Chapter 5
Understanding Surface Water Flow and Storage Changes Using Satellites: Emerging Opportunities for Bangladesh

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Contents

Abstract This paper overviews the monitoring of surface water flow and storage using satellites. The overview is cast in the context of surface water-related problems of Bangladesh and South Asia. The paper then provides a basic introduction of a planned space-borne mission for surface water called SWOT (Surface Water and Ocean Topography) mission suggested for launch in 2015. The opportunities offered by SWOT for enhancing the capacity for flood hazards monitoring and adaptation to climate change for Bangladesh are also overviewed.

Keywords Bangladesh • Space-borne discharge • SWOT • Surface water • Floods • Climate change

Abbreviations

GBM Ganges, Brahmaputra, Meghna
FFWC Flood Forecasting and Warming Center

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IWM	Institute of Water Modeling
GIS	Geographic Information System
SWOT	Surface Water and Ocean Topography
WSOA	Wide Swath Ocean Altimeter
KaRin	Ka band Radar Interferometer

5.1 Introduction

Bangladesh is largely a riverine delta situated at the most downstream end of three large river basins – the Ganges, the Brahmaputra and the Meghna, i.e. the GBM basin (Fig. 5.1; Paudyal 2002). The flood plains of these three international rivers, together with smaller rivers and streams, account for about 80% of the area of Bangladesh (Hofer 1998). Yet only around 7–8% of the total drainage area of the GBM basins is situated inside the boundaries of Bangladesh.

Problems related to surface water availability are very widespread in Bangladesh. In general, the geographic location and average land elevation of Bangladesh are conducive to the four major water related problems: (1) Flood; (2) Erosion; (3) Drought and (4) Storm Surges. For about 7 months of the year (the non-Monsoon period spanning October–May), drought, exacerbated by the impoundment of the Ganges river in upstream India, creates acute water shortage in the Western regions of Bangladesh (Fig. 5.2). Estimates also indicate that about 3,000 km of the river banks will have been

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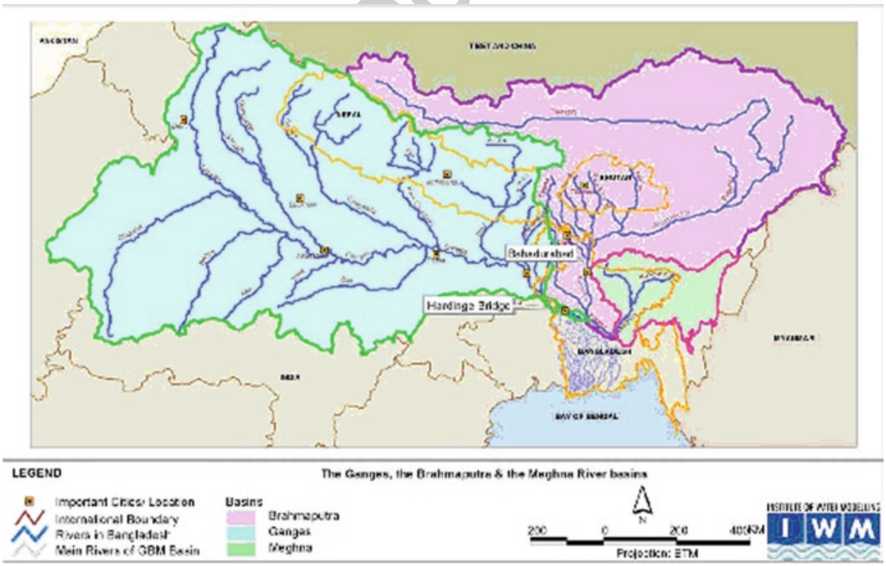

Fig. 5.1 The Ganges–Brahmaputra–Meghna river basin (GBM). Map produced by Institute of Water Modeling (IWM), Bangladesh

