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Short Note

Global Warming and Its Effect on Flow in Ganga River

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Abstract: In this work, water flow in the Ganga River has been analyzed based on the available data starting from the year 1850 to the average of years 2002 to 2006 at Farakka in West Bengal. The flow has been related with rainfall data in the Ganga basin starting in the year 1980, and the average rainfall data in the years 2002 to 2006. The year 1980 has been chosen based on the fact that after this year the global warming trend has increased (Adhikari and Huybrechts, 2009). The location at Farakka has been chosen to incorporate the contributions of entire Himalayan glaciers in enhancing the flow of Ganga upstream of Farakka. This way, the results have been presented to include the effects of glaciers melting at the source of Ganga and also the contributions of other rivers which are tributaries of Ganga. The result shows that there is significant effect of global warming on melting of Himalayan glaciers and the flow rate of Ganga.

Key words: Global warming, melting of glaciers, flow in Ganga, glacier fed rivers.

Introduction

One of the alarming environmental challenges that the world is facing at present time is unabated global warming and its effect on climate change. According to the report of Intergovernmental Panel on Climate Change (IPCC), the global average air temperature near earth's surface has increased to 0.74 ± 0.18^{o} C in the last century and the rate of increase has doubled since the year 1979. This unparalleled rise in temperature would affect the global hydrological system, ecosystems and other related processes. One severe effect of global warming would be melting of glaciers and future of several rivers originating from the glaciers. In India three major rivers, originating from glaciers are Indus, Ganga and Brahmaputra. Figure 1 shows the map of these three river basins. It also shows the location of glaciers from where these rivers originate. These glaciers are in high altitude on the Himalayan mountains in Tibetan plateau. Glaciers produce melt water only during warm periods, i.e., periods with above-freezing temperatures. The main flow of these rivers is contributed by rain. With the melting of polar ice caps, an alarm has been raised about the future supply of water from the Himalayan glaciers which were formed during the last ice age, and hold large supply of water feeding these three rivers.

Several works in the literature have described the serious effects of global warming on glaciers melting. Raupa et al. (2007) and Huffmanet et al. (2007) used remote sensing technique to measure the retraction of glaciers due to melting. Immerzeel et al. (2010) have discussed the effect of melting of Himalayan glaciers on the discharge of five rivers originating from the glaciers. They have concluded that melt water is extremely important in the case of Indus and the Brahmaputra basins, but only a modest effect for the Ganga, Yangtze, and Yellow rivers. They also believe that it will affect water availability and food security

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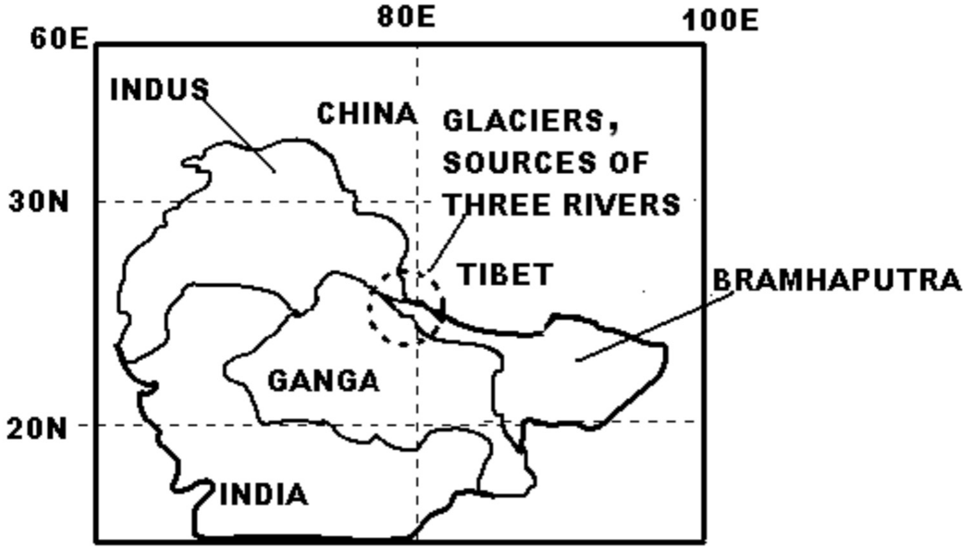

Figure 1: Three river basins.

to large number of people living in all these basins and that the Brahmaputra and Indus basins are most susceptible to reductions of flow. However the effect of glacier melting has not been studied by analyzing the discharge of a particular river. Since India's population is the heaviest along the Ganga basin, it is a matter of extreme importance that one looks into this problem in greater depth. In the present work an effort has been made to correlate the flow rate of Ganga with the rainfall data so that the contribution of glacier melting on the flow rate can be estimated. The flow rate has been taken from Adel (1999) and Report (2009) while rainfall information has been taken from data provided by Indian Institute of Tropical Meteorology (http://www.tropmet.res.in/static_page.php?page_id=53).

