

MONITORING PRE-MONSOON DROUGHT IN BANGLADESH USING  
REMOTE SENSING TECHNIQUE

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REMOTE SENSING TECHNIQUE

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A thesis submitted in fulfillment of the  
requirements for the award of the degree of  
Master of Philosophy

Faculty of Geoinformation and Real Estate  
Universiti Teknologi Malaysia

MARCH 2018

Alhamdulillah Syukur ke hadrat ALLAH dengan limpah kurnianya aku masih bernafas untuk detik ini dan mampu menyiapkan thesis ini dengan jayanya

Aku dedikasikan thesis ini khas untuk Mak,

Jamaliah Binti Manab  
15/08/1955 ~ 10/1/2016

Sebagai tanda terima kasih atas segala jasa dan pengorbanannya.

Semoga ALLAH membalas kebaikan Mak hingga ke akhirnya

Al-Fatihah

*“..Whenever you want to give up, just remember why you started...”*

## **ACKNOWLEDGEMENT**

All praises to ALLAH S.W.T for giving me courage and determination as well as guidance in this research study, despite all difficulties. I would like to take this opportunity to express my gratefulness to the people who have given me help and support during the process of the study and finishing my master thesis.

Thank you from the bottom of my heart to my supervisor, Dr Latifur Rahman Sarker and Assoc. Prof Dr Baharin Ahmad for all their helpful instruction, guidance and encouragement from time to time for keeping me on the right track of my work. Their endless patience and guidance for helping me to learn and developing my skill during my master journey.

To my beloved family and friend for their undying support, their unwavering belief that I can achieve so much. Unfortunately, I cannot thank everyone by name because it would take a lifetime but, I just want you all to know that you count so much. Had it not been for all your prayers and benedictions; were it not for your sincere love and help, I would never have completed this thesis. So thank you all.

May ALLAH bless all of you for the contribution that you made.

## ABSTRACT

Drought has been a prevalent concern in Bangladesh over the past few decades, and the findings of several studies have indicated that Bangladesh has a high risk of drought, in association with a significant increasing trend of temperature. However, little attention has so far been given in Bangladesh to the mitigation and monitoring of drought, although few studies have been conducted for drought assessment based on either rainfall and temperature or a drought index based on rainfall, such as the Standardized Precipitation Index (SPI). The objective of this study is to assess drought conditions in Bangladesh using long-term satellite data from January to May (2001-2014). Temperature-Vegetation Dryness Index (TVDI) is a drought index based on remote sensing data that exploits the relationship between Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) for estimating soil moisture condition has been used. A systematic approach was adopted in the methodology for considerations to; i) identify the spatial and temporal variation of drought using TVDI, ii) examine the relationship between TVDI and other climatology as well as environmental variables (such as soil moisture, LST, NDVI, rainfall, and Land Use Land Cover (LULC)), and iii) compare TVDI result with field investigation. Results indicate that drought is a concerning problem in Bangladesh and drought conditions varies spatially and temporally. It is clearly observed from the TVDI results that the problem of drought was not prominent in January and February (2001-2014) due to low temperatures. But the effect of drought was considerably high for the rest of the three months, of March, April and May (2001-2014) due to high temperature. However, there were still severe drought conditions have been observed in several small parts of the study areas where no additional water supply were available during that time, except rainfall. Nevertheless, a large part of the study area was still unaffected by the drought even during very hot weather condition due to massive irrigation which has been ascertained during the field investigations. Among the investigated parameters, very closed agreements were found between TVDI and LST as well as NDVI and LULC, although relationships between TVDI and rest of the parameters were not well-defined. This study also found that the TVDI result is in a good agreement with the field investigation. Most importantly, the correlation between TVDI and field investigation clearly indicates the important of this TVDI for the investigation of drought in a complex environment in Bangladesh, where drought estimation using only meteorological data (rainfall and temperature) is ineffective due to anthropogenic and environmental factors which modified the soil moisture condition across the ground very severely. Finally, this study highlights the potential of drought monitoring using remote sensing technique especially on the use of TVDI in Bangladesh due to lack of meteorological data.