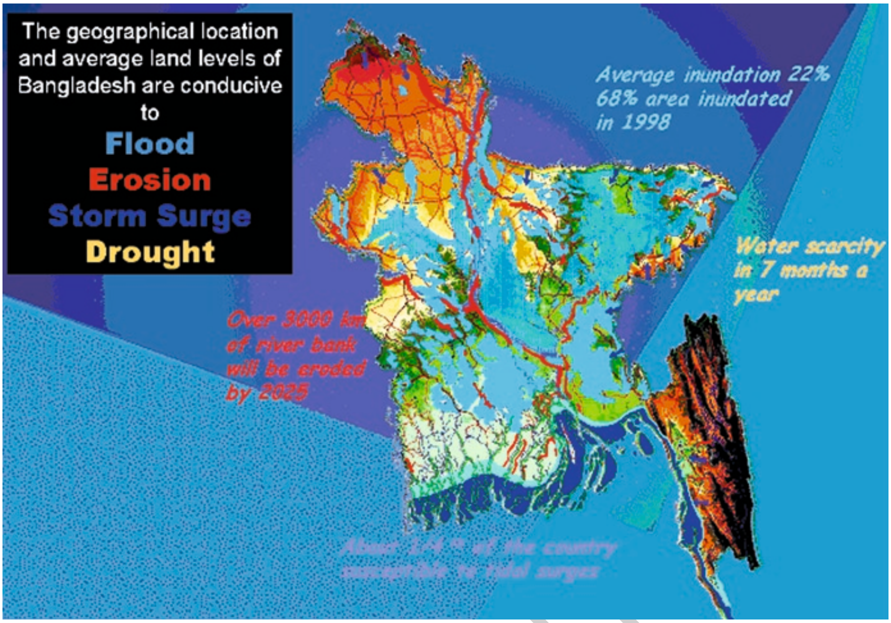

Fig. 5.2 Overview of surface water related environmental hazards of Bangladesh. (Map courtesy of Institute of Water Modeling, Bangladesh)

eroded by 2025, while in any given year about 22% of the total land area is usually inundated by Monsoon-driven flooding by the major rivers. For extreme wet years, this inundation can swell to 68% of the total land area as has been witnessed during the recent catastrophic floods of 1998 (Chowdhury 2000). Finally, about one-fourth of the country is susceptible to tidal surges from cyclones (Fig. 5.2).

Because many of the water-related problems are 'routine', Bangladesh government has invested in a monitoring network and a forecasting system. The most notable system in this regard is the one designed for floods, called the 'FLOOD WATCH', developed and operated by the Flood Forecasting and Warning Center (FFWC) of the Bangladesh Government Ministry of Water Resources. FLOOD WATCH is currently operated in real-time by the FFWC and believed to be the world's largest flood forecasting model (4,200 grid points) presently in operation (Kjelds and Jorgensen 1997). Technical support for system modifications and upgrades are continuously provided by the Institute of Water Modeling (IWM) of Bangladesh. Every day during most of the monsoon season the model simulates the water level conditions during the previous 7 days (hind-cast simulations) and during the coming 3 days (forecast simulation). These forecasted levels are then converted for decision support to either one of the five outputs for public dissemination (e.g., internet: www.ffwc.gov.bd; radio, TV and news dailies) and for disaster management (e.g., Prime Minister's Office and Disaster Management Bureau). These five outputs are: (1) normal (river stage expected to remain below the danger level); (2) warning (river stage projected to threaten the danger level);

(3) danger (river stage projected to exceed the danger level); (4) severe (over bank flooding in progress) (5) no data. The danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. Currently, FLOOD WATCH issues flood warnings for 30 river stations in the country using in-situ rainfall information from 84 stations (see Fig. 5.3).

Despite the significant reduction of the average number of deaths associated with catastrophic floods after the implementation of FLOOD WATCH in 1995 (flood related deaths in 1988 were 2379, compared to 918 in 1998 floods; Ninno et al. 2001; Chowdhury 2000), a significant amount of annual damage of lives and property by floods is nevertheless endemic in Bangladesh. Two challenging factors identified in this regard suggest that an even better decision support or monitoring with satellite data might be possible. These are: (1) increasing the lead time of river flow forecast beyond 3 days by early estimation of surface flow conditions further upstream of Bangladesh within India, Nepal and Bhutan (Hossain and Katiyar 2006); and (2) reducing high operational costs of daily in-situ rainfall measurements to maintain long-term sustainability of FLOOD WATCH. An increase in lead time has potential significance for reducing the country's agricultural vulnerability to flooding hazards. For example, 7- to 10-day forecasts are much more useful than daily forecasts in agricultural decision support as they inform farmers of the potential benefits of delayed sowing or early reaping of crops, while a 21-day forecast is considered most ideal for South and Southeast Asian nations (Asian Disaster Preparedness Center – ADPC 2002).

