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Adaptation of a technique to estimate rainfall from satellite data in Bangladesh

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Abstract

In order to estimate rainfall from satellite data GMS (Geo-stationary Meteorological Satellite) Precipitation Index (GPI) was calculated for northeastern part (Sylhet) of Bangladesh. GPI was calibrated with ground-based raingauge rainfall. As was found, GPI underestimated i.e., raingauge rainfall overestimated for a few stations. Then GPI was adapted as Adjusted GMS Precipitation Index (AGPI). Satisfactory results were found using AGPI in estimating rainfall from satellite data. As expected, the raingauge rainfall was found about 68% of AGPI.

1. INTRODUCTION

Flood is a common phenomenon in Bangladesh. Every year about one fifth of the country gets flooded [1]. The main component of flood is rainfall. Usually raingauge and radar are used to estimate rainfall. There are some problems associated with raingauges; the shape of the container, its exposure, the wind and evaporation between measurements. Also a dense network of raingauges is required to produce accurate estimates of areally averaged precipitation. Such a network is impossible over ocean and inaccessible areas. Despite problems such as variation in the reflectivity rainfall relation varying droplet size spectra and beam attenuation among others good estimates of areally averaged rainfall can be obtained using suitably calibrated digital radars [2]. However radar ranges are rather small (100–500 km approximately) and its deployment is impracticable over the ocean and it would be prohibitively expensive to have a large radar network on land. So the solution to overcome the difficulties of land-based equipment is to make use of satellite based remote sensing devices. Satellite provides data round the clock and they can monitor very large areas. Therefore meteorological satellite data are the only realistic means to monitor the spatial and temporal distribution of precipitation. Though there is inherent indirectness of satellite observable quantities (e.g., cloud top reflectance or thermal radiance) as measures of surface precipitation intensity; but cloud infrared area is highly crenellated with rain area [3, 4]. So these data become useful when averaged over large space and or time scales and then only when carefully calibrated for the region and monsoons in question [5].

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In recent years researchers are trying to estimate rainfall from satellite data [3, 4, 6]. In this paper we described the estimation of precipitation from satellite data and calibration with raingauge rainfall for the northeastern region of Bangladesh.

2. DATA AND PROCEDURE

We used three hourly satellite infrared (IR) data, provided by the Institute of Flood Control and Drainage Research (IFCDR), Bangladesh University of Engineering and Technology (BUET), Dhaka, from the Japanese Geo-stationary Meteorological Satellite (GMS-5). We also used hourly rainfall data from 9 automatic digital raingauge stations at Sylhet for the period 1995–1996 installed by Japan International Cooperation Agency (JICA). The locations of raingauges in Sylhet are shown in Figure 1.

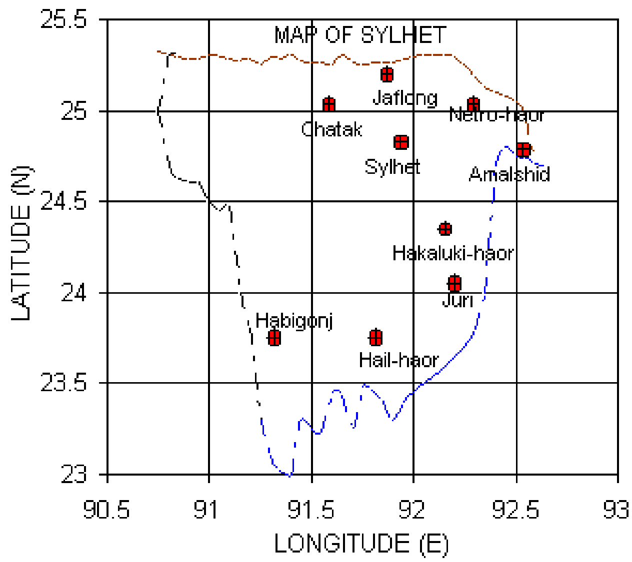

Figure 1. Raingauge locations in northeastern part (Sylhet) of Bangladesh.

We compared satellite estimated rainfall (GPI) with raingauge rainfall in the northeastern region of Bangladesh to calibrate the GMS Precipitation Index (GPI) for this region. To get GPI the steps are given below.

Step 1. The whole region was divided into five boxes each having an area of $0.5^{o}\times0.5^{o}$. We assigned each location a name; they are Jaflong, Chatak, Amalshid, Habiganj and Hakaluki. Each box contains 30 pixels, while each pixel was 11 km×9 km.