## ABSTRAK

Kemarau telah menjadi kebimbangan lazim di Bangladesh sejak beberapa dekad yang lalu dan penemuan beberapa kajian telah menunjukkan bahawa Bangladesh mempunyai risiko kemarau yang tinggi berkaitan dengan peningkatan ketara corak peningkatan suhu. Namun, hanya sedikit perhatian telah diberikan untuk mengatasi dan memantau kemarau di Bangladesh walaupun beberapa kajian penilaian kemarau telah dijalankan sama ada berdasarkan hujan dan suhu atau indeks kemarau berdasarkan hujan seperti indeks hujan seragam (SPI). Objektif kajian ini adalah untuk menilai keadaan kemarau di Bangladesh menggunakan data satelit jangka panjang dari Januari hingga Mei (2001-2014). Indeks kekeringan suhu tumbuhan (TVDI), iaitu suatu indeks kemarau berdasarkan data penderiaan jauh yang mengeksploitasi hubungan antara indeks perbezaan tumbuh-tumbuhan (NDVI) dan suhu permukaan tanah (LST) untuk menganggarkan keadaan kelembapan tanah telah digunakan. Pendekatan sistematik telah dipertimbangkan untuk diguna pakai di dalam metodologi iaitu untuk i) mengenal pasti perubahan ruang dan masa kemarau menggunakan TVDI, ii) memeriksa hubungan antara TVDI dan pemboleh ubah secara klimatologi dan alam sekitar yang lain (seperti kelembapan tanah, LST, NDVI, hujan dan kawasan lutan dan guna tanah (LULC), dan iii) membuat perbandingan hasil TVDI dengan siasatan lapangan. Keputusan menunjukkan bahawa kemarau mendapat perhatian di Bangladesh dan keadaan kemarau adalah pelbagai dari segi ruang dan masa. Adalah jelas diperhatikan daripada keputusan TVDI menunjukkan masalah kemarau tidak ketara dalam bulan Januari dan Februari (2001-2014) kerana suhu rendah. Tetapi kesan keadaan kemarau adalah agak tinggi sepanjang tiga bulan yang lain iaitu Mac, April dan Mei (2001-2014) disebabkan suhu tinggi. Namun, masih ada kesan kemarau teruk yang hanya dilihat pada beberapa bahagian kecil dalam kawasan kajian di mana tiada bekalan air tambahan boleh didapati pada masa ini kecuali air hujan. Walau bagaimanapun, sebahagian besar kawasan kajian masih tidak terjejas oleh kemarau walaupun keadaan cuaca yang sangat panas disebabkan sistem saliran secara besar-besaran di sesetengah kawasan yang dikenalpasti sewaktu siasatan lapangan. Di antara pemboleh ubah yang dikaji, terdapat kesamaan yang sangat dekat di antara TVDI dengan LST dan NDVI dengan LULC, walaupun hubungan antara TVDI dan pemboleh ubah yang lain tidak dapat dijelaskan dengan tepat. Kajian ini juga mendapati keputusan TVDI mempunyai hubungan yang rapat dengan siasatan lapangan. Yang paling penting, korelasi di antara TVDI dan siasatan lapangan jelas menunjukkan kebolegunaan TVDI dalam siasatan keadaan kemarau di persekitaran yang kompleks di Bangladesh, di mana anggaran kemarau yang hanya menggunakan data meteorologi (hujan dan suhu) adalah tidak berkesan kerana faktor antropogenik dan alam sekitar yang mengubah keadaan kelembapan tanah di seluruh permukaan dengan amat teruk. Akhir sekali, kajian ini menekankan potensi teknik pemantauan kemarau menggunakan penderiaan jarak jauh terutamanya TVDI di Bangladesh kerana data meteorologinya adalah sangat kurang.