However, basin level hydrological modeling of large international river catchments is gradually becoming a more challenging task due to the complexity in collecting and handling information and data such as rainfall, river discharge, topographic parameters, land use, cropping pattern etc. For example, the general trend on global data collection for discharge and rainfall measurements is reported to be on the decline (see Stokstad 1999; Shiklomanov et al. 2002). Similarly, topography, accessibility and to a large extent economic considerations restrict the routine data collection which can consequently limit the accuracy of the data. In international rivers, such as the GBM, further restriction in the availability of data and information beyond borders is a major hurdle to any large scale water resources modeling work (Hossain et al. 2007).

5.2 The Potential Role of Satellites for Bangladesh: The SWOT Mission

Recently, satellite based remotely sensed data have found increasing use in support of a wide variety of applications in water resource management, disaster emergency preparedness, weather and flood forecasting. Remote sensing can provide data at various scales (from the meso-scale level up to the global earth coverage) and at regular temporal resolutions. Most of the remotely sensed data is also regularly updated and freely accessible on the internet. The data is mostly available in grid

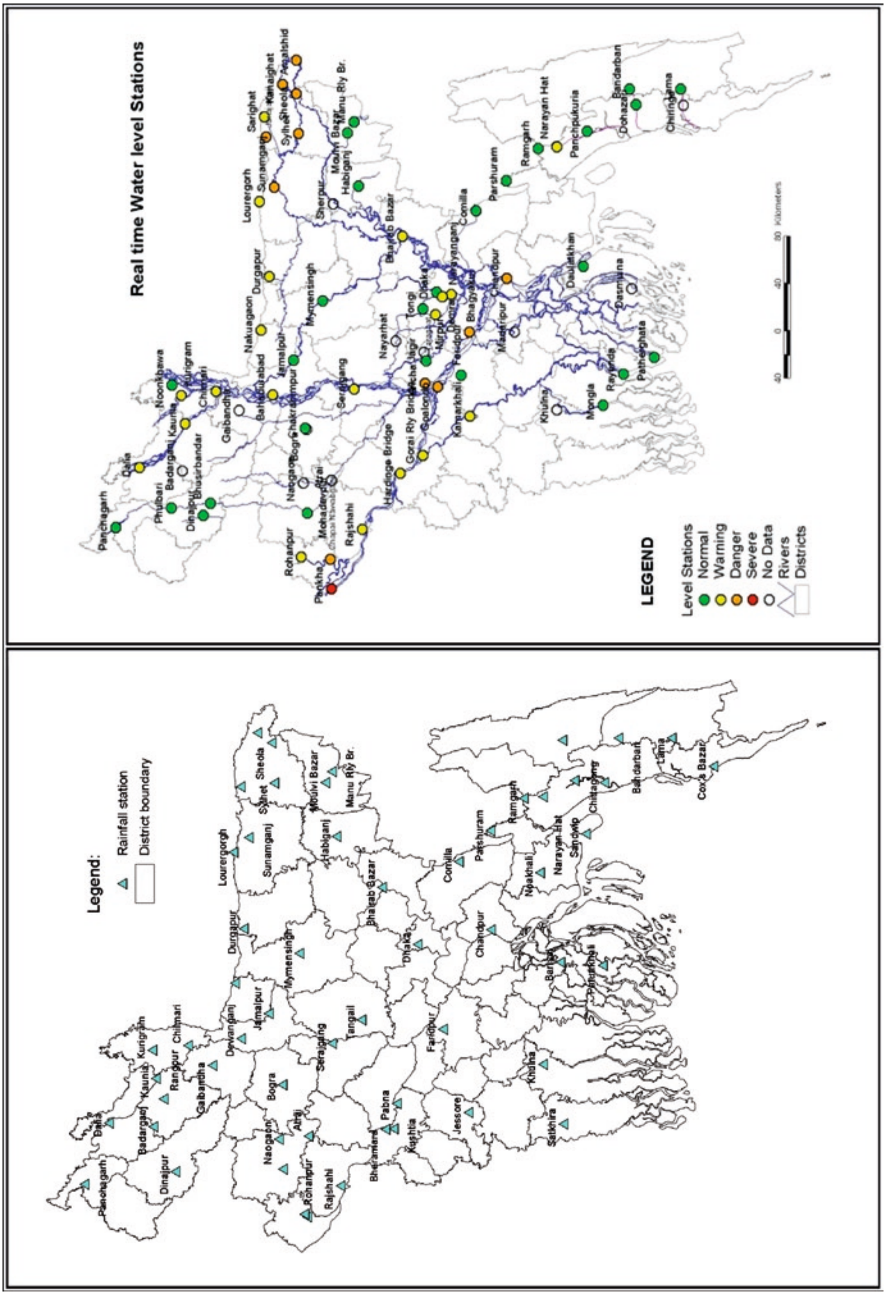

Fig. 5.3 The FLOOD WATCH Network in Bangladesh. *Left panel* – Rainfall Monitoring Stations. *Right panel* – River Discharge or Water Level Stations for Issuing Flood Warnings by FLOOD WATCH. The five different warning levels are shown in five colors

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format and easy to extract with Geographic Information System (GIS) tools and can be used to develop more realistic models, and identify changes in water resources or assess 'what-if' scenarios more accurately. In particular, given the unique vantage of space that is possessed by satellites (which allows them to cover a large area overcoming the hurdles on the ground), water-measuring satellites, therefore, have the potential to: (1) extend the accuracy and range of forecasted flood levels in the lowermost riparian nation through early assessment of the surface runoff evolution in the upstream nations and (2) minimize the negative impact of unavailable data and/or high operational costs of in situ networks.

