the use of best crop choices may minimize the applications of inorganic fertilizers, thereby, reducing the pollution of water bodies and water quality impairment. Also, the reforestation in barren areas of the watershed is likely to increase the areas for infiltration process which would reduce the runoffs and sedimentation from reaching the river and other water bodies minimizing the possibilities of higher organic and pathogenic pollutions in water. Moreover, the preparations and implementations of climate risk preparedness plan (CRPP) for each catchment protect the vegetation buffer zone vegetation of the water bodies, provision of dams for flood control and wetland protections. These action would help to reduce the risks of pollutions resulted from climate change.

**Table 1. Impacts of climate change on the water quality level of water bodies**

S/N	Climate Change parameters	Impacts on WQ	Ultimate impacts	References
1	Increased stream temperature	Water Quality parameters	Reduced discharge, increased phytoplankton and deficit of oxygen	Ducharme 2007 [18], Du et al. 2019 [6]
2	<ul style="list-style-type: none"> <li>• Surface runoff</li> <li>• Sediments</li> </ul>	Suspended Solids	Increased chloride concentration of water, Fluctuations in stream flow and nutrients	Göncü et al. 2007 [19], Mehdi et al. 2017
3	Drought-Flood fluctuations	Water quality parameters (alters nutrients)	<ul style="list-style-type: none"> <li>• Increased nutrients in downstream plain areas</li> <li>• Higher levels of Total nitrogen in water</li> </ul>	Bi et al. 2019 [20]
4	Tidal estuaries	Water quality parameters	<ul style="list-style-type: none"> <li>• Reduced DO leading to toxic water use</li> <li>• Increase in nutrient making water unfit for drinking purposes</li> </ul>	Liu et al. 2016 [21]
5	Increased air temperature	Excess evaporation, increase in nutrient loading	<ul style="list-style-type: none"> <li>• Reduced stream flow and fluctuations of basic water quality parameters.</li> <li>• Increase in total Nitrogen, phosphorous and chlorophyll-a</li> </ul>	Escurra et al. 2014 [13], Delpla et al. 2009 [5] Wang et al. 2018 [11] Nguyen et al. 2017 [8]
6	Increased GHG emissions	Risks in Water Quality	Reduced river flow and increased chances of flooding and drought events	Döll et al. 2015 [14], Yang et al. 2019
7	Dynamic precipitation	Biological water quality parameters	Increased levels of Enterococcus in surface water	Semenza et al. 2014 [15]
8	Stream discharges	Water quality parameters	Increased concentrations of ammonia, phosphorus and chlorophyll-a	Hrdinka et al. 2014 [22]
9	All climate extreme events	Water quality parameters	<ul style="list-style-type: none"> <li>• Destructions of storage reservoirs</li> <li>• Affects the drinking water treatment plant performance</li> </ul>	Khan 2015 [4]
10	Increased volume of water	Pathogens	<ul style="list-style-type: none"> <li>• Increased fecal coliform</li> <li>• High sediment loads in the steam</li> </ul>	Jeon et al. 2019 [7]
11	Changes in river hydrology	Water quality	Increased annual water temperature	Li et al. 2011 [23]

CC: climate change, DO: dissolved oxygen, GHG: greenhouse gas emissions, WQ: Water quality