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## LIST OF ABBREVIATIONS

<b>GRFP</b>	Ganges River Floodplain
<b>HBT</b>	High Barind Tract
<b>HYV</b>	High Yielding Variety
<b>LULC</b>	Land Use Land Cover
<b>LST</b>	Land Surface Temperature
<b>MODIS</b>	Moderate Resolution Imaging Spectroradiometer
<b>NDVI</b>	Normalized Difference Vegetation Index
<b>PCI</b>	Precipitation Condition Index
<b>PDSI</b>	Palmer Drought Severity Index
<b>RMSE</b>	Root Mean Square Error
<b>SDCI</b>	Synthesized Drought Condition Index
<b>SDI</b>	Synthesised Drought Index
<b>SPI</b>	Standardized Precipitation Index
<b>TCI</b>	Temperature Condition Index
<b>TRMM</b>	Tropical Rainfall Measuring Mission
<b>TVDI</b>	Temperature Vegetation Dryness Index
<b>VCI</b>	Vegetation Condition Index
<b>VTCI</b>	Vegetation Temperature Condition Index
<b>NASA</b>	National Aeronautics and Space Administration
<b>PR</b>	Precipitation Radar
<b>TMI</b>	TRMM Microwave Imager
<b>VIRS</b>	Visible And Infrared Radiometer System

## CHAPTER 1

### INTRODUCTION

#### 1.1 Background of Study

Drought is recognized as a complex natural disaster that has severe effects on agriculture, human life, flora fauna and the economy. This disaster differs from other hazards (Wilhite, 2000) including the difficulty to i) determine the onset and the end of a drought (Tannehill, 1947), ii) define drought precisely (Gibbs, 1975; Dracup *et al.*, 1980), iii) manage drought affected areas due to large geographical extent, iv) perceive the effect of complex human activities that can directly trigger a drought, v) access the impact of different types of droughts, and vi) understand the changeable inter-relationships among different types of drought in time and space.

A widely diverse view of the definition of drought has been utilized among scientist's due to drought's functional and conceptual differences (Yevjevich, 1967; Wilhite and Glantz, 1985). Nevertheless, drought can generally be defined as a prolonged period of precipitation deficiency that results in a significant hydrological imbalance, often causing damage to crops, and loss of crop yield. Notable several other definitions of drought have also been reported by several organizations and scientists (WMO, 1986; UN Secretariat General, 1994; Schneider, 1996). However, droughts are generally classified into four categories (Wilhite and Glantz, 1985), which include: i) meteorological drought; a lack of precipitation, ii) hydrological drought; a period soil moisture deficit, iii) agricultural drought; a continuous from hydrologic drought and effect to crop production, and iv) socio-economic drought;



shortages for economic good due to limited water supply. It gives an impact towards the crop production that affects the large areas (Lobell and Field, 2007).

In the recent years, there have been many large-scale droughts affecting sizable areas in all over the parts of the world (Woods and Woods, 2007; IPCC Special Report, 2012) that can be linked to significant economic loss, limited food supply and, in some cases, starvation for millions of people. The adverse effect of drought is normally increased, if drought is observed in an agrarian and densely populated country (Miyan, 2015) such as Bangladesh where about 84% of the 145 million (currently 160 million) people are depended on a wide range of agricultural activities (Rahman, 2004). The findings from several studies on climate change indicated that the risk of drought in Bangladesh found to be very high in association with a significant increasing trend of temperature (Karmakar and Shrestha, 2000; Debsarma, 2003; Mia, 2003; Karmakar, 2003) due to global warming (IPCC, 2007) which are thought to eventually increase natural hazards such as drought.

In the recent years, there have been many initiatives in observing large scale drought over the entire continent that led to the bad impact to economy, ecological destroyed and also give an effect to food shortages which causes millions of people died due to starvation (Kogan, 2001). These scenarios have led to the awareness to the importance of drought monitoring (Downing and Baker, 2000). Therefore, many drought indices have been developed using climate data and used in different context for drought characterization and monitoring around the world. Drought indices are quantitative measures that characterized levels of drought by assimilating data based on meteorological parameter from one or several indicators, into a single value. These indices can indicate the nature of drought by reflecting different events and conditions based on climate dryness anomalies (Zargar *et al.*, 2011). But several limitations of climate data based drought index have been highlighted in the previous studies especially its dependency on interpolation technique and unavailability of adequate climate data particularly in developing countries (Mendelsohn *et al.*, 2007; Rhee *et al.*, 2010; Dutta *et al.*, 2015).

