Asian Journal of Water, Environment and Pollution, Vol. 9, No. 3 (2012), pp. 67–72.

Melting Away of Himalayan Glaciers and Resulting Water Shortages in India and Pakistan

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Received September 1, 2010, revised and accepted May 15, 2012

Abstract: This paper deals with an important phenomenon taking place these days – melting of polar ice caps and glaciers on various mountains around the globe. This phenomenon has already affected the population in India and Pakistan due to the drying up of rivers. This is an indication for those living in South East Asia, and Far East that without the rivers to irrigate fields, there would be major food crisis. In addition, it would result in mass migration of people due to the shortage of water.

This paper, at first, provides evidences of drying up processes of rivers Indus in Pakistan and Ganga in India—to show that the adverse effect of the global warming is already there in India and Pakistan, and this fact was completely missed out at the Copenhagen Conference in December 2009.

Next, the paper shows that, without the glaciers on the Himalayas, vast areas in India and Pakistan would turn into deserts because in these areas the climate would change drastically due to lack of vegetation and influx of solar energy.

Key words: Melting of glaciers, melting of Himalayan glaciers, formation of desert, global food crisis, migration of populations.

Melting of Arctic Ice and Glaciers

The recent research expedition to the Southern Patagonia Ice Field has revealed that alpine glaciers in the Chilean and Argentine Andes are disappearing at far more rapid rate than previously thought by the scientific community. The scientists have discovered that here, in Patagonia, the glaciers are melting in higher proportions and at much higher alpine zones than in any other part of the world, including Alaska and the Himalayas. Glacier ice accounts for around 75 per cent of the world's fresh water. The higher temperatures involving melting of glaciers and corresponding climate change are largely caused by CO_2 or "greenhouse gas" emissions.

Coming to the Himalayas, the glaciers of the Himalayas contain more ice than anywhere in the world except for the Polar Regions and Alaska; the flow of water from their melting results into seven of the major rivers of Asia. Unfortunately now, due to global warming and related changes in the monsoons and trade winds, the glaciers are receding at an alarming rate, and scientists say that the ancient ice-fields in these could nearly vanish within two to three generations.

Himalayan glaciers feed water round the year, which includes during the hot, and dry, season (summer) when water is most needed. It was believed that with the melting away of the glaciers, major rivers like the Ganga and Indus could become more seasonal i.e. filled with water only during the monsoon, and their tributaries may vanish completely during non-monsoon periods. Similar effects can be felt elsewhere in the world such as China, Laos, Vietnam etc. where rivers originate from the Himalayas (TEDGlobal, 2010**;** Redorbit, 2006, 2009; Science Daily, 2009; NewScientist, 2009; National

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Nomenclature

α	Angle in vertical plane
α_s	Angle in horizontal plane
Y	Latitude of the place
δ	Declination
h_s	Hour angle at any instant of time
h_{sr}	Hour angle at sunrise measured from noon
I_0	Incident solar energy intensity of beam radiation
N	Day number of a year

Geographic News, 2002; U.S. News, 2008; Science Gogo, 2007; Ledger Enquirer, 2009**;** Current Green, 2009).

Recent publication (Science, 2010) by Immerzeel et al shows that the flow of water in these rivers would reduce to different extents in the next 40 to 50 years, and they point out that the Indus river is the one which will be the most at risk. They based their work on the data collected by satellites. Declining rainfall trends in India was reported (Kothyari and Singh, 1996). However, this paper deals with availability of snow-fed water during the non-monsoon period.

Unfortunate fact is that the water crisis is already there and the Indus river has already dried up as can be seen in various literature (The Globe and Mail, 2010/07; British Broadcasting Corporation (BBC), 2010/article1650301; British Broadcasting Corporation, 2010/07/100725; British Broadcasting Corporation, 2010/10625534; U.S. News, 2008).

These references show that the entire recent debate about the global warming in Copenhagen in December, 2009 was not based on ground realities. Quite a significant population is facing the problem now, and it is being felt in areas which have high population density. One can see in the publication (The Telegram, 2010) that there were unsound scientific principles used to criticize those who believe that the global warming is actually taking place now.