In particular, the proposed Surface Water and Ocean Topography (SWOT) space mission to estimate surface water flow and storage changes will have tremendous implications for Bangladesh (Alsdorf et al. 2007). The SWOT satellite mission concept is an international effort by the scientific community founded on many years of research heritage on surface water monitoring from space (Alsdorf et al. 2007). SWOT recognizes that the ideal instrument for measuring surface water hydraulics (i.e., movement as well storage) is a device capable of providing image based measurements of water levels and its temporal and spatial derivatives of this water level. The technology for SWOT is a Ka-band Radar Interferometer (KaRIN) that has been developed from the efforts of the Wide Swath Ocean Altimeter (WSOA). More details on the SWOT mission may be found at http://swot.jpl.nasa.gov/.

5.3 How Useful Can Be SWOT for Bangladesh?

SWOT will measure water surface elevations using near-nadir radar interferometry. It will aim to provide discharge of large rivers at least 10 days or less (Alsdorf et al. 2007). With SWOT's suggested launch in 2015, Bangladesh may anticipate two ground breaking developments in its effort to monitor and forecast surface water related hazards. These are: (1) the availability of water elevations and discharge information from the upstream regions of the Ganges and Brahmaputra river in India and Nepal; and (2) a more complete coverage of the large seasonal wetlands (or 'haors') and other water bodies/rivers that are sparsely gaged inside Bangladesh. In particular, #1 can be expected to improve the flood forecasting capability of Bangladesh tremendously by monitoring the early evolution of river flow several thousand kilometers upstream of Bangladesh.

In order to gauge the potential of a SWOT-like mission, an exercise was carried out to understand how useful a mission like SWOT would be for Bangladesh discharge measurement. Readers can refer to the work of Jung et al. (2009) for details of this assessment. Herein, only a summary is provided below.