Different satellite sensor has been used to develop a number of drought indices. They are typically based on satellite derived vegetation indices (VIs), Land Surface Temperature (LST) and empirical methods using a certain combination of LST versus VIs (Ghulam *et al.*, 2007). However, the performance of the drought indices is varied based on the characteristics of the study sites under investigation. Nevertheless, it is quite clear from the literature that Normalized Difference Vegetation Index (NDVI) is the most widely used index for drought monitoring (Bayarjargal *et al.*, 2006; Vicente- Serrano *et al.*, 2006; Murali Krishna *et al.*, 2009) due to its ability for observing droughts in long term series of data (Ghulam *et al.*, 2007). Several studies found significant correlations between NDVI and precipitation (Unganai and Kogan, 1998; Yang *et al.*, 1998; Peters *et al.*, 2002). Although the NDVI has been found to be an effective indicator for drought characterization (Ji and Peters, 2003; Tadesse *et al.*, 2005), studies found that NDVI has a delayed response to precipitation or soil moisture deficit, and thus that the initial deficiency in soil moisture is not apparent in the NDVI signals (Rundquist and Harrington, 2000; Swain *et al.*, 2011). The lapse of time between the occurrence of a drought and the NDVI change is one of the limitations of NDVI based methods for real time monitoring of drought conditions (Ghulam *et al.*, 2007).

In contrast, Land Surface Temperature (LST) is more sensitive to initial water stress (Wan *et al.*, 2004). LST has been used in estimating surface soil moisture (McVicar and Jupp, 1998) and evapotranspiration (Granger, 2000; Anderson *et al.*, 2007). Several indices have been developed using satellite-derived LST observations such as Temperature Condition Index (TCI) (Unganai and Kogan, 1998) for drought monitoring (Singh *et al.*, 2003). Furthermore, studies found that the Vegetation Health Index (VHI) (Kogan, 1997, 2004), an additive combination of Vegetation Condition Index (VCI) and Temperature Condition Index (TCI), has a better capability to assess the stress of vegetation related to both water and temperature than VCI and TCI separately. Although VHI has been successfully applied globally for drought assessment in parts of Asia, Africa, Europe, and the America. However, Karnieli *et al.*, (2006) stated that this VHI index were limited indicated that this index should be used in caution especially in humid regions of high-latitude, where vegetation growth is primarily limited by lower temperatures.

However, the relationship between LST and NDVI has been investigated by several researchers (Moran *et al.*, 1995; Goetz 1997; Nemani and Running, 1997). These studies found that thermal and the visible/near infrared wavelengths can provide complementary information related on vegetation stress and soil moisture based on the combination of LST and NDVI. Temperature Vegetation Dryness Index (TVDI) is one of the index that derived from the combination of LST and NDVI (Sandholt *et al.*, 2002). A number of studies have employed TVDI for monitoring vegetation stress, surface moisture condition and drought considering the simplicity and effectiveness of this method (Son *et al.*, 2012; Huang *et al.*, 2013; Dhorde and Patel, 2016).

Therefore, it is comprehensible from the above background and existing literatures that drought is one of the most complex and the least understood natural disaster (He *et al.*, 2013). The impact of the drought has become a serious matter nowadays due to the population increase, environmental degradation, industrial development and fragmented government authority in the water and natural resources management (Rezayi *et al.*, 2011). As a result, any contribution for understanding and predicting drought conditions will be a step toward minimizing the impacts of drought. Numerous indices are available for drought monitoring based on both meteorological and remote sensing (satellite based) data, however, selection of drought indices need to be done based on the field condition and availability of data, since not all indices are equally effective for drought detection or monitoring in all field situations.

## **1.2 Problem Statement**

Bangladesh is one of the drought prone countries in the world. This country has already suffered by several severe drought events in the past (Paul, 1995). For example, drought in 1973 was one of the most severe on record and was responsible for a local famine in northern Bangladesh in 1974. Several studies stated that drought has been observed in Bangladesh an average once in 2.5 years (Adnan, 1993; Shahid and Behrawan, 2008) although severity and duration varied in time and space.

