Journal of the Arkansas Academy of Science

Volume 53 Article 17

1999

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Recommended Citation

Adel, M. M. (1999) "Microlevel Climate Change due to Changes in Surface Features in the Ganges Delta," *Journal of the Arkansas Academy of Science*: Vol. 53, Article 17.
Available at: https://scholarworks.uark.edu/jaas/vol53/iss1/17

Microlevel Climate Change due to Changes in Surface Features in the Ganges Delta

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Abstract

The Ganges had been the world's 8th largest river in terms of the volume of water discharge of 490 km^3/yr to the ocean prior to 1975. Since that time, over a period of two decades, India has reduced the Ganges discharge through Bangladesh to 40% from its original annual average discharge of 1,932+/-223 m^3/s by diverting water for irrigation in her upper states. The resulting consequences have been disastrous due to the depletion of the surface water resources. One of the devastating consequences has been the generation of extreme climate. The summertime maximum temperature has risen to about 43.33°C (110°F) from about 37.22°C (99°F). The heating degree days (HDDs) calculated with the base temperature of 30°C (86°F) show that the average value of HDD after the generation of extreme climate is 637C° (1146.6F°) more than the value before the generation of the climatic extremity. During the era of the pre-diversion of water the relative humidity had to rise to 75% to generate heatstroke conditions at the then summertime maximum temperature of 37.22°C (99°F), whereas under the current summertime maximum temperature, the same conditions begin at a relative humidity value of 45%. This results in prolonged exposure to heatstroke conditions for 40 million of the world's poorest people. Further, the wintertime minimum temperature has dropped from about 8.33°C (47°F) to about 4.44°C (40°F), and it still shows a dropping trend. This low temperature along with a wind speed of 16 to 24 km/hr creates hypothermal conditions, particularly for the oldest and the youngest persons and takes a heavy death toll. Cooling Degree Days (CDDs) calculated from a base temperature of 15°C (59°F) show that there are more fluctuations in CDDs in post-diversion time than in pre-diversion time. An estimation shows that at least 20 million trillion calories of heat are generated during the summertime in the Gangetic Bangladesh because of early drying of the surface water resources. Since water and the wet soil used to retain that heat due to the highest thermal capacity of water, there is a shortfall of the same amount of heat creating an environmental heat deficit during the wintertime in the absence of the surface water resources. To improve length and quality of life for the people of Biosphere III, the Farakka Barrage has to be demolished, and the original flow of the Ganges through itself and its distributaries in the delta must be restored.

Introduction

The Ganges basin in Bangladesh, hereafter called Biosphere III because of the unique ecodisastrous effects it has been suffering, has had an almost continuous shortage of water for more than two decades beginning in 1975. While Biosphere II is an artificially enclosed environment to simulate the living conditions is space, the term Biosphere III is introduced for this region marked with artificially created critical shortage of water and subsequent evolution of a series of situations like climatic extremes, fading tolerance of different species of living beings, arsenic poisoning of groundwater, epidemic form of environmental diseases, etc. In 1975, India started withdrawing the Ganges water by the operation of the Farakka Barrage, which is built over the Ganges about 18 km upstream from the Indo-Bangladesh common border. Although its stated purpose was to maintain navigability of the Calcutta Port located about 260 km downstream from the barrage point, its main use so far has been to provide the Ganges water for irrigation for the upper states of India (Crow, 1981; Bindra, 1982; Begum, 1988; Crow et al., 1995; Sattar, 1996; New York Times; 1997).

Figure 1 illustrates the Ganges-Brahmaputra basin in the Indian Subcontinent. The Ganges starts in the Himalayas, passes through the upper states of India and enters Bangladesh through the north-west side. Biosphere III, the study area, is the region to the west side of the river through the delta. Figure 2 illustrates the river systems in Bangladesh - the Ganges enters from the northwest, the Brahmaputra from the north, and the Meghna from the northeast. All these rivers join together before falling to the Bay of Bengal. The Biosphere III is shown by cross-hatched lines. The Ganges water had been the sustainer of life for the ecosystems that flourished in the basin for thousands of years. The Ganges water along with the monsoon runoffs