Step 2. The fractional coverage of cloud 'F_c' was calculated for each $0.5^{o}\times0.5^{o}$ grid cell. "F_c" was defined as for each $0.5^{o} \times 0.5^{o}$ cell covered by clouds whose cloud top temperatures are colder than 253K. The threshold so chosen to include all kind of precipitating clouds.

According to the definition-

$$F_c = \frac{\text{total number of cloudy pixels}}{\text{total pixels}} \qquad (2.1)$$

Step 3. Estimation of precipitation is carried out using a linear [7]. The rainfall estimates are referred to as GMS-5 precipitation index (GPI).

The Linear form of GPI is,

$$\text{GPI (mm)} = K \times F_c \times T \qquad (2.2)$$

Where 'Fc' is the fractional coverage of cloud and 'K' is a constant related to rain rate and is taken as 3 mm/h as by Arkin and Meissner [7]. And 'T' is the length of averaging period in hour.

Steps 1 to Step 3 were repeated for each 8 images of the day. Then the total number of pixels for the day was calculated by simple addition. The daily GPI values were averaged for three-days and seven-days to produce 3-day and 7-day average GPI for each $0.5^o \times 0.5^o$ grid cell.

Step 4. We also calculated raingauge rainfall for the time resolution of 1-day, 3-day and 7-day period. GPI and rainfall for $0.5^o \times 0.5^o$ boxes were then compared with each other.

Step 5. AGPI was also calculated for the time resolution of 1-day, 3-day and 7-day period. In calculation of AGPI, we used 4 mm/h instead of 3 mm/h for 'K' in equation 2.2. The value of 'K' was found as the best fit for this study.

Step 6. AGPI and rainfall for $0.5^o \times 0.5^o$ boxes were then compared with each other.

3. RESULTS AND DISCUSSION

3.1 GPI and raingauge rainfall

Among five stations of Figure 2 we found that two stations named Chatak and SUST show higher raingauge rainfall (RAIN) than GPI.

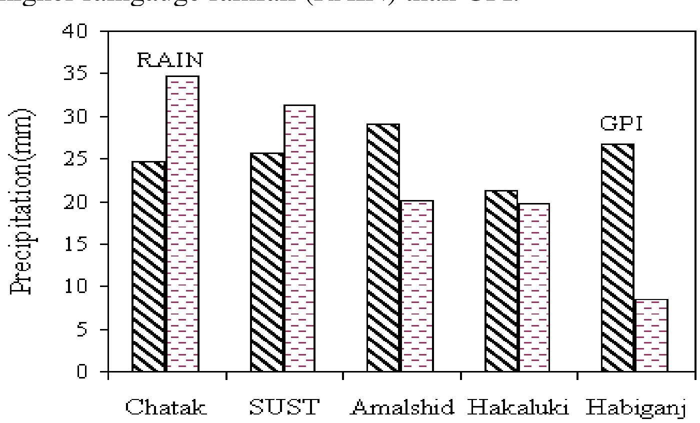

Figure 2. Daily rainfall calculated by raingauge (RAIN) and satellite(GPI) in Sylhet

This result is inconsistent with meteorological point of view. As expected, GPI value must be higher than RAIN value because whole precipitable water does not reach to the surface. At Chatak the daily average raingauge rainfall (RAIN) was 35 mm where the satellite estimated an average rainfall (GPI) of 25 mm. Hence RAIN was 140% of GPI. This result implies an overestimation of raingauge rainfall. As we know, raingauge is conventionally used as a ground truth tool. Then GPI is underestimated for this station. The same situation prevails at the station SUST, where the raingauge rainfall was 32 mm/day and satellite rainfall was 26 mm/day. Hence the daily average RAIN was 123% of GPI. This station again indicates the underestimation of GPI. At Amalshid the daily rainfall was 20 mm where GPI was 29 mm. Here we found that RAIN was 67% of GPI. This result is good enough as expected. At Hakaluki-haor RAIN was 20 mm/day while GPI was 22 mm/day. The percentage of RAIN was 90% of GPI. This station indicates overestimation of RAIN because our expectation is about 70% (8). At Habigang RAIN was 9 mm/day while GPI was 27 mm/day. The percentage of RAIN was 33% of GPI. This station indicates underestimation of RAIN because our expectation is about 70%.

Figure 3 shows the accumulation of 3-day variation in GPI and RAIN in Sylhet. Among five stations we again found that two stations Chatak and SUST show higher raingauge rainfall than GPI.