Droughts mostly occur in Bangladesh during the pre-monsoon (January-May) and post-monsoon (October-December) seasons (Banglapedia, 2006), affecting all three rice varieties regionally grown (Aman, Aus and Boro) as well as other crops grown in different seasons (Tanner *et al.*, 2007). Pre-monsoon season is the warmest season in Bangladesh due to the scarcity of rainfall and high temperature (Banglapedia, 2006). In the past, during this season, Aus (local rich variety), Jute and few other crops were cultivated over large areas in Bangladesh depending on very little rainfall. Therefore, slightly decrease in rainfall and increase in temperature had a devastating impact on agriculture productions.

In recent decades, the scenario of pre-monsoon season in several parts of Bangladesh has been altered completely due to intensive irrigation using the easily available underground water for the cultivation of High Yield Variety (HYV) Boro rice (Miyan, 2015). Approximately 88% of the potentially available agriculture is under the cultivation of Boro rice during this time (Tanner *et al.*, 2007; Wahid *et al.*, 2007; Shahid and Behrawan, 2008). Significant water supply (240 mm/month) is required for Boro rice cultivation but average monthly rainfall for January, February, March, and April is only 5mm, 10mm, 30mm, and 85mm respectively. This huge gap between required and observable soil moisture is compensated by the massive extraction of a slowly declining ground water supply (GOB, 2002). However, three factors have created a complex scenario of the drought in this period at present: i) increasing trend of temperature; ii) intensive irrigation; and iii) depletion of underground water. As a result, three circumstances can be seen i.e. i) meteorological drought which perhaps exist due to high temperature and low rainfall, ii) agriculture drought may or may not able to activate owing to irrigation, and iii) future threat to irrigation practice due to regular depletion of underground water. This situation emphasizes an urgent need for a detailed investigation of the recent drought scenario in Bangladesh considering the future potential risks of this irrigated agriculture practice.

Several studies have been conducted to assess the drought and its spatial and temporal variation focusing on several parts of the country (Shahid and Behrawan, 2008; Habiba *et al.*, 2011; Dash *et al.*, 2012; Alamgir *et al.*, 2015). However, the

problems associated with the most previously conducted studies are that drought assessment was conducted based on either rainfall/temperature or a drought index based on rainfall such as standardized precipitation index (SPI; McKee *et al.*, 1993, 1995). Consequently, the impact of human induced activity particularly irrigation on drought is mostly absent from their outcomes. Additionally, previous studies are also influenced by several notable limitations of climate data as well as the SPI method itself which include; i) dependency on distribution and density of weather stations across the landscape (Brown *et al.*, 2008; Rhee *et al.*, 2010) as well as spatial interpolation techniques (Brown *et al.*, 2002; Mendelsohn *et al.*, 2007; Rhee *et al.*, 2010), ii) lack of sufficient and reliable climate data particularly in developing countries (Dutta *et al.*, 2015), and iii) inability to consider environmental factors which can influence droughts. Therefore, drought detection was not accomplished successfully through the effort of the previously conducted studies because of the complex situation in Bangladesh where climate variables (temperature and rainfall) and human induced activity (irrigation) are interacting with each other for modifying drought intensity.

In contrast, during the past several decades, remotely sensed data have been used in plant biophysical and climate change related studies, including drought monitoring (Ji and Peters, 2003; Bayarjargal *et al.*, 2006) since this data can be used to assess ground soil moisture condition (whether it is due to climatic factors, environmental factors or human induced activities) by generating several useful indices using different spectral bands. Moreover, remote sensing satellite provides a spatially contiguous and temporally repetitive view of the earth surface which is very useful for drought monitoring (Du *et al.*, 2013). Indeed, several drought indices based on satellite data have been developed and many studies have also been carried out successfully for the monitoring of drought around the world using a wide range of simple to complex drought indices derived from different kind of satellite data (Tadesse *et al.*, 2005; Mallick *et al.*, 2009; Rhee *et al.*, 2010; Son *et al.*, 2012; Wang *et al.*, 2014). Unfortunately, very little effort has been made to characterize drought in Bangladesh using satellite derived drought indices (Murad and Islam, 2011) although a robust technique for drought monitoring is necessary which can

comprehend not only the rainfall but also other factors that affecting the drought across the landscape under investigation.