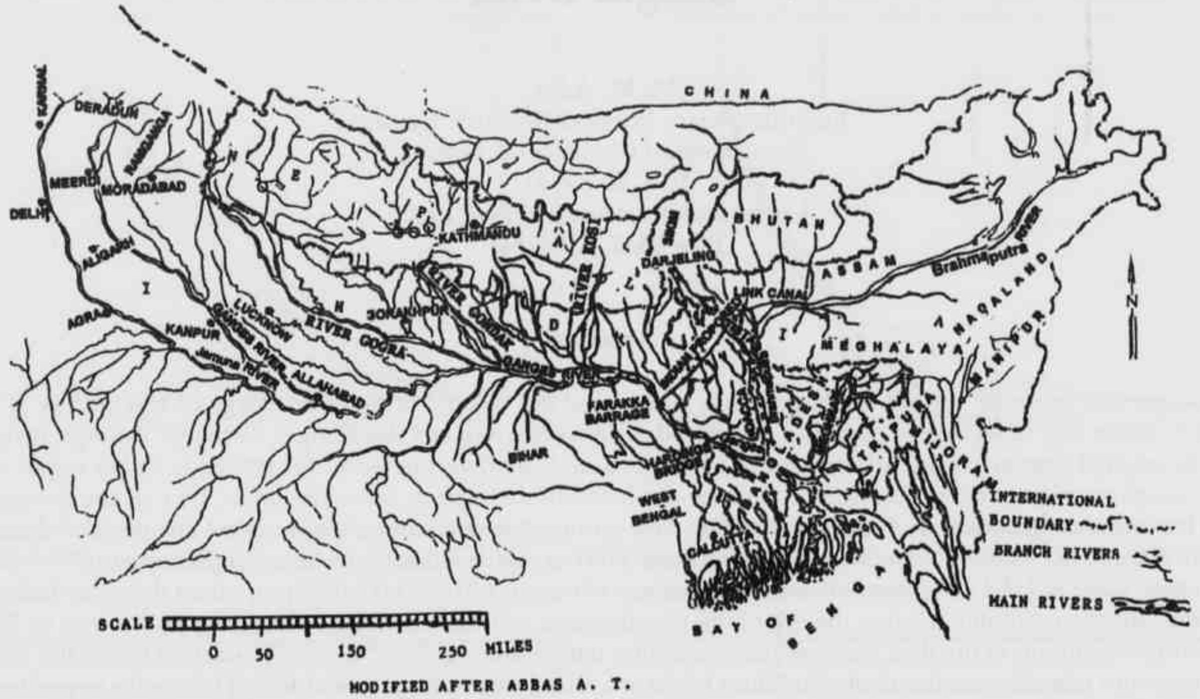
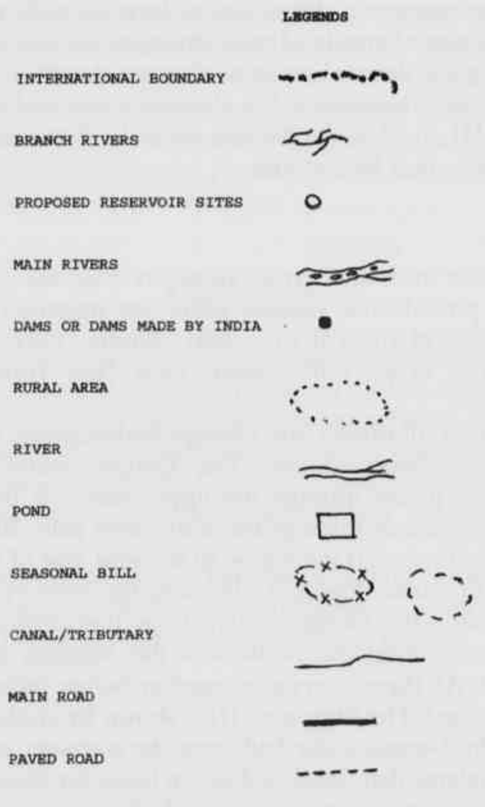


Fig. 1. Illustration of the course of the Ganges from the Himalayas through the upper states of India, Bangladesh, and then to the Bay of Bengal (modified after Abbas A. T.)



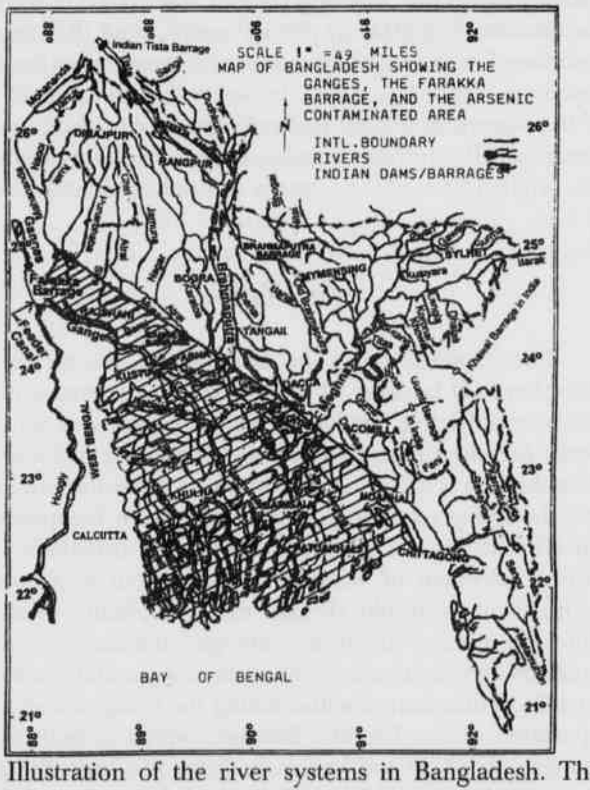


Fig. 2. Illustration of the river systems in Bangladesh. The cross-hatched part is the Ganges basin called Biosphere III. It also illustrates the locations of the Farakka Barrage, the Hoogly river, and the Calcutta Port (modified after Abbas A. T.)