Melting of Himalayan Glaciers

Adhikari (2007) has studied the effect of temperature rise on melting of glaciers. In this study, he assumes a forcing function proportional to linear variation of ambient temperature with respect to height from the sea level. However, it has been found that the Himalayan glaciers in the Tibetan plateau are located at elevations of about 4500 metres. In the case of Tibetan plateau, since it is elevated, it should be noted that the solar radiation causes input of extra thermal energy into air which is over and above that given by equation mentioned in Adhikari (2007). Radiosity in heat transfer is the total radiation (reflected plus emitted) leaving a surface (Holman, 1990). This process is nonlinear in nature.

Due to this effect, the thermal energy input for melting of glaciers is much more than normally given in the equation form in Adhikari (2007). The higher the altitude of a land, the more rapid is the warming, a fact that has been noted in temperature records in Nepal (Shrestha, 1999) and China (Liu and Chen, 2000). Therefore, the ice melts at a much faster rate than what is given by a forcing term in Adhikari (2007). The melted ice will give rise to increased flow in the river. Once all the ice is gone then there will not be as much water in lean months— March to May of every year.

Analysis of Data and Results

As mentioned earlier, the flow rate has been taken from Adel (1999) and Report (2009) while rainfall data of major rivers in Ganga basin have been taken from Indian Institute of Tropical Meteorology. The flow and discharge data were considered for the year 1980, since that year the global warming trend showed a significant increase (Adhikari and Huybrechts, 2009). The location at Farakka has been chosen to incorporate the contributions of entire Himalayan glaciers in enhancing the flow of Ganga upstream of Farakka. This way, the results have been presented to include the effects of glaciers melting at the source of Ganga and also the contributions of other rivers which are tributaries of Ganga. The catchment areas of main states of Ganga river basin and rainfall in the year 1980 and 2004 during March to May, October-November and December-February have been shown in Tables 1, 2 and 3 respectively. Table 1 shows the data during

Table 1: Change in volume of rainwater during March to May period

		1980 March-May		*2004 March-May*	
States	*Catchment area* ($\times 10^6$, m^2)	*Rain* ($\times 10^{-2}$, *m*)	*Volume* (m^3) (*columns 2 × 3*)	*Rain* ($\times 10^{-2}$, *m*)	*Volume* (m^3) (*columns 2 × 5*)
1	2	3	4	5	6
West Bengal	8875.2	2974	2.64E+07	1926.4	1.71E+07
Jharkhand	71730	1266	9.08E+07	896.2	6.43E+07
Bihar	94164	1523	1.43E+08	1089.4	1.03E+08
East Uttar Pradesh	119283	203	2.42E+07	375.4	4.48E+07
West Uttar Pradesh	119283	369	4.40E+07	460.4	5.49E+07
Uttarakhand	53566	369	1.98E+07	103.89	5.56E+06
Haryana	30948.4	401	1.24E+07	604.6	1.87E+07
West Rajasthan	85559	219	1.87E+07	183.4	1.57E+07
East Rajasthan	136894.4	92	1.26E+07	247	3.38E+07
West Madhya Pradesh	77036	13	1.00E+06	252.4	1.94E+07
East Madhya Pradesh	123257.6	120	1.48E+07	430.2	5.30E+07
Vidarbha	46156.95	44	2.03E+06	501.2	2.31E+07
Chandigarh	135194	401	5.42E+07	604.6	8.17E+07
Total			4.64E+08		5.35E+08
Percentage change					**Increase = 15.1589**

March to May—the pre-monsoon period when snow or the glaciers starts melting. The bottom row shows the total volume of water in these two years, and it shows that there is an increase of about 15% in the year 2004 (column 6) over 1980 (column 4). Similar increase in rainfall volume has been observed for other two periods (Tables 2 and 3). It can be noted that significant increase of rainfall during last 50 years has been also reported by Goswami et al. (2006).

Figure 3 shows the total flow variation during the years 1850 to 2004 for those months (March-May, October-November and December-February). It shows that the flow has increased in the months of March-May and October-November in the year 2004 over year 1980.

How much or what fraction of this rainwater gets into the Ganga river is not possible to know as it depends on other factors prevailing in different areas of the basin. However, one can assume that in a given period (from 1980 to 2004)—whatever the values those factors have in any individual area—it would remain constant over the period (1980 to 2004) under consideration. It shows that the total flow has also increased. The increase in the flow could arise from the melting of ice or increase in rain or both. No data is available during the months of June to September, the monsoon period. It is well known that the maximum melting takes place during this period when the temperatures are high.