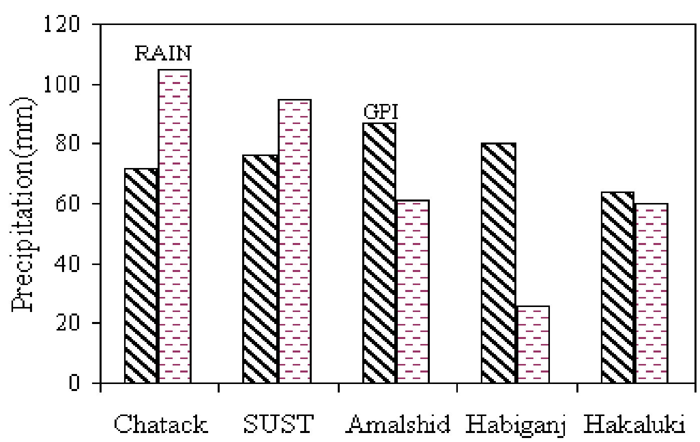

Figure 3. Same as Figure 2 except for 3-days

At Chatak the 3-day accumulated raingauge rainfall (RAIN) was 105 mm where the satellite estimated an average rainfall of 72 mm. Hence the 3-day accumulated RAIN was 145% of GPI. This implies an overestimation of raingauge rainfall i.e., underestimation of GPI for this station. The same situation prevails at the station SUST where the raingauge rainfall was 95 mm/3-day and satellite rainfall was 76 mm/3-day. So the 3-day accumulated RAIN was 125% of GPI for this station. This station again indicates the underestimation of the GPI. At Amalshid the 3-day rainfall was 61 mm where GPI was 87 mm. Hence we found RAIN was 70% of the GPI as expected. At Hakaluki-haor RAIN was 60 mm/3-day while GPI was 64 mm/3-day, so the percentage of RAIN was 94% of the

GPI. This station indicates overestimation of RAIN. However at Habigang the 3-day accumulated rainfall was 26 mm while GPI was 80 mm. Hence RAIN was 33% of GPI for this station. Here we found over estimation of GPI.

Figure 4 shows the 7-day accumulated precipitation estimated by raingauge and satellite. Among five stations in Sylhet we found that two stations named Chatak and SUST show higher RAIN than GPI. At Chatak the 7-day accumulated RAIN was 235 mm where the satellite estimated 167 mm. So the 7-day accumulated RAIN was 141% of GPI. Hence GPI made an underestimation for this station. At SUST the raingauge rainfall was 212 mm/7-day and satellite rainfall was 175 mm/7-day. So the 7-day accumulated RAIN was 121% of GPI. This station again indicates an underestimation of GPI. At Amalshid the 7-day RAIN was 136 mm where GPI was 197 mm. Hence RAIN was 69% of GPI as expected. At Hakaluki-haor RAIN was 134 mm/7-day while GPI was 144 mm/7-day, so the percentage of RAIN was 93% of GPI. This station indicates overestimation of RAIN. At Habiganj the 7-day accumulated RAIN was 58 mm while GPI was 181 mm, so RAIN was 32% of GPI. Here we found over estimation of GPI.

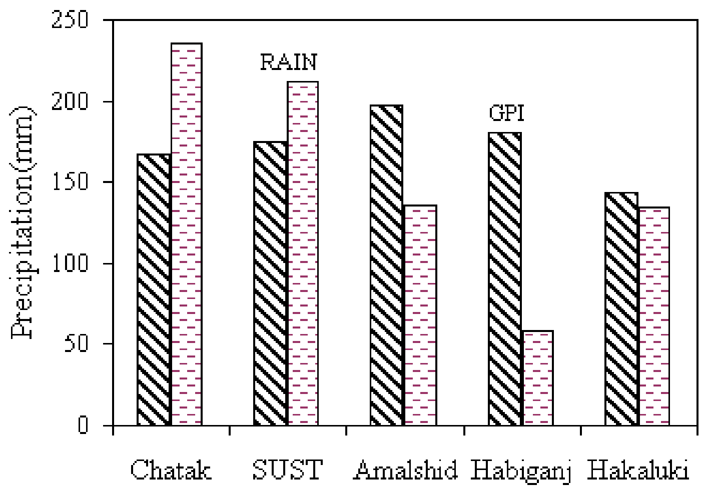

Figure 4. Same as Figure 2 except for 7-days.