had been the source of the surface and groundwater resources. The surface water resources included the distributaries of the Ganges, canals, floodplains, ponds, and ditches. The pre-dam Ganges discharge of 490 kM^3/yr had been equivalent to 455 mm/yr (Dingman, 1994); the latter unit (equals the volume discharge per year divided by the area under consideration) is introduced for comparison with the monsoon rainfall that ranged from 1500 mm/yr on the north to 2750 mm/yr on the south over the Ganges delta (Huq, 1974). While the flood season Ganges discharge in the distributaries currently varies from zero to about one-quarter of the original discharge in quantity and about one-half of the original duration, the post-Farakka monsoon rainfall is reduced to about 70% of the pre-Farakka rainfall (Miah, 1999a) because of the depletion of the surface water resources that used to supply additional moisture on land by evapotranspiration from surface water resources to the incoming saturated air from the sea in the south to meet some critical condition to cause precipitation. As to the dry season condition of the Ganges, Hillary (1979) writes in his travel account on the Ganges that during this season (November - May) nearly all the water from the Ganges is diverted by India through the Ganges canal. Further, the depletion of the surface water has led to a big impact upon the groundwater resource. While the groundwater extraction previously in Bangladesh had been about 5 mm/yr and was for drinking alone, the extraction in post-Farakka years is about 325 mm/yr for domestic, 133 to 246 mm/yr for irrigation, and about 40 mm/yr for fish farming. The volume extraction of groundwater can be obtained multiplying the figures by the area factor under consideration. Once again, this way of expressing the unit of groundwater extraction can be related to the depth of the sinking groundwater table and the monsoon rainfall. Following the weak discharge from the Ganges, the sedimentation rate of about 1.2 kg-m^{-2}-yr^{-1} in the Ganges water has formed large shoals in the Ganges itself blocking the discharge in the distributaries (Miah, 1996a). The monthly average discharge for pre- and post-Farakka years is illustrated in Fig. 3 (Miah and Samad, 1999). The top three curves corresponding to 1850, 1900, and 1980 apply to the Farakka point (Schwarz et al., 1993) in India. The bottom two curves corresponding to 1963 and 1993 are applicable to the Hardinge Bridge point located near the proposed Ganges Barrage site in the delta shown in Fig. 2. The dry season flow at the Hardinge Bridge point had been 2,000 m^3-s^{-1} or more as found from the hydrograph for 1963. However, the hydrograph for 1993 in the post-diversion era shows about 45% reduction all the year round.

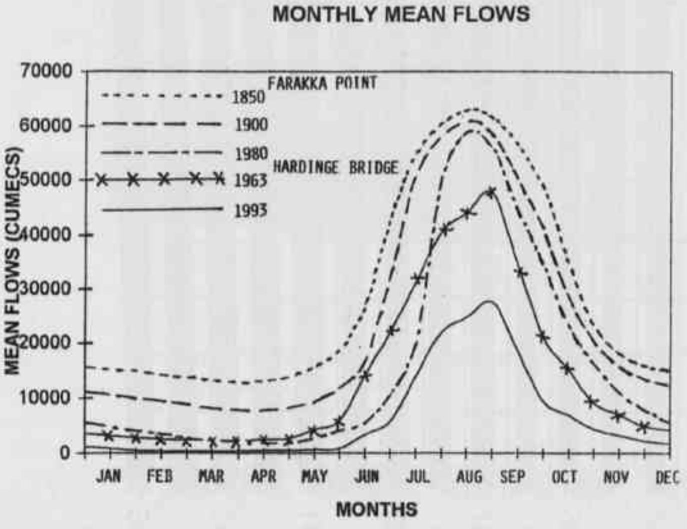


Fig. 3. Illustration of the monthly average flow rate of the Ganges for the years 1850, 1900, and 1980 at the Farakka point, and for 1963 and 1993 at the Hardinge Bridge point located near the proposed Ganges Barrage in Biosphere III.

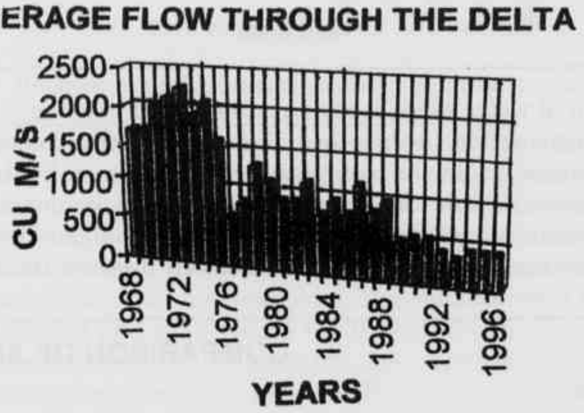


Fig. 4. Illustration of the average annual discharge rate of the Ganges through Biosphere III (courtesy of Hebblethwaite, 1997).

The average annual discharge in pre- and post-Farakka years is illustrated in Fig. 4 (courtesy of Hebblethwaite, 1997). The average flow (770+/-285 m^3-s^{-1}) in the post-Farakka years is 40% of the average flow (1932+/-223 m^3-s^{-1}) in pre-Farakka years. Figure 5 shows the resulting condition of the Ganges at the Hardinge Bridge point, the observation point for the Water and Power Development Authority of Bangladesh, following the water diversion. The dry and fissured bed reflects, absorbs, and radiates heat instead of almost totally absorbing heat when the bed is covered with water.

A multitude of effects including the depletion of surface water resources, a loss of professions, the obstruction of irrigation, a drop in cash crop production, the extinction and near-extinction of an unknown number of aquatics and amphibians, an increase in malnutrition, a drop in horticultural production, the closure of navigable routes, the deple-

Fig. 5. The dry and fissured Ganges bed.

tion of water sports facilities, an increased pressure on land transportation, a drop in soil organic matter content, an increase in inland intrusion of saline water fronts, the overextraction of groundwater, the contamination of groundwater by arsenic, an outbreak of skin and lung cancers, the occurrence of environmental diseases, the development of extreme climate, the occurrence of strokes and asthma, and the feedback effects have occurred since the water shortage began (Miah, 1994a, 1994b, 1995a, 1995b, 1995c, 1995d, 1995e, 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, 1996g, 1997a, 1997b, 1997c, 1997d, 1997e, 1998a, 1998b, 1998c, 1998d, 1998e, 1998f, 1999b, 1999c, 1999d, 1999e, 1999g; Miah and Samad, 1996, 1999). These said effects surpass the ones created by the diversion of water from the Amudarya and the Sirdarya, the two feeder rivers for the Aral Sea, for the cultivation of cotton in the former Soviet Union (Micklin, 1988; Brown, 1991; Sneider, 1992). One of the disastrous effects is the generation of extreme climate leading to human sufferings and even fatalities. This is the focus of this paper. Although the name of India is involved in the construction of the Farakka Barrage, the paper unveils science for the suffering humanity and does not take any political stance against anything.