**Table 2. Approaches used to assess the impacts of climate change on surface water quality**

Name of water body	Study Area(location)	Catchment area (km <sup>2</sup> )	Method(s)	Impacts on water quality	References
Yuqiao Reservoir	China	2060	<ul style="list-style-type: none"> <li>•Mann-Kendall,</li> <li>• Seasonal Kendall tests</li> <li>•The paired t tests</li> </ul>	Trends of NH <sub>4</sub> -N, NO <sub>3</sub> -N, NO <sub>2</sub> -N and TN in water with CC	Zhang et al. 2018 [24]
Huai River basin	China	270000	<ul style="list-style-type: none"> <li>•Mann-Kendall test</li> <li>•Piper diagrams</li> </ul>	Assessing impacts of climate Change on water quality with	li, et al. 2011 [23]
Vistula Lagoon	Europe(Poland and Rusia)	20 730	SWIM and 15 climate scenarios	Risks of climate change on water quality	Hesse et al. 2014 [25]
	Southern Sweden	(1900	CAM and GCM SOILNBD, BIOLA and HBV-N Model	Effects of climate change and LULCC on the surface water quality	Arheimer et al. 2005
Mississippi river	North America	20,000	SWAT and GCM	The future climate change impacts on water quality	Yang et al. 2019 [7]
Elbe River	Germany	1094	Qsim model and GCM	Impacts of climate change on oxygen budget of a water bodies	Hein et al. 2016 [26]
Duffins Creek watershed	Southern Ontario	293	AGNPS, CGCM1 and HadCM2 models	The sensitivity of water quality to climate changes impacts	Booty et al. 2013 [27]
Mahanadi river	East-Central India	141,589	Multi-branched INCA models and GCMs	Comparison of climate change and socio-economic impacts on water quality	Jin et al. 2018 [28]
Byonseong stream watershed	Korea	433.11	CSIRO-Mk3.0, SWAT and TANK model	Assessment of stream flow, SS, and TN changes with change in precipitation	Choi et al. 2012 [29]
SeomjinRiver	Korea	4911.89	SWAT, GCM(RCP 4.5 & 8.5) and HEC-ReSim	Assessment of water quality changes at different climatic scenarios	Ahn et al. 2017 [30]
Minija River basin	Columbia	159000	SWAT and GCM(RCP 4.5 and 8.5)	Assessing stream temperature changes with water quality	Du et al. 2018 [6]
Kabul river basin	Pakistan	92600	SSP(1& 2), GCM (RCP 4.5 &8.5) and SWAT	Flux of E.coli load with climate and socio-economic change	Iqbal et al. 2019 [31]
Taehwa river watershed	Korea	417.6	SWAT, GCM and MMES	Impacts of climate change on Fecal Coliform transportation	Jeon et al. 2019 [31]

<b>Name of water body</b>	<b>Study Area(location)</b>	<b>Catchment area (km<sup>2</sup>)</b>	<b>Method(s)</b>	<b>Impacts on water quality</b>	<b>References</b>
Millbrook reservoir	South Australia	361	SWAT & SALMO	Influence of climate change variability on nutrient fluctuations	Nguyen et al. 2017 [31]
Krishna river basin	Peninsular India	258948	SWAT and GCM	Climate change impacts on surface water bodies	Tirupathi et al. 2018 [32]
Fergus catchment	Western Ireland	711	SWAT and GCM	Impacts of climate change and land use on the future water quality in water bodies	Coffey et al. 2016 [33]
Bilate watershed	Ethiopia	74,536	SWAT, GCM and WEAP	Effects of climate change on surface water availability	Hussen et al. 2018 [34]
Parts of Minnesota, Wisconsin, Iowa, Illinois and Missouri rivers	North America	492,000	SWAT and GCM	Variation of freshwater quality with changing climate and land management practices.	Li et al. 2018 [35]
The upper part of the Altmühl watershed	Germany	993.4	SWAT	Evaluation of water quality variables under climate change	Mehdi et al. 2017 [9]
Miyun Reservoir basin	Northern China	5,788	SWAT and GCMs	Impacts of climate change on stream water quality parameters	Wang et al. 2018 [11]
Minija River(Lithuania)	Lithuania(Europe)	3097.04	SWAT-LAB and GCM	Stream flow and nutrient variations in the near future	Cerkasova et al. 2019 [36]