The rainfall results of October-November period have been shown in Table 2. Considerable increase in rain (about 62.13%) has been observed for the period 1980 to 2004. The increase in flow rate during this period has also been observed in Figure 3, where the flow rate has increased 66%. Thus the rate of increase of flow rate is greater than the rate of increase of rainfall volume. In this period, the temperature remains above the melting point of ice. Therefore, the increase in the flow could arise due to glacier melting. During the months of March to November, the rate of increase of flow rate is more than the rate of increase of rainfall volume.

Thus, during these months the excess (as compared to pre-1980 years) glacier melting contributes to the increase in discharge rate; there is a change in the trend in flow after 1980.

Finally, the period between December to February shows strange behaviour of discharge with the rainfall data. During this period, ice does not melt. The rainfall results are shown in Table 3 which shows that there is an increase by about 19%. However, Figure 3 shows a decline in flow for this period. This leads to a conclusion that during the March to May period, with the same increase in the rainfall, the increased flow had arisen from melting of ice not from rainfall. In December to February period, the decline in flow has been observed due to absence of melting of ice even though the rainfall had increased by about 19%.

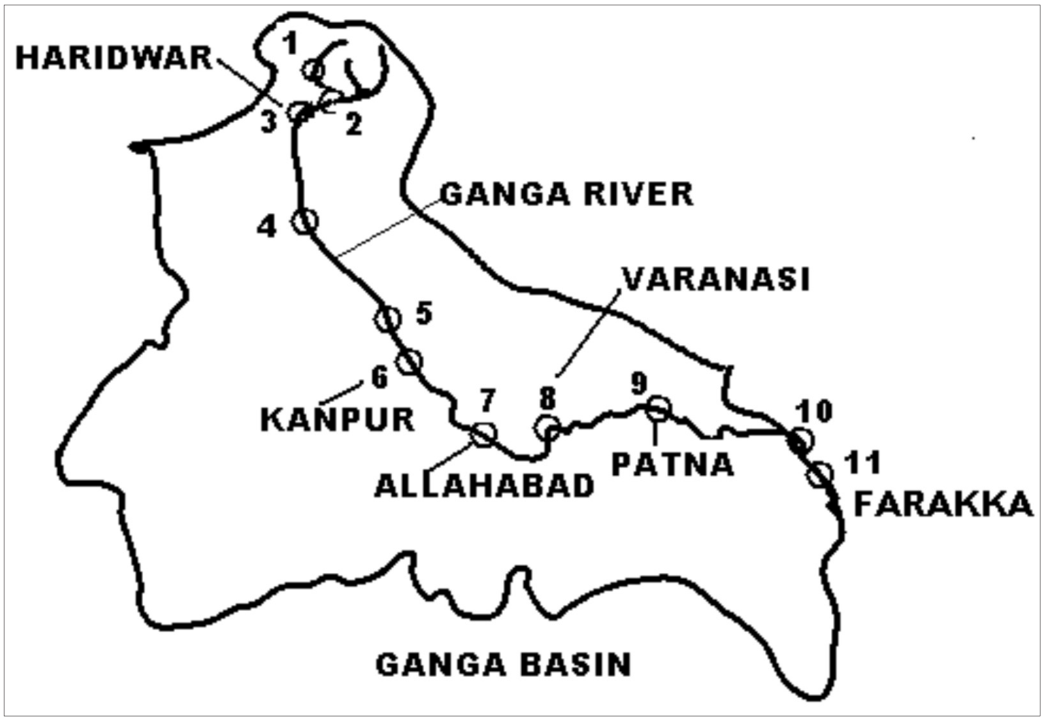

Figure 2: Map of Ganga basin.

Table 2: Change in volume of rainwater during October to November period

		1980 October-November		*2004 October-November*	
States	*Catchment area ($\times 10^6$, m^2)*	*Rain ($\times 10^{-2}$, m)*	*Volume (m^3) (columns 2 × 3)*	*Rain ($\times 10^{-2}$, m)*	*Volume (m^3) (columns 2 × 5)*
1	2	3	4	5	6
West Bengal	8875.2	1357	1.20E+07	2601	2.31E+07
Jharkhand	71730	736	5.28E+07	1144.6	8.21E+07
Bihar	94164	276	2.60E+07	547	5.15E+07
East Uttar Pradesh	119283	208	2.48E+07	225.4	2.69E+07
West Uttar Pradesh	119283	176	2.10E+07	162.8	1.94E+07
Uttarakhand	53566	176	9.43E+06	162.8	8.72E+06
Haryana	30948.4	223	6.90E+06	130.2	4.03E+06
West Rajasthan	85559	42	3.59E+06	54.8	4.69E+06
East Rajasthan	136894.4	26	3.56E+06	108.2	1.48E+07
West Madhya Pradesh	77036	25	1.93E+06	135.4	1.04E+07
East Madhya Pradesh	123257.6	69	8.50E+06	303.2	3.74E+07
Vidarbha	46156.95	2	9.23E+04	538.8	2.49E+07
Chandigarh	135194	223	3.01E+07	130.2	1.76E+07
Total			2.01E+08		3.26E+08
Percentage change					**Increase = 62.130**

Conclusions

In this work, the flow data in the river Ganga have been presented in two different periods: one from 1850 to 1980, the pre-global warming period and the average of flows for 2002 to 2006 has been represented as 2004, during the global warming period.