Not only the Indus river, but also the Ganga river is drying up fast as can be seen in Figures 1 and 2. These pictures were taken at Patna, the capital of the state of Bihar. This city is about 300 miles west of Calcutta (Figure 3). The spot where the picture was taken is shown in Figure 1. The author has been visiting this spot over 50 years and has never seen the condition of the Ganga river like this.

To understand the situation in a better way, one can see Figure 4 which shows that in the states of Punjab, in both India and Pakistan, there are very many rivers whose sources are the Himalayan glaciers. From the last century, numerous irrigation canals were made and these areas have very extensive irrigation systems.

However, these areas are located above the Tropic of Cancer, and the work presented later will show that these are prone to be converted into desert if no water flows through these rivers from the glaciers. Figure 5 shows the annual rainfall, in centimetres, in areas just to south of Punjab (both India as well as Pakistan each have a state called Punjab). The rainfall in Pakistan is even less than the minimum range shown in this figure.

There is a notion amongst many that deserts are formed due to lack of rainfall only, and are independent of glacier fed rivers flowing through the areas. Therefore, the limits of desert in India or Pakistan, as we are seeing presently would not exist at the same places in future also.

The sad fact is that the present borders of the desert in India or Pakistan are kept from expanding due to the flow of water in rivers from the glaciers in the Himalayas. It is for this reason that we are not seeing desert in some of the crop or grain producing areas of Punjab (in India and Pakistan) and Haryana (in India).

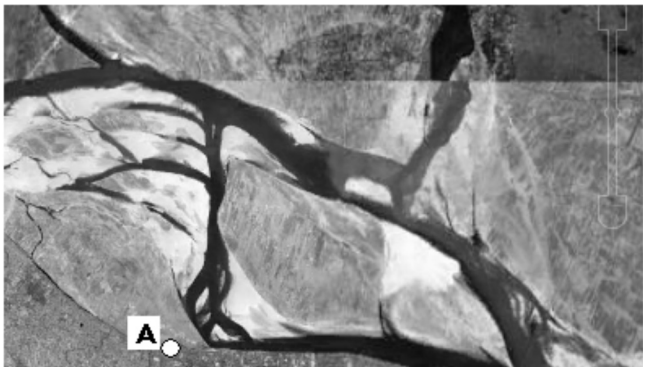

Figure 1: Aerial view of Ganga River in 2009 showing the spot 'A' mentioned in Figure 2.

Figure 2: A view of the Ganga river from the spot 'A' mentioned in Figure 1. It shows the river full of water.

Figure 3: Location of Patna in India.

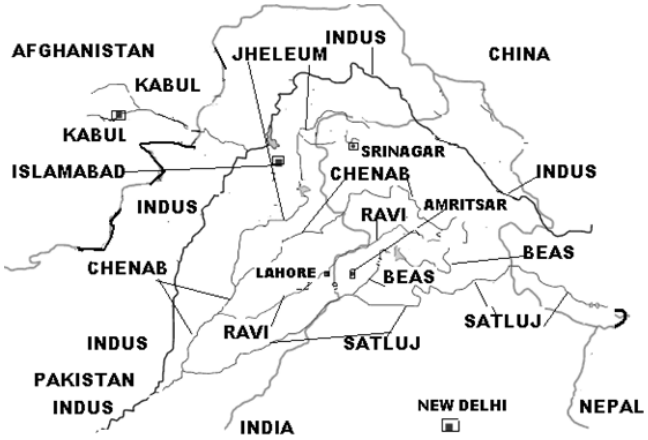

Figure 4: Map showing various Himalayan rivers in Punjab.

Figure 5: Map showing annual rainfall in centimetres in areas near India-Pakistan border.

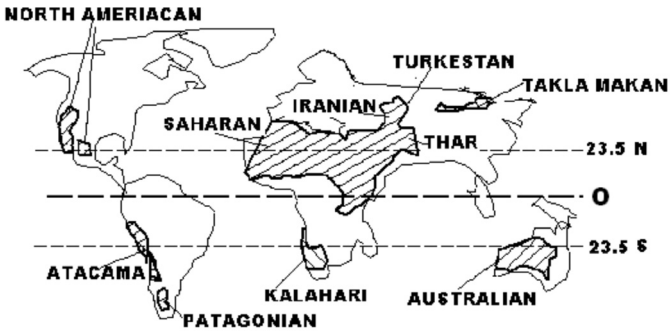

Figure 6: Global distribution of deserts.