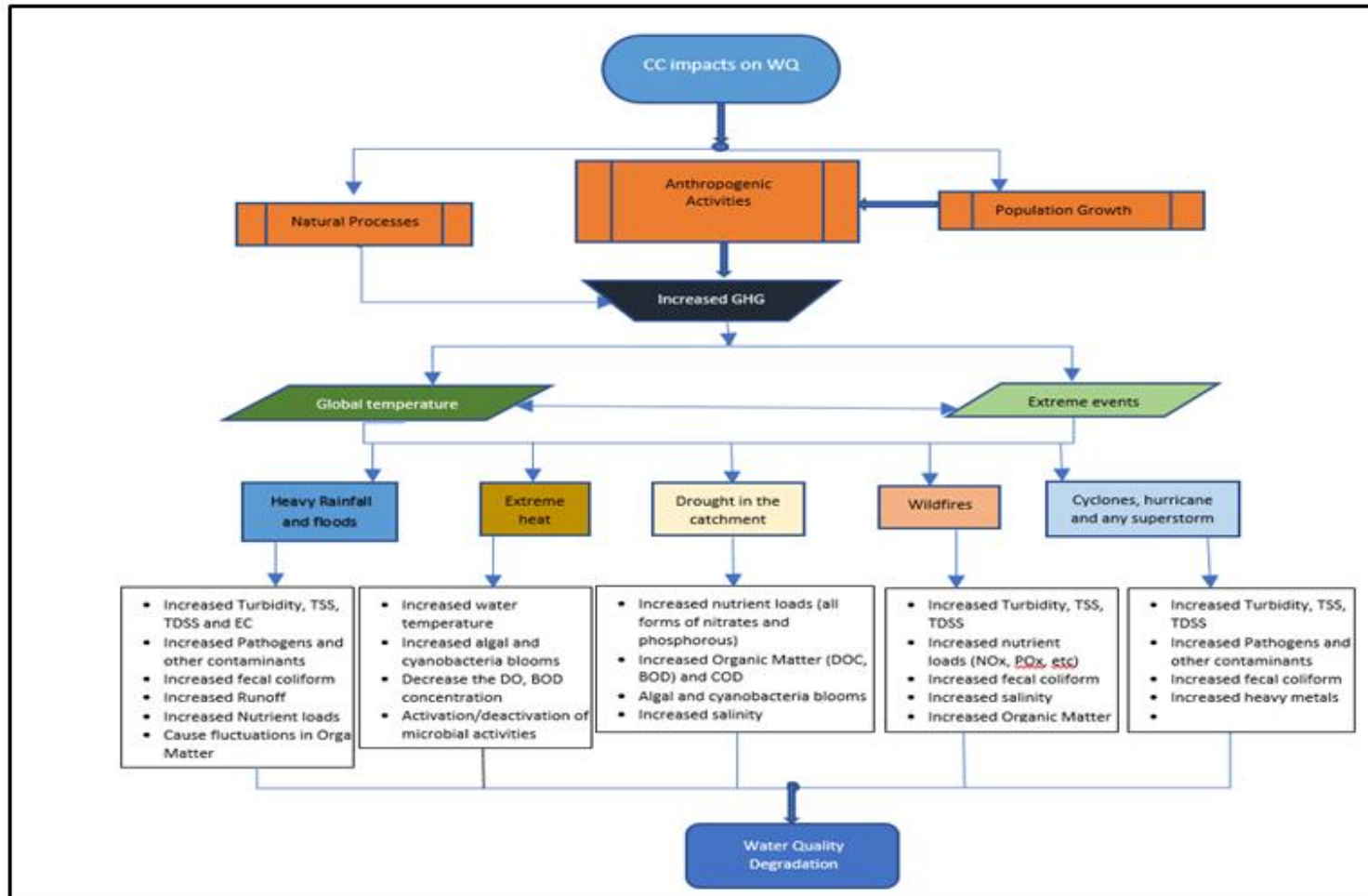


Fig. 1. Mechanism of occurring of the impacts of Climate Change on water quality of waterbodies