Therefore, this study is going to take an opportunity to study drought in Bangladesh and its spatial and temporal variation using long-term satellite data. This study investigates the present drought scenario of a Bangladesh area using a remote sensing based drought index TVDI considering its ability to incorporate both LST and NDVI in an effective way. TVDI was conceptually and computationally straightforward methodology, simple data requirement (only satellite-derived information) and already demonstrated the potential for drought monitoring in various geographical regions (Qi *et al.*, 2003; Son *et al.*, 2012). However, in this study, drought assessment will be carried out during pre-monsoon season (January, February, March, April and May) from 2001 to 2014 taking into account the availability of all necessary data. This study provides a new insight in recent change of droughts in Bangladesh which in turn will help policy makers in taking the necessary steps for preventing future drought hazards and making drought mitigation planning.

### **1.3 Aim and Objective**

#### **1.3.1 Aim of Study**

The overall objective of this study is to examine the potential of remote sensing technique for monitoring long term drought in Bangladesh.

#### **1.3.2 Objectives of Study**

1. To identify the spatial and temporal variation of drought during pre-monsoon by using Temperature Vegetation Dryness Index (TVDI),

2. To examine the relationship between TVDI and other climatologically and environmental variables (such as soil moisture, LST, NDVI, rainfall, and land use/land cover), and
3. To compare the TVDI result with field observation.

### **1.3.3 Research Question**

1. How much drought phenomena changed spatially and temporarily in Bangladesh during the last decade?
2. How is the relationship between the TVDI and the other meteorological parameter?
3. What is the main reason behind the different situation of drought condition in Bangladesh in these five different months?

### **1.4 Scope of Study**

1. This study uses MODIS Terra for LST and NDVI determination. MODIS has been selected in this study because of the long-term data availability (since 2000), better spatial coverage (i.e. 250m, 500m and 1km) and higher temporal resolution (1 to 2 days).
2. The other satellite data that were used are Tropical Rainfall Measuring Mission (TRMM) used for precipitation measurement and ESA CCI Soil Moisture data for the soil moisture measurement in the study area. These two additional data were selected due to the availability of data for the overall period of the study

3. Other than the satellite data, this study were also meteorological data such as temperature and precipitation from different meteorological stations. This data that covers from year 1950 up to 2014 were obtained from the Bangladesh Meteorological Station (BMD). This data is freely available for end users and very simple to be used for analysis purposes.
4. This study was carried out in focusing on total Bangladesh, since there is an occurrence of drought once in every 2.5 years (Adnan, 1993; Hossain, 1990; Murad and Islam, 2011).

### **1.5 Significance of Study**

Generally, due to global warming, species and habitat of flora and fauna have been declined and chances for ecosystem to adapt the changes naturally have been diminished. The variability in climate system will influence imperative divisions in Bangladesh. Additionally, increasing of temperature would increase evaporation and transpiration, hence, it could lead to the risk of the increasing hydrological and agricultural drought as the temperature rises. Therefore, it is necessary to understand the trend of water-related disaster such as drought with respect recent variable climate and land use/land cover scenario. Drought causes the agricultural planning in Bangladesh to be distracted and alters the future food security production.

During monsoon, the available rainfall may fulfil the crop water demand, but during the dry season the evapotranspiration exceeds the amount of rainfall by an amount of more than 0.5 times the rainfall. Therefore, water deficit exists in the dry months of the year, as the demand is higher than the total rainfall (Paul, 1995). Thus, the groundwater is used as one of the alternative sources for soil moisture supply for agricultural activities in dry season in several parts of this country (Habiba *et al.*, 2010). This ground water-based intensive irrigation for practice helps to reduce the severity of soil moisture deficit but continuous high pumping of groundwater leads to



the overexploitation and groundwater depletion (Bangladesh Bureau of Statistics (BBS), 2005).