The flow in the Ganga in the year 1980 has been compared to that of year 2004 during March to May, October to November and December to February. It

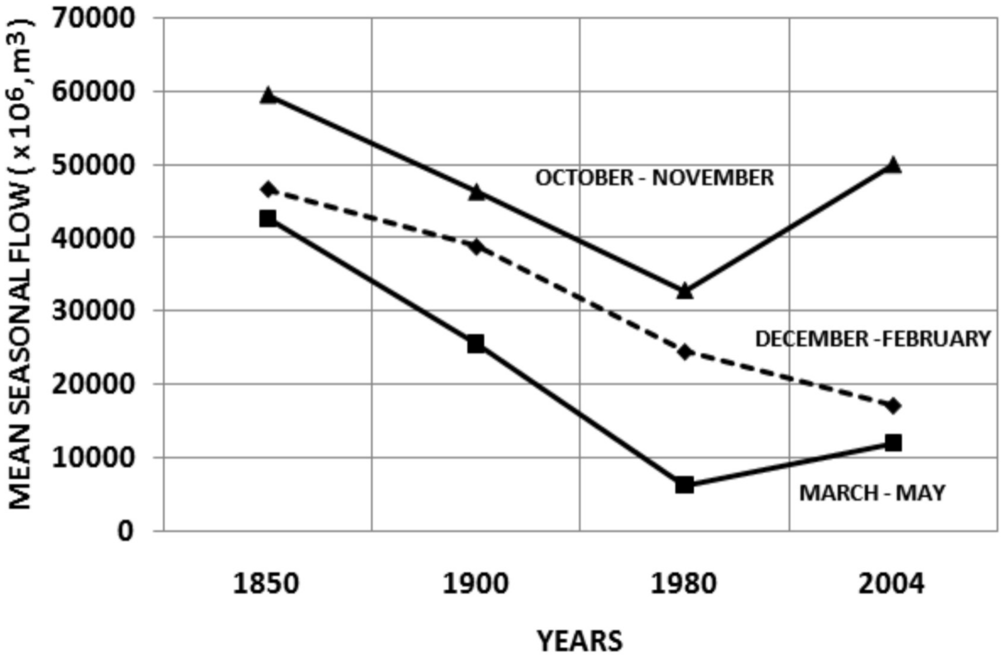

Figure 3: Flow variations in Ganga river.

Table 3: Change in volume of rainwater during December to February period

States	Catchment area ($\times 10^6$, m^2)	1980 December-February Rain ($\times 10^{-2}$, m)	1980 December-February Volume (m^3) (columns 2 × 3)	2004 December-February Rain ($\times 10^{-2}$, m)	2004 December-February Volume (m^3) (columns 2 × 5)
1	2	3	4	5	6
West Bengal	8875.2	346	3.07E+06	259.6	2.30E+06
Jharkhand	71730	197	1.41E+07	371.8	2.67E+07
Bihar	94164	110	1.04E+07	347.4	3.27E+07
East Uttar Pradesh	119283	247	2.95E+07	399.6	4.77E+07
West Uttar Pradesh	119283	397	4.74E+07	408.2	4.87E+07
Uttarakhand	53566	444	2.38E+07	417.4	2.24E+07
Haryana	30948.4	444	1.37E+07	417.4	1.29E+07
West Rajasthan	85559	23	1.97E+06	104	8.90E+06
East Rajasthan	136894.4	200	2.74E+07	120.4	1.65E+07
West Madhya Pradesh	77036	330	2.54E+07	178.8	1.38E+07
East Madhya Pradesh	123257.6	210	2.59E+07	445.2	5.49E+07
Vidarbha	46156.95	389	1.80E+07	303.4	1.40E+07
Chandigarh	135194	444	6.00E+07	417.4	5.64E+07
Total			3.01E+08		3.58E+08
Percentage change					**Increase = 19.048**

has been observed that rainwater is the main source of the river Ganga.

The percentage increase in rainfall of approximately same amount between December to February period (non-melting period), and March to May period (melting period) have given rise to very different results; during the first period the flow decreases whereas during the latter period (the melting period), the flow increases. This clearly points to the reason that it is primarily the melting of glacier which has caused the increased flow during the latter months.

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