Materials and Methods

The climate data for Biosphere III were supplied by the Meteorological Office in Dhaka, Bangladesh for pre- and post-Farakka years. Due to the time lag of a few years in archiving data, any year's data are not available until 4 to 5 years later. The supplied data were analyzed to see if there

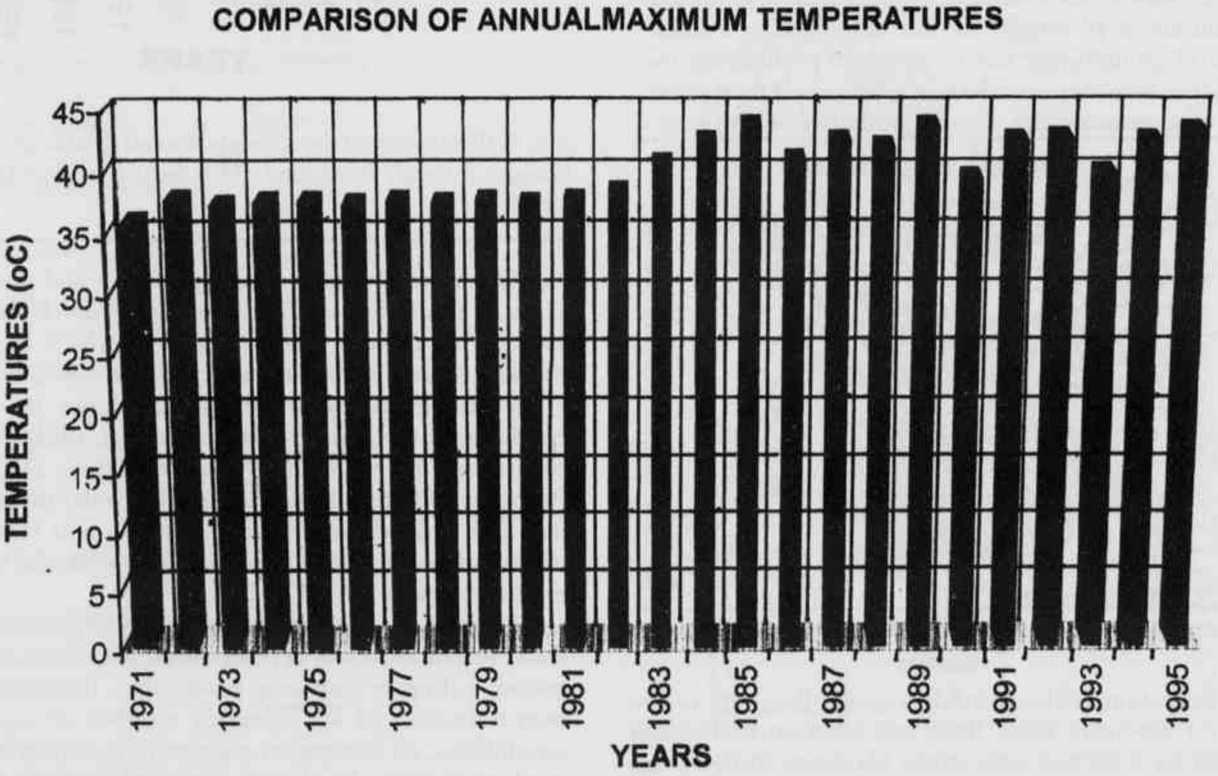


Fig. 6. The summertime maximum temperature in Biosphere III.

have been any changes in the climate following water diversion. Although the pre-dam data spanned decades back beyond the beginning year of water diversion, only a few years up to 1971 have been included in the analysis because of finding no changes in the data trend. The maximum temperatures for the years 1971 through 1995 were plotted. This is illustrated in Fig. 6. The illustration shows that the increase in maximum temperature started after 1981. It can be said that the pre-Farakka maximum temperature of about 37.22°C (99°F) has increased to about 43.33°C (110°F) in post-Farakka years.

Further, Heating Degree Days (HDDs) were calculated with the base temperature of 30°C (86°F) (Mitchell, et al., 1973) In that part of the world where the people live in open-windowed houses and work in open air, the base temperature is assumed not to be uncomfortable for them. For an average temperature larger than the base temperature, the difference between the average and the base temperature was calculated. This calculation was done for the days in March through November of every year. An average temperature equal to or lower than the base temperature contributed nothing to HDD. Afterwards, these differences were added to get the HDD for every year in the interval 1971-95. HDDs have been plotted in Fig. 7. It shows HDDs are larger beginning in 1983. Average values of HDDs from 1983 onward are 637°C (1146.6°F) more than that for previous years for Biosphere III.