The Brahmaputra River was chosen for an investigation of the utility of the SWOT-like mission (Fig. 5.4). The Manning's equation (Equation below) was used for estimation of river discharge. Manning's equation yields water flow velocity as a function of water surface slope, hydraulic radius and an empirical value, Manning's roughness coefficient, n. (Albertson and Simons 1964). It is an empirical

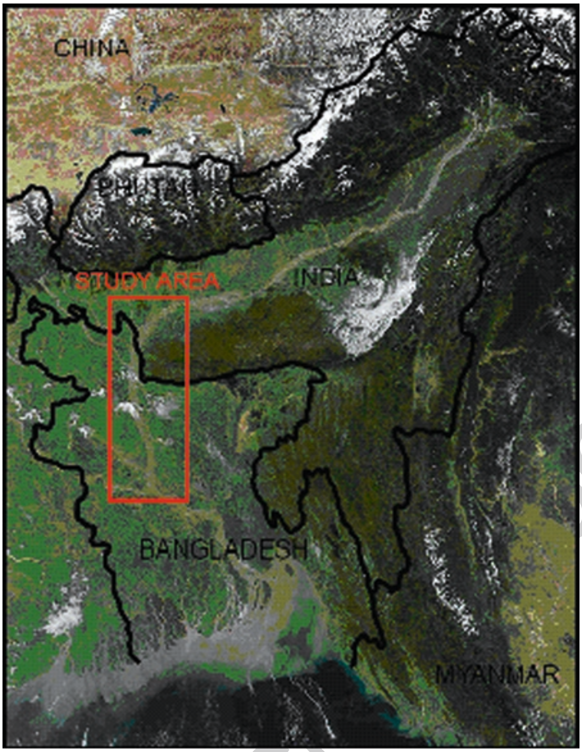


Fig. 5.4 Study area (shown in *red box*) of the Brahmaputra river for assessing the usefulness of the SWOT mission for Bangladesh

equation, but nevertheless well used in the hydrological sciences (i.e. LeFavour and Alsdorf 2005; Bjerklie et al. 2005). Multiplying flow velocity by channel cross-sectional area yields discharge (Fig. 5.5). [AU1]

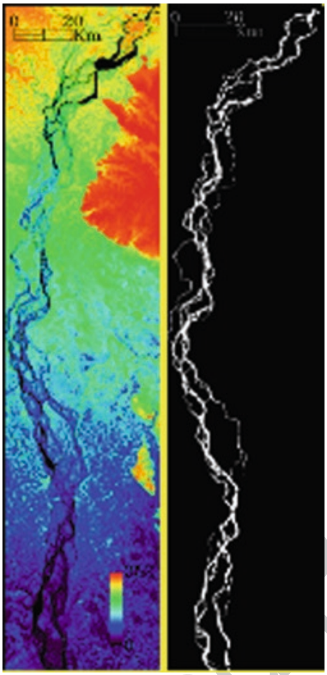
$$Q = \frac{AR^{2/3}\left(\frac{\partial h}{\partial X}\right)^{1/2}}{n}$$

A = river flow cross-section (width × depth); R = hydraulic radius (A × (width + 2 × depth)$^{-1}$); ∂h/∂x = water surface slope; n = Manning's roughness coefficient; Q = discharge.

The Brahmaputra River is sand bedded, without vegetation, therefore n is estimated to range from 0.018 to 0.035 (Ashworth et al. 2000; Albertson and Simons 1964; Coleman 1969). The value n = 0.025 was used for discharge estimations in this study because it is suggested for natural streams in fair condition by Albertson and Simons (1964).

The Shuttle Radar Topography Mission (SRTM), which flew during the month of February 2002, provided elevation at 90 m resolution for the study region. This was

Fig. 5.5 *Left panel* – SRTM derived elevation of the Brahmaputra river reach. *Right panel* – land-water classification using LandSat data



overlaid with Landsat data at 30 m resolution to identify the pixels that were land or water (Fig. 5.5). IWM provided detailed bathymetry and measured discharge for the river reach as part of a 5-year technical arrangement with the host institution of the first author. Using knowledge of bathymetry and the space-derived river width, the hydraulic radius was computed and then used for calculation of the Manning's discharge. Figure 5.6 shows the estimated discharge as a function of flow distance using space-borne data. Comparison with observed measurement of flow shows that a SWOT-like mission is capable of estimating the low-flow (non Monsoon) river discharge of a braided river like Brahmaputra within reasonable confidence.