Discussing all the above figures (Figure's 2-4) we found that GPI often made an underestimation. As Mukammel et al. (1998) reported, the precipitable portion of the cloud in and around Bangladesh was 74%. Also all the precipitation does not reach to the ground. Islam et al. (1998) reported that 90% of the precipitable portions of the cloud reach to the ground as rain. So we expect 90% of 74% i.e., 67% of GPI should reach to the ground as rain. Hence we may expect the ratio between raingauge and satellite rainfall should be at least 7:10 or near.

3.2 Adaptation of GPI as AGPI

In order to get acceptable rain estimates from satellite data we may readjust constant rain rate in calculating GPI. We tried to find a better constant rain rate in calculating GPI from GMS-5 for this region. In this work we used the constant rain rate 4 mm/hour instead of 3 mm/hour used by Arkin and Meissner [7]. This new rain rate better enabled us to calculate rain from satellite IR data. In this study the new adjusted GPI is termed as AGPI which is described in this sub-section.

Figure 5 shows the daily average raingauge rainfall (RAIN) and our Adjusted GMS Precipitation Index (AGPI) for five selected stations at Sylhet. All stations except Chatak show that RAIN was smaller than AGPI. This result is consistent with meteorological point of view. At Chatak RAIN was higher than AGPI. This result is inconsistent with meteorological point of view. The fact is that one day there was very strong rain (418 mm) at this station. This one-day rain overestimated raingauge rain. This rain may be from short liver small convective clouds, which were not detectable by satellite. In this work 3-hourly GMS-5 data with 0.5° grid resolution data are used. These temporal and spatial resolutions are low for small scale convections may be the cause of failure of satellite scanning the proper clouds identity. In general the rainfall estimated from satellite must be higher or equal to RAIN. The percentage of RAIN at Chatak, SUST, Amalshid, Hakaluki and Hobigang were 106%, 94%, 54%, 70% and 24% of AGPI respectively. The mean percentage of RAIN was 69.6% of AGPI. This value fully satisfies our expectation.

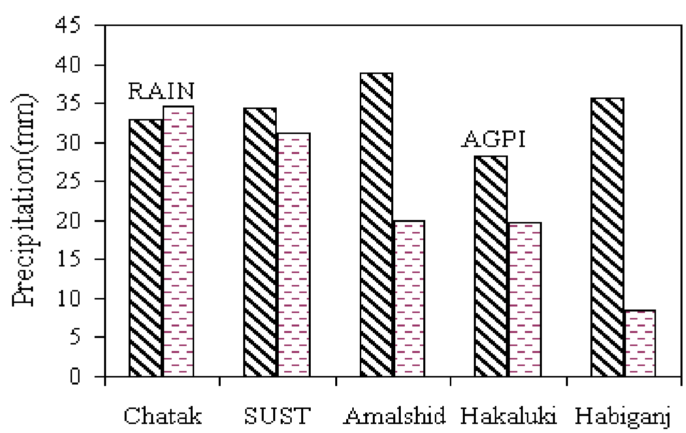

Figure 5. Same as Figure 2 except for AGPI.

Figure 6 shows the 3-day accumulated raingauge rainfall (RAIN) and Adjusted GMS Precipitation Index (AGPI) at Sylhet. All stations except Chatak show that RAIN was smaller than AGPI, which is expected. At Chatak we see that the 3-day accumulated RAIN was 9 mm higher than AGPI, hence RAIN was 109% of AGPI. This is a bit underestimation by satellite. The reason is discussed for daily average in Figure 5. Without this enormous rain in a day AGPI might be higher than RAIN as expected. The percentages of RAIN at different stations were almost same as in the case of daily average.

The percentage of RAIN at Chatak, SUST, Amalshid, Hakaluki and Habigang were 109%, 94%, 53%, 71% and 24% of AGPI respectively. The mean percentage of RAIN was 70.2% of AGPI. So the average percentage of RAIN again presents expected result for 3-day average rainfall.