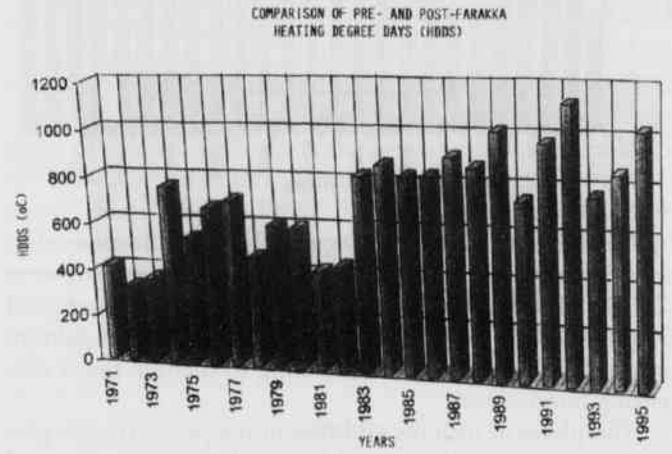


Fig. 7. The Heating Degree Days (HDDs) for Biosphere III.

An evidence of a dangerous environmental condition has been revealed in this study as discussed below. Since that condition is the result of the maximum temperature and humidity, and having discussed the maximum temperature, the variation of relative humidity is now examined by a plot of the comfort index. The monthly averages of the daily maximum and minimum values of the relative humidity for 1990 have been plotted in Fig. 8. The maximum value stays above 95% and the minimum stays above 40%. A relative humidity value above 45% is dangerous in conjunction with the current maximum temperature as is evident from the plot in Fig. 9 (Pearce and Smith, 1984). This figure shows the comfort index as a function of temperature and humidity. The oblique lines are humidity lines. The comfort index has been divided into six divisions by drawing five horizontal lines that pass through the humidity lines. The level of discomfort for each division is indicated to the left of the 100% humidity line. The combination of temperature and relative humidity results in distinct stress, great discomfort, and high danger of heatstroke. Two dotted vertical lines have been drawn. One corresponds to the maximum temperature in the pre-Farakka period, and the other corresponds to the current maximum temperature. In pre-Farakka days, distinct stress would start at about 40% relative humidity and heatstroke at about 75%. In post-Farakka days, the distinct stress starts at lower than 20% relative humidity, and heat stroke condition starts at about 46% relative humidity. What the comparison of Figs. 8 and 9 reveals is that from mid-April to mid-November 40,000,000 of the world's poorest people live under heat stroke conditions. This condition becomes unbearable for cardiovascular and asthma patients, which are comparatively more numerous in Biosphere III than in any other part of the country (Miah and Samad, 1999). Also, infants and elderly persons suffer from dangerous heat stress. There are reports that under these climatic conditions, occurrences of hypertension, apoplexy, etc. become common (Hays and Hussain, 1995; Hussain and Hays, 1993, 1997; Rogot, 1973; Rogot and Padgett, 1976). Kalkstein and Valimont (1987) give many examples of mortality and morbidity due to high temperatures. For

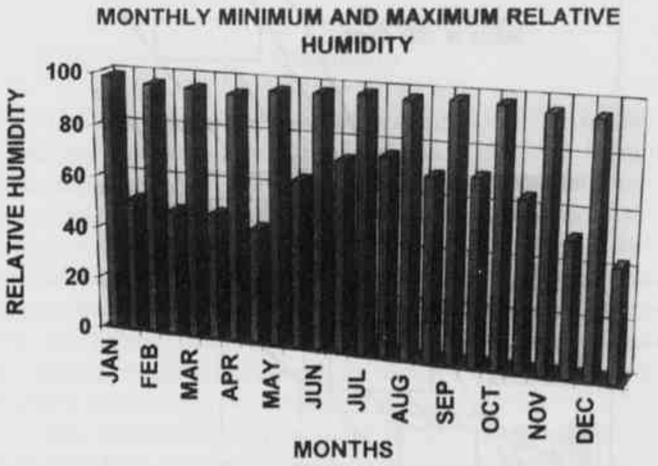
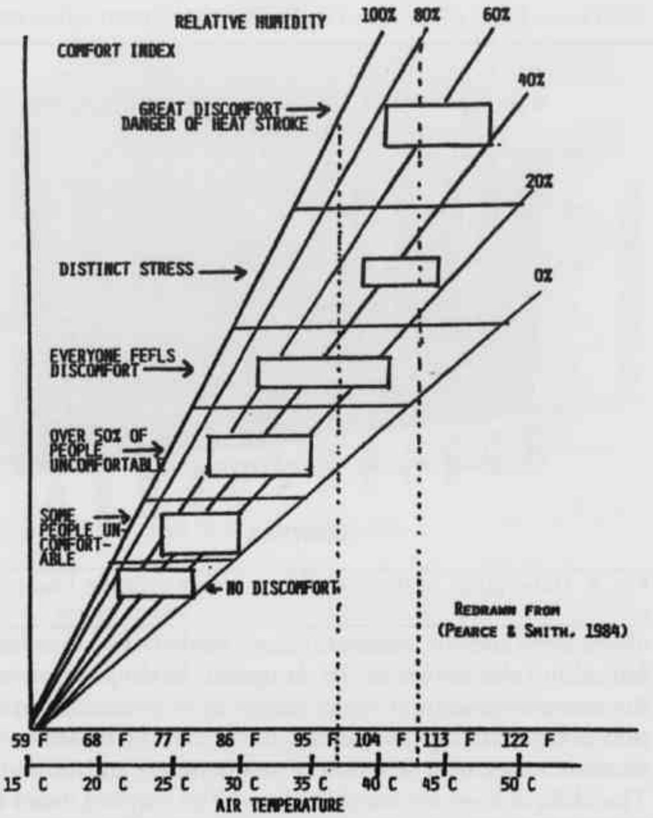


Fig. 8. Illustration of the monthly average relative humidity.