Therefore, the specific contribution of the present work is to express caution that even bleaker days lie ahead for these areas unless massive intervention is made by the corresponding governments to provide alternatives to the population living in these areas.

Climates and Deserts Around the World and their Locations

Climate is the characteristic condition of the atmosphere near the earth's surface at a certain place on earth. It is the long-term weather of that area (at least 30 years). This includes the region's general pattern of weather conditions, seasons and weather extremes like hurricanes, droughts, or rainy periods. Two of the most important factors determining an area's climate are air temperature and precipitation.

There are 12 distinct deserts around the world, at least one on every continent except Europe and Antarctica (see Figure 6). All together, they take up about one fifth of the earth's surface.

The deserts of the world tend to form bands around the globe. These can be divided roughly into two categories: (a) those around 23.5 degrees—Tropic of Cancer or Capricorn, and (b) at higher latitudes than those mentioned in (a). Hemisphere-wise, these deserts are:

Northern Hemisphere: The Takla Makan-Gobi in China; The Turkestan in Southern Russia; India's Thar; The Iranian, Arabian and Saharan; and The North American Desert.

Southern Hemisphere: The Kalahari and Namib in Africa; The Patagonian and Atacama in South America; and The Australian.

Characteristics of Deserts

There are certain things they all have in common:

- Super-dry air
- Little rain—less than 10 inches a year
- High day time temperatures

These latitude belts are centered on the Tropics of Cancer and Capricorn, which lie just north and south of the equator. They coincide with the edge of the equatorial subtropical high pressure belt and trade winds. Winds are light, which allows for the evaporation of moisture in the intense heat. This makes for a very dry heat. The dry arid desert is a true desert climate.

What has not drawn attention of the scientists is that many of the rivers flow through areas which would have been actually deserts without permanent availability of water due to the melting of glaciers as their sources. If the glaciers vanish, these areas would turn into deserts. In North India, Pakistan and China, there are vast areas which lie along the desert belt of the globe. Large amounts of food grain are grown in these areas, and if the glaciers vanish - so will be the surplus of food grains in India and Pakistan, resulting into extreme shortages of food grains around the globe.

Sad fact is that these countries (India, Pakistan, China etc.) are economically poor and spend vast amount of money on armaments – obviously an unfortunate choice. At the same time, these countries have the major population of the world also. To adapt to the impending crisis—shortage of water—it would require enormous capital. Where would that capital come from?

It is to be clarified at the outset that although the sunshine data on a horizontal surface is widely available in texts (Kreider and Kreith, 1979) but, one cannot infer from these data as presented—the existence of two types of deserts.

Theoretical Formulations

Figure 7 shows the sun's rays incident on a horizontal plane and its direction is defined with the help of two angles, α_s and α, which are in the horizontal and vertical planes respectively.

If the intensity of solar energy is I_0, the three components in X_1, Y_1, and Z_1 co-ordinates will be (refer Figures 7 and 8)

$$I_{X_1} = -I_0 \cos(\alpha) \cos(\alpha_s) \quad (1)$$

$$I_{Y_1} = -I_0 \cos(\alpha) \sin(\alpha_s) \quad (2)$$

$$I_{Z_1} = -I_0 \sin(\alpha) \quad (3)$$

Let us represent the solar energy by a vector

$$\{I\} = \{I_{X_1}, I_{Y_1}, I_{Z_1}\}^T.$$

It should be remembered that we are only interested in the negative component in the Z_1 direction i.e. I_{Z_1} should be negative for the incident solar energy when the incident energy is oblique.

One can calculate α_s and α using the following formulas (Kreider, and Kreith, 1979; Kreith and Black, 1980; Duffie and Beckman, 1991)

$$\delta = 23.45 \sin\{(360/365)(284 + N)\} \quad (4)$$

where δ is the declination of the sun in degrees and N is the day number, which is the number of the day in a year. For example, on January 1, N is equal to 1.