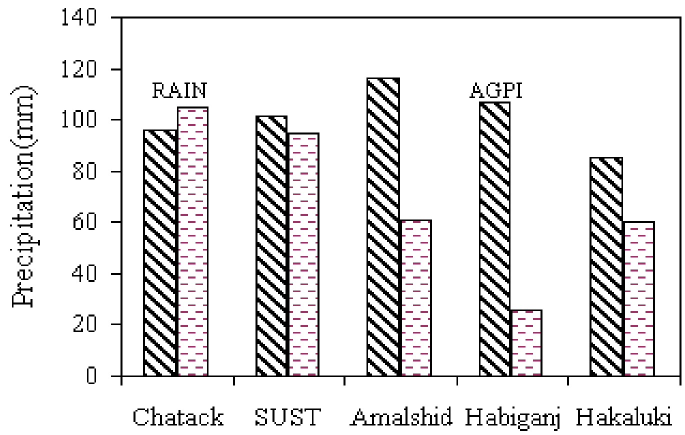

Figure 6. Same as Figure 3 except for AGPI I

Figure 7 shows the 7-day accumulated RAIN and AGPI at Sylhet. The situation was almost same as in the case of 3-day accumulation. Here five stations except Chatak show that RAIN was lower than AGPI as expected. At Chatak RAIN was 105% of AGPI, which is a bit lower estimation by satellite. The reason we mentioned earlier. The percentages of RAIN at different stations were almost same as in the case of daily or 3-day values. The percentage of RAIN at Chatak, SUST, Amalshid, Hakaluki and Habigang were 109%, 94%, 53%, 71% and 24% of AGPI respectively. The mean percentage of RAIN was 70.2% of AGPI. So the 7-day average percentage of RAIN again gives satisfactory result.

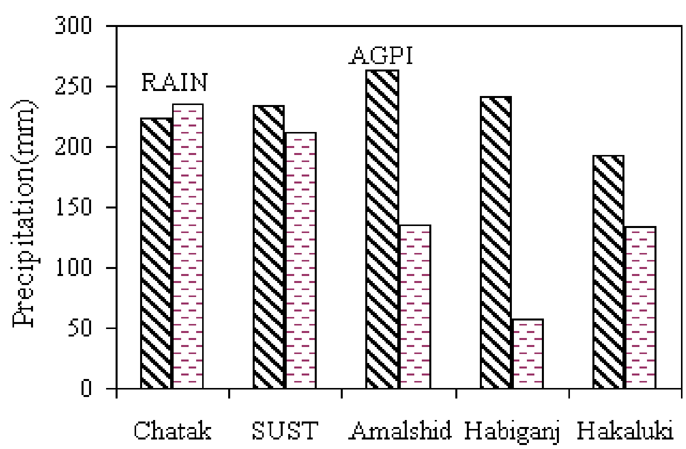

Figure 7. Same as Figure 4 except for AGPI

3.3 Accumulated precipitation at Sylhet

Figure 8 represents the accumulated precipitation for the period of 1-day, 3-day and 7-day at different stations in Sylhet from June-July 1996. In the case of 1-day accumulation, the percentage of RAIN was 67.8% of AGPI. The percentage was 68.7% and 67.2% for 3-day and 7-day respectively. The average RAIN was 68% of AGPI. Hence AGPI gives very satisfactory rainfall from satellite data.

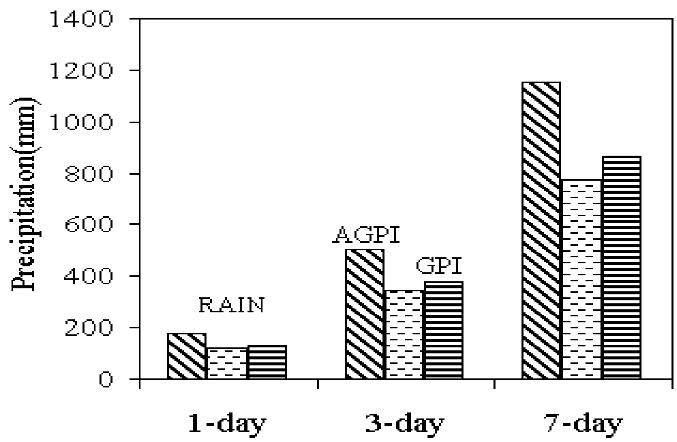

Figure 8. Accumulated precipitation for the period of 1-day, 3-day and 7-day at Sylhet from June - July 1996

4. CONCLUSIONS

From this study we found that the percentage of raingauge rainfall was 67.8%, 68.7% and 67.2% for 1-day, 3-day and 7-day average respectively of AGPI. Hence, we may conclude that AGPI is good enough to estimate rainfall from satellite data. AGPI was applied successfully at different stations in Sylhet. In future we may expand the analysis area for whole of the country to apply this method of estimation of rainfall from satellite data. This may be our next task in near future.

5. ACKNOWLEDGEMENTS

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