Redrawn from (Pearce & Smith, 1984)

Fig. 9. Illustration of the comfort index as a function of relative humidity and temperature (Pearce and Smith, 1984).

Biosphere III, such statistics have yet to be prepared.

In addition to plotting the summertime maximum temperatures, wintertime minimum temperatures have been plotted in Fig. 10. The minimum temperature of about 8.33 °C (47°F) of pre-Farakka days has dropped to 4.44°C (40°F) or below. The curve still shows a dropping trend. The dropping trend is just an indication of a continuous heat loss by Biosphere III. Like HDDs, CDDs (Cooling Degree Days) were calculated with a base temperature of 15°C (59°F) (Mitchell et al., 1973) . It was assumed that the people of Biosphere III could tolerate this temperature because they work under natural conditions and live in open-windowed houses. The plot of CDDs in Fig. 11 shows that there is great variation in the number of CDDs per year. The number of CDDs in 1983 and 1989 is particularly high. The pre-Farakka highest CDD was 281.3°C (506.34°F) in 1972. As the plot shows, the post-Farakka highest CDDs have been 372.4°C (670.32°F) in 1983 and 475.7°C (856.26°F) in 1989.

If the wind chill is taken into account, the equivalent temperature will be even lower. In the delta, the wintertime wind speed may reach about 27 Km/hr. For a temperature of 4.44°C (40°F), the equivalent wind chill temperature is -5.28°C (22.5°F) (Ruffner and Bair, 1987). The people of Biosphere III do not have the wintertime heating capability nor do they have the winter clothing to tolerate these sub-freezing temperature.

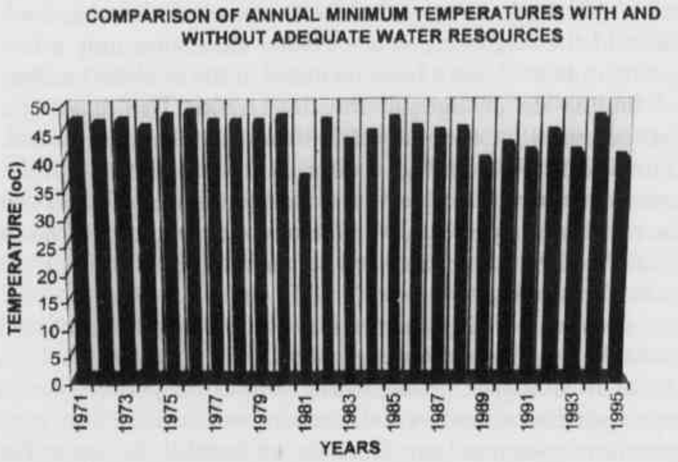


Fig. 10. The wintertime minimum temperature for Biosphere III.

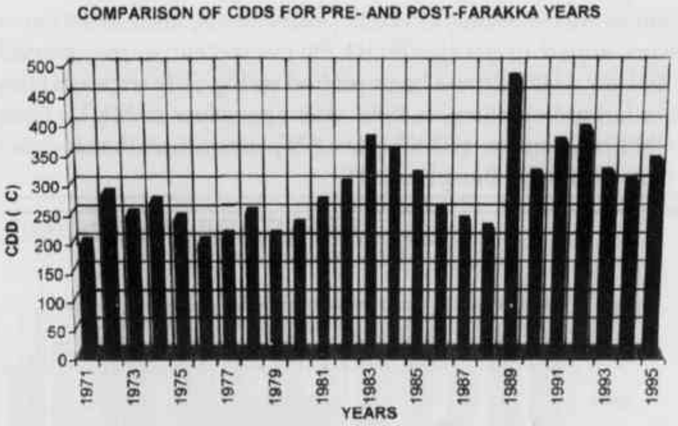


Fig. 11. The Cooling Degree Days (CDDs) for Biosphere III.

The physical feelings at different temperatures are presented in Fig. 12 (Pearce and Smith, 1984). The diagonal lines are the wind speeds. Along the vertical axis are plotted the wind chill indices. The horizontal axis represents the wind chill temperature. The horizontal lines through the wind speed lines divide the wind chill index into, beginning from the bottom, cool, very cool, cold, very cold, bitterly cold, dangerous conditions when exposed flesh freezes, and very dangerous conditions when exposed flesh freezes in 60 seconds. Two dotted vertical lines have been drawn to show the post-diversion period minimum wind chill temperatures of -2.22°C (28°F) and -5.28°C (22.5°F) corresponding to the