The time of sunrise, h_{sr} in hour angle from the noon is calculated from

$$h_{sr} = \cos^{-1}\{-\tan(\delta)\tan(\gamma)\} \quad (5)$$

Denoting the instant of time in terms of the hour angle from the noon as h_s, one can write

$$\sin(\alpha) = \cos(\gamma)\cos(\delta)\cos(h_s) + \sin(\gamma)\sin(\delta) \quad (6)$$

and by expressing the angles in degrees

$$\alpha_s = \sin^{-1}\{\cos(\delta)\sin(h_s)/\cos(\alpha)\}$$

$$\text{if } \cos(h_s) > \{\tan(\delta)/\tan(\gamma)\} \quad (7)$$

$$\text{or } \alpha_s = 180^o - \sin^{-1}\{\cos(\delta)\sin(h_s)/\cos(\alpha)\}$$

$$\text{if } \cos(h_s) < \{\tan(\delta)/\tan(\gamma)\} \quad (8)$$

Results and Discussions

For a given day, N, the hours of sunshine was calculated from Equation (5). Twice the value of h_{sr} gives the total hour angle of sun shine. The number of hours was

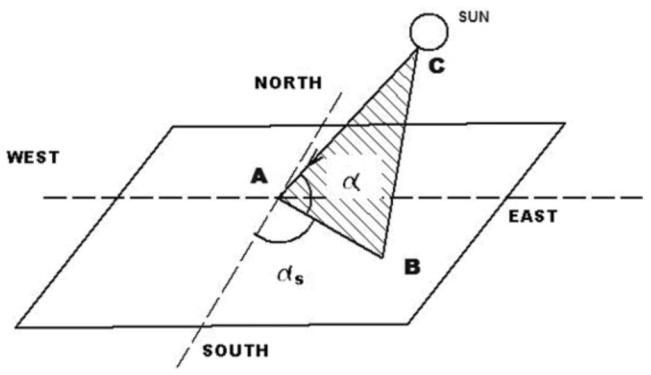

Figure 7: The solar ray direction using two angles.

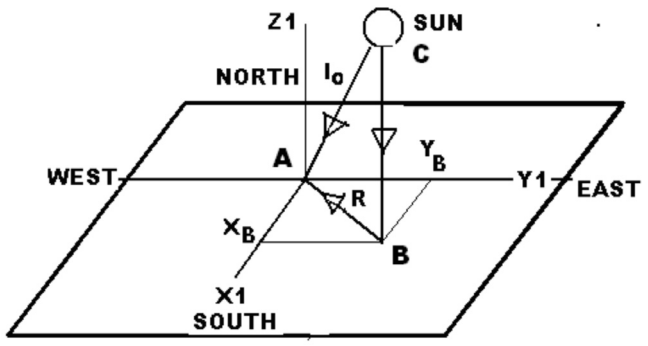

Figure 8: Three components of solar energy flux I_o.

calculated based on the spin rate of the earth which is 15 degrees per hour approximately. Since there is symmetry about the noon time, the energy shown in the results are only for the morning hours. The actual values will be twice the values shown in the results.

The incident energy per metre square at any instant of time is based on the vertical component I_{Z_1} only. By calculating α and α_s using Equations (5) and (6) respectively, one could determine the intensities in all the three orthogonal directions.

The morning period was divided into 100 instants of time spaced at equal intervals of time. The average of these vertical intensities was calculated. This way, one could compute the total energy per day in the morning hours at a given location.

Figure 9 shows the motion of earth on the ecliptic. The days are longer in the northern hemisphere because of the obliquity of the earth's spin axis on the ecliptic plane. The rays are vertical (maximum I_{Z_1} values because α is equal to 90 degrees) at noon on June 21 at locations on the Tropic of Cancer. One must, however, understand that maximum I_{Z_1} value does not mean that the total incident energy over a day on this day will be maximum at those locations on the Tropic of Cancer. Besides the vertical intensity I_{Z_1}, total hours of sun shine (twice h_{sr}) is also a factor. The days become longer at higher latitudes than at lower latitudes in the northern hemisphere.

These calculations were performed over the span Dec. 22 to June 21. The useful spans selected were 15 to 95 days at 10 days interval from June 21 (summer solstice). The reference of June 21 was selected because, on this day, maximum solar energy is incident for deserts in northern hemisphere. For the deserts in southern hemisphere, similar reasoning can be used.

In the calculations, the value for the energy flux, I_o, used was 800 Watts/metre^2, although other values would not make any difference in conclusions.