5.4 Implications of SWOT for Developing Adaptation Strategies for Climate Change

It is difficult to foresee how exactly the routine measurements from SWOT will facilitate developing strategies for climate change for Bangladesh and the greater South Asian region. However, one aspect that is clear is that the spatially distributed nature on surface water levels from SWOT, which is often missing but valuable in the current state-of-the art, can identify the low-lying coastal regions most vulnerable

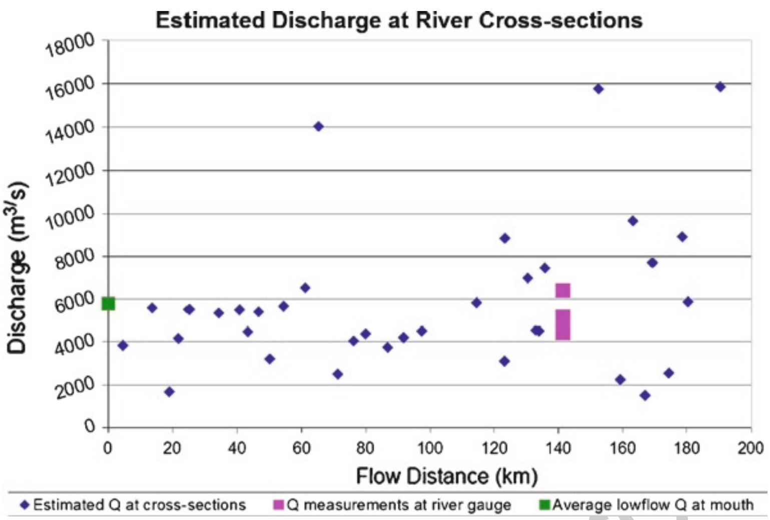


Fig. 5.6 Discharge estimation from space for Brahmaputra river. *Blue diamonds* indicate the estimated discharge using satellite-derived elevations. *Pink rectangles* are the measured flow on the Brahmaputra river reach. Flow distance is measured from upstream region of the river reach. (Figure taken from: Jung et al. 2009 and Hamski et al. 2008)

to sea level rise or where the reclamation by sea is in progress. Consequently, this can help the Bangladesh government prioritize areas in greater need of adaptation strategies. For example, for farmers in the low lying regions, floating garden beds for growing vegetables have lately become increasingly common. With SWOT's detection of water levels, such adaptive farming strategies can be proactively made available to the inhabitants of the region as the first instances of sea level rise is detected by SWOT.

Also, SWOT measurements of inland water bodies can help identify storage and storage change of freshwater resources in lakes, ponds, 'haors' or wetlands. With a more accurate assessment of storage change, drought management can be made more effective. For example, most often times, drought is forecasted on the basis of future rainfall patterns (such as an on-going or future anticipated failure of the Monsoons). Usually, the amount of water availability from atmospheric sources is not assessed in conjunction with the dynamic nature of freshwater storage changes. SWOT has potential to provide the governments of South Asian region with an additional tool to make more accurate assessment of the hydrology question – 'how much water will be available?'

5.5 Conclusion

This paper overviewed the monitoring of surface water flow and storage using satellites. The overview was cast in the context of surface water-related problems of Bangladesh. The paper provided a brief introduction of a planned space-borne mission for surface water called SWOT (Surface Water Ocean and Topography) mission suggested for launch in 2015. The opportunities offered by SWOT for enhancing the capacity for flood hazards monitoring and adaptation to climate change for Bangladesh were also overviewed. Preliminary assessment indicated that a SWOT-like mission can indeed estimate the flow of large rivers like the Brahmaputra river with confidence for use in operational forecasting systems.

Around the world, we have a poor understanding of both surface water flows in rivers and the changes in waters stored in lakes, wetlands, and reservoirs. The problems are not unique to Bangladesh, but are certainly felt more intensely.

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