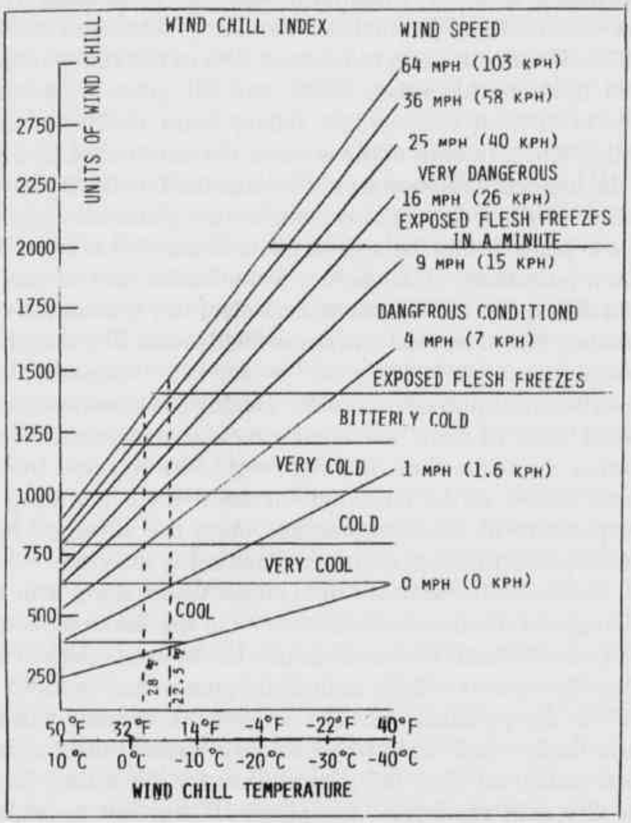


Fig. 12. Illustration of physical feelings as a function of temperature and wind speed (Pearce and Smith, 1984).

wind speeds of 16 km/hr (10 mi/hr) and 24 km/hr (15 mi/hr) respectively. These temperatures are below the freezing point of water and flesh. A dangerous condition existed in 1998. By the first week of January, government reported 500 deaths (Bangla Barta, 1998). It is not unlikely that the death toll rose over 2,000 by the end of the winter. Countries, such as Germany, donated thousands of blankets to the people of Biosphere III. Also, a few hundred people died in 1997 from the extreme cold (Sonardesh, 1997).

Results

The summertime maximum temperatures in Biosphere III rose sharply after 1981 from about 37.22°C (99°F) to about 43.33°C (110°F). The maximum temperature shows a very steep gradient during 1981-85. The HDDs are almost the same after the maximum temperature reached 37.77°C (100°F) . The average value of HDD is 637°C (1146.6°F) more in post-Farakka days than it was in pre-Farakka days. People of Biosphere III are exposed to heat stroke conditions for a longer time since the water shortage started. The wintertime minimum temperature has dropped from 8.33°C (47°F) to 4.44°C (40°F) following the water shortage and still shows a dropping trend. Calculation of CDDs shows that the wintertime minimum temperature has fluctuated greatly.

Discussion

The climatic severity in Biosphere III is the result of changing the land-cover and land-use. This is in keeping with the findings reported earlier (Salati and Vose, 1984; Bouwman, 1990). Lands that were under water more than two decades ago can accumulate little water for much shorter duration today. The latent heat sources (i.e., the water reservoirs) have been converted to sensible heat sources (i.e., dry lands). Water has an extremely high thermal capacity, which causes water reservoirs to serve as heat reservoirs. Today's dry lands have increased the albedo.

The amount of excess heat in the summer and the deficit of heat during the winter can be calculated from the information on the land areas that would remain inundated during the rainy season (July through October). Only the rural areas will be considered in this calculation because of their vast aggregate expanse. There are about 28,000 villages in rural Biosphere III. The number of urban areas is about 28. Figure 13 is a map of the rural Biosphere III adapted from the infrared color aerial photographic survey

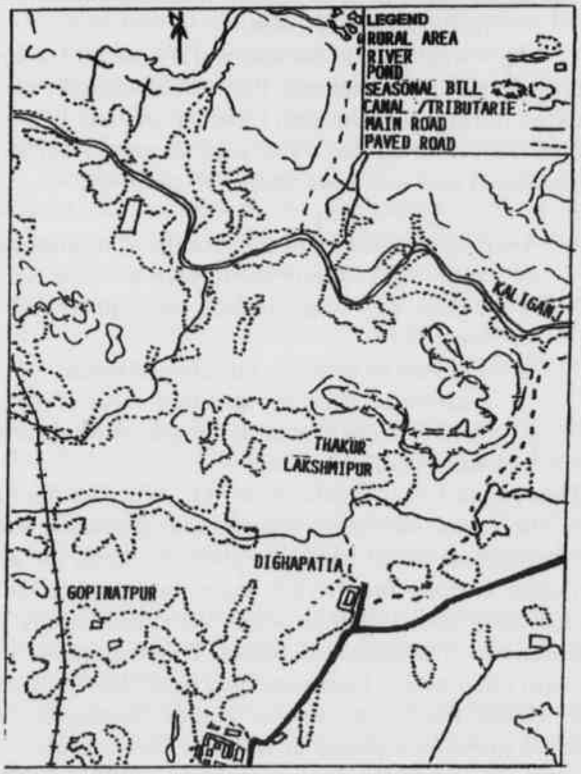


Fig. 13. A glimpse of the rural Biosphere III (SPARSO, 1993)

done during February 1983 and updated with SPOT satellite-acquired data in February and March 1989 by Bangladesh Space Research and Remote Sensing Organization (SPARSO, 1993). The figure shows many features including floodplains (*bills*) up to large ponds. In the pre-Farakka days, the land area between rural units would remain watersoaked and/or water-logged during July through November. Each village is located on a high land area. In each of these high land areas, there are ponds and ditches which may be called the permanent and seasonal surface water bodies of rural Biosphere III. Further, every two to six villages surround a floodplain which may be a shallow one or a deep one. In pre-Farakka days, significant parts of the deep ones held water almost the year around. Total area occupied by floodplains, ponds, and ditches that used to be under water, i. e., the area occupied by the permanent and seasonal water bodies, can be found from the following relations:

$$A_H = n_V A_V - n_V A_{PD}$$
$$A_{SW} = A_B - A_H$$

where A_H = total area of homesteads in Biosphere III
n_V = total number of villages in Biosphere III = 28,000
A_V = average area of a single village = 0.07 sq km
A_{PD} = average areas of ponds and ditches per village = 0.027 sq km
A_{SW} = total area of surface water bodies in Biosphere III, and
A_B = total area of Biosphere III = 46,080 sq km