Figure 10 shows various curves for different spans in terms of number of days from June 21. It shows that over longer span, for example, over 95 days, the peak (maximum) energy occurs at 24 degree latitude (near the Tropic of Cancer) but as the spans are shortened, the

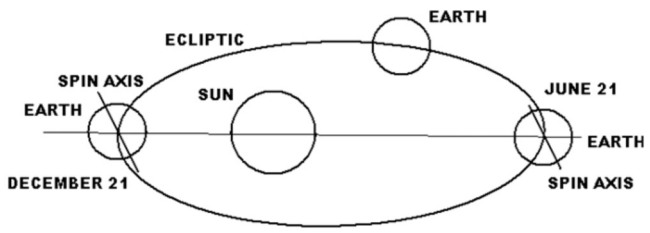

Figure 9: Position of Earth on ecliptic on solstices.

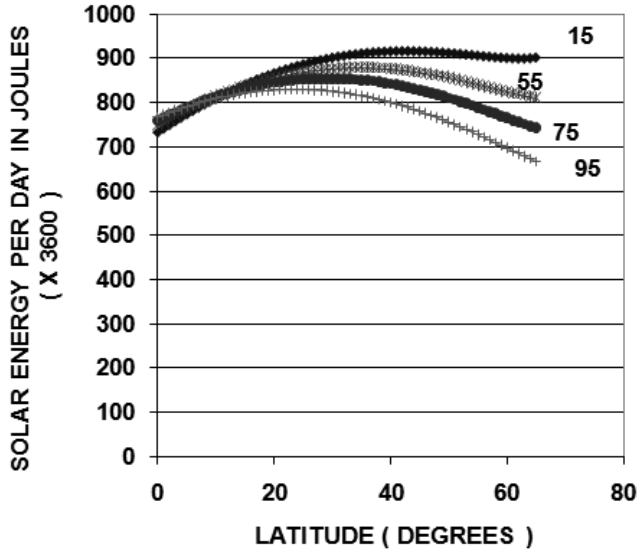

Figure 10: Plot of energy per day over different spans versus latitude.

peak shifts towards higher latitudes even though the rays are never vertical on those locations.

Corresponding to the shortest span of 15 days, the latitude for the peak is 42 degrees. At the same time, these curves also show that magnitudes of the peaks also increase with higher latitudes. This means that at higher latitudes, those areas receive more solar energy per day during the respective time spans, even though the rays do not fall vertically at any time of the day. This happens because the days at higher latitudes are much longer than those near the Tropic of Cancer.

Table 1 shows the data for (a) various spans, (b) corresponding peak values and (c) corresponding latitudes. Looking at this table one can understand the

Table 1: Occurrence of maxima corresponding to different spans

Span (Number of days before June 21)	*Latitude corresponding to the maximum (Degrees)*	*Maximum average solar energy per day (× 3600) (Joules)*
95	24	830.2
85	27	842.5
75	30	855.1
65	32	867.8
55	35	880.0
45	37	891.6
35	41	901.9
25	42	910.5
15	42	916.8

existence of deserts at locations such as Takla Makan, Turkestan and a part of North American desert; these deserts are not on Tropic of Cancer but at much higher latitudes. It shows that even with 15 days criteria (relatively shorter spans) one can have deserts if the area lacks precipitation.

Conclusions

In this study, a brief discussion was made to describe the water shortages faced by people in India and Pakistan. This was followed by a review on topics such as the melting of glaciers, climates and locations of deserts. After this, the calculations for incident solar energy at various latitudes of the earth were carried out. These calculations were divided into different spans – starting from 15 days to 95 days at the interval of 10 days from the summer solstice.

The results obtained show:

1. As the latitude increases, the magnitude of the peak energy also increases but the length of the span decreases.
2. The areas north of the Tropic of Cancer receive more energy during a day as compared to those near Tropic of Cancer even though the sun rays do not fall from the vertical direction at higher latitudes.
3. The areas of the world which have drier climates presently but get their supply of water from glacier fed rivers are in imminent danger of being converted into deserts when the glaciers will melt away.
4. The world food-grain supply is heading towards drastic shortages when the glaciers will melt away and it can result into a humanitarian crisis.
5. The lack of availability of fresh water will result into mass migrations in India and likewise in other countries—just like the migrations from the Indus Valley area around 4000 years ago.

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