**Table 3. Impacts of climate change on watershed resulting to surface water quality impairment**

S/N	Changes in water shed	Pollutions to surface water	Impacts on WQ	References
1	Soil erosion	Deposition of soil particles in water bodies Weathering of land surface	Increase in Total Suspended and dissolved solids Nutrient loading dynamics in water bodies	[26,27] [27,37]
2	Surface soil washout due to runoff	Siltation of rivers	Increased pathogens and contaminant concentrations	[19,27]
3	Decay of living organisms in watershed.	Flush flooding	Organic carbon/organic matters flux	[19,31,37]
4	Change in surface temperature	Increased evaporation	Decrease in DO concentration in water bodies	[8]
5	Land degradation	Polluted runoffs	Increased heavy metals	[27]
6	Excessive agricultural practice	Depositions of more Nitrogen and phosphorous in surface water	Eutrophication in water bodies	[31]

**Table 4. Risks associated with Impacts of climate change on water quality parameters**

S/N	Water Quality Parameters affected	Impacts of Climate Change on water quality parameters	Associated climate change events	Level of risks	References
1	Temperature	<ul style="list-style-type: none"> <li>Increased Water temperature</li> <li>Increasing bio-chemical reactions in streams</li> </ul>	Extreme heat, increased Global temperature	High*	[5,6,7,8]
2	Dissolved Oxygen(DO)	Decrease in DO and transformations	Extreme heat and increased global temperature	Medium	[5,16]
3	Sediments	Increased sediment loading in streams	Heavy rainfall and flood, hurricane, wildfires, drought cyclones and super storms	High **	[13,18]
4	River discharge	Fluctuations in Stream flow	Extreme heat, increased global temperature, drought	Medium	[5,7,9,11]
5	Nutrient and Temperature	<ul style="list-style-type: none"> <li>Increase in chlorophyll-a concentrations</li> <li>Nutrient loading dynamics in water bodies (Total N, Total P, Nitrates and Phosphorous)</li> </ul>	Global temperature, Heavy rainfall and flood, hurricane, wildfires, drought cyclones and super storms	High ***	[8,5,7,9,11,12]
6	DOC, BOD, COD and NOM	Organic carbon/organic matters flux (DOC, BOD, COD and NOM)	Heavy rainfall and flood, hurricane, wildfires, drought cyclones and super storms	Medium	[5,37]
7	E. Coli F. Coliform Bacteria(pathogens)	Increased pathogens and contaminant concentrations	Heavy rainfall and flood, hurricane, cyclones and super storms	High****	[5,10]
8	Turbidity, Total solids	Increase in Turbidity, Color, TSS and TDS	Heavy rainfall and flood	Low	[5]

DOC: dissolved organic carbon, BOD: biochemical oxygen demand, COD: chemical oxygen demand, NOM: natural organic matter, TDS: total dissolved solids, TSS: total suspended solids

The buffer zone vegetation acts as a filter for the polluted runoffs from the catchment, while the dams and wetland absorbs the sediments and other pollutants in the runoff before reaching the water bodies.

## 6. CONCLUSION

The climate change impacts on water quality are posing threats not only to aquatic organisms but also to river ecology and man. The water treatment plants are now experiencing inefficiency in their performance leading to high risk of micro pollutant loss, eruption of pandemic diseases such as cholera and typhoid due to reaching of pollutant to the water bodies. It is evident that water quality is prone to impairment due to climate change impacts resulted from associated extreme events. The water quality is affected by changes that takes place in watersheds and are driven by the climatic extreme events like extreme heat, heavy rainfall, wildfires, drought and floods. The direct impacts to water quality like depositions of GHG from the atmosphere to water direct heating of water from air temperature has been a challenge to quantify in analyzing the impacts of climate change to water quality. The watershed management practices are suggested in terms of cropping pattern choices to reduce the associated water quality pollutions from the climate change.

## 7. FUTURE STUDY

The prospected work in studying the impacts of climate change on water quality will be but not limited to the following; development of the best management plan of watershed practice to reduce the impacts of climate change on surface water bodies and preparation of climate risk preparedness plan for each catchment area as means to address climate change effects at regional level.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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