Prior to 1975, the total area that would annually remain inundated during July through October and wet later on is found to be 44,876 sq km. The solar energy absorbed by this inundated and wet areas would be given by

$$Q = A_{sw} t q$$

where t = time in minutes of the months (6 months per year and 12 hours per day) of the year during which A_{sw} would remain water-filled and wet, and
q = calories of heat per minute per sq km (calculated from the standard value of 0.44 cal/min of solar radiation) of Biosphere III = 4.4×10^9 cal/sq km/min

This yields 2.6×10^{19} calories for Q. Whereas the floodplains, the major source of seasonal and perennial surface water resources, would have rice plants in them, the above calculation is done for the lost water bodies that did not have anything else other than water. We need to apply some corrections to this estimated figure. The floodplain arable areas and other arable land areas had been the rice growing fields. Before the harvest season (end of November), there would be green rice plants in water or in wetlands. After harvest there would be rice straws in water or in wetlands. Several facts relate to the amount of heat absorbed. (1) Lake water reflects less than 10% of the sunlight falling upon it (Mirinova, 1973). (2) Maximum reflection of sunlight from wet soil is 20% of the incident amount (Tucker and Miller, 1977). (3) Straw reflects more than 40% of the sunlight incident upon it (Mirinova, 1973), and (4) green vegetation reflects 30% of the sunlight falling upon it (Tucker and Miller, 1977). In each of those cases, the unreflected amount of the incident radiation would be absorbed by the bodies of water. Further, floodplains without rice plants are equivalent to lakes. It may be a good guess to take 0.3 as the maximum reflectivity of the surface water bodies and 0.7 as the least absorptivity. The maximum reflectivity is chosen to be between that of wet soil and straw-filled lands. The absorbed heat is then $0.7 \times 2.6 \times 10^{19} = 1.8 \times10^{19}$ calories. This absorbed heat played two roles. During the summertime, it would help to keep the environmental temperature low. During the wintertime, this heat would be released by the water bodies to the environment when there is a drop of temperature in the environment. Thus, the absorbed heat would protect the environment from being too cold.

Today, the absence of the Ganges water along with the shortage of the monsoon rain water in the floodplains and other arable lands leaves the arable lands water-soaked only after downpours whose annual frequency has reduced to 50% in the postdam era. The floodplains are now agricultural lands which absorb, reflect, and radiate the incident solar radiation. They fail to store heat for the winter. So do the dry soils elsewhere. Biosphere III has lost its highest thermal capacity material, water. With ditches no longer in existence and deaths of shallow ponds, A_{PD} is estimated to be reduced by 50% to the new value of 0.0135. The rural areas have increased, at least by 10%. This gives A_V value as 0.077. The time factor t has to be given some equivalent value on the ground that the distributaries with clogged mouths either cannot flow water to floodplains or has reduced the flow to the floodplain both in duration and quantity by about one-quarter. The equivalent value may be estimated, assuming a proportionality, by the consideration of a 60% (40% of the original) decrease in the Ganges flow and a 70% decrease in the monsoon rainfall. Thus 6 months' time of the pre-dam period is reduced to 1.68 (= $6 \times 0.40 \times 0.70$) months. The new Q value, the heat retained by water and wet soil mass is then 4.95×10^{18} calories which is less than 30% of the pre-Farakka value.

Though the water diversion that led to the creation of Biosphere III started in 1975, the summertime rise of the maximum temperature and the wintertime drop of the minimum temperature started after 1981. This is probably due to the fact that it took a few years at the beginning for depletion of the surface water resources and for nature to react.

Conclusions

The generation of extreme climate leading to the summertime higher maximum and the wintertime lower minimum temperatures in the post-diversion era of the Ganges water compared to the prediversion era shows a close temporal correlation to the depletion of surface water resources following the water diversion. The climatic extremity has increased the suffering of the people of Biosphere III. To alleviate the suffering and restore the original climatic conditions, the Farakka Barrage has to be demolished with the assurance of a minimum flow at the Farakka point for adequate discharge through the Ganges and its distributaries in Biosphere III to revitalize the original surface water resources and to facilitate the groundwater recharging. International agencies should take urgent steps to resolve water disputes among riparian countries in the light of the global environmental awareness.

ACKNOWLEDGMENTS.—The author is thankful to ERDA/NIH. The author is also thankful to Arkansas Space Grant Consortium for partial funding of the project. Thanks are also due to the Ministry of Defense, Government of the People's Republic of Bangladesh, particularly the Agriculture Secretary M. N. Islam and Defense Secretary M. H. Rahman for supplying the climate data from the Bangladesh Meteorology Office in expectation of benefits for the nation from the research results. Thanks are also due to the staff members of the Meteorology Office for making the data available in time and also to M. A. Samad, who frequently visits the government offices in Dhaka from Biosphere III, for getting the appropriate data. Further, thanks are due to the Bangladesh Water and Power Development Authority for supplying the Ganges discharge rate at the Hardinge Bridge observation point and to the Bangladesh Space Research and Remote Sensing Organization for supplying the aerial observation map of part of Biosphere III.

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