A potential threat of drought is expected in Bangladesh since global temperature is increasing, evapotranspiration is exceeding the amount of rainfall in pre-monsoon, and underground water is declining very rapidly. Therefore, it is necessary to develop an efficient drought monitoring system for Bangladesh using freely available satellite data with usable spatial and temporal resolution since only climate data (such as rainfall) is unable to detect drought in Bangladesh effectively. However, very little effort has been made so far using satellite data and effective drought index for the detection of drought in Bangladesh due to several reasons. Therefore, it is expected that the outcome of the study will provide useful information in relation to drought, its recent trend, and spatial as well as temporal distribution in Bangladesh. This long-term observation (more than a decade) can benefit different stakeholders such as farmers, government and planner to understand the drought problem more accurately. Government can use this method to develop a systematic drought monitoring system over this region. Additionally, scientist who is interested to study drought in this region may also be benefitted as this study provides a comprehensive outcome about the detection of drought using satellite and its relationship with several environmental and climatic parameters as well as field data.

## **1.6 Study Area**

Bangladesh is located on the northern coast of the Bay of Bengal, surrounded by India with small common border with Myanmar in the Southeast (Figure 1.1). Climatically, Bangladesh region is located at Tropic of Cancer, so it has tropical monsoon climate that can be categorized by heavy seasonal rainfall, high temperature and high humidity. Three distinct seasons can be recognized in the area from climatic point of view: (1) the pre-monsoon dry winter season from December to February, (2) the pre-monsoon hot summer season from March to May, and (3) the rainy monsoon season which lasts from June to October (Shahid and Hazarika,

2010). January is known as the coolest month with temperature averaging near 26°C and April with the warmest with temperature from 32°C to 36°C.

Climatically, the study area belongs to dry humid zone with annual average rainfall vary between 1,400 and 1,650 mm, among which almost 83% rainfall occur in monsoon (June to October). Rainfall in the area varies widely from year to year. For example, the rainfall recorded at Rajshahi in 1997 was 2,062 mm, but in 1992 it was 798 mm only. Average temperature in the region ranges from 25°C to 35°C in the hottest season and 9°C to 15°C in the coolest season. In summer, some of the hottest days experience a temperature of about 42°C or even more. In winter it falls to about 5°C. So the region experiences extremes that are clearly in contrast to the climatic condition of the rest of the country (Banglapedia, 2003).

Bangladesh is subject to devastating cyclones, originating from the Bay of Bengal, in the periods of April to May and September to November. Other natural calamities such as floods, drought, tornadoes and tidal bores affect the country almost every year. Bangladesh experiences drought severity when the rainfall distribution is normally low, which can affect crop production and vegetation growth. Water deficit has become a major problem in Bangladesh during the post to pre-monsoon season (November to March). The inland and coastal zone in southwest region is connected to Ganges River which suffers from water shortages during dry season and also problem related to arsenic contamination.

Drought plays an important role for agricultural productivity in several physiographic areas in Bangladesh such as Piedmont regions, level and high Barind Tracts areas and Madhupur Tract areas during the winter season. This causes a big challenge to agriculture labourers and others considering the fact that country's main economic activity is agriculture, which is overwhelmingly, dependent on timely onset, duration, and distribution of the rainfall (Gebrehiwot *et al.*, 2010). Drought usually occur in Kharif (March to June) which is also called pre-monsoon, and Rabi (October to February) that is also called post-monsoon season, and affect the agricultural product such as Aman, Aus and Boro rice cultivation.



**Figure 1.1** Map of Bangladesh

## 1.7 Chapter Organization

There are six chapters in this thesis which are i) introduction of the study, ii) literature review, iii) methodology, iv) result and analysis, v) discussion, vi) conclusion and recommendation.

Chapter one describes the background of research based on topics related to this study. This chapter include with problem statement, aim and objective, scope of study, significance of study and study area.

Chapter two briefly describes the drought and its definition, theory and concepts of drought indices including meteorological and satellite data based drought indices. This chapter also describes the concept of remote sensing for drought monitoring, their capabilities, satellite application, the advantages and disadvantages of remote sensing data based drought estimation technique. Moreover, the indices that are suitable for drought monitoring in this study were also introduced in this chapter based on existing published literature including journal articles, thesis and worldwide web.

Chapter three describes the research methodology where all the processing steps are explained in detailed. The result and the analysis of the study are presented in chapter four. Results of this study are presented with help of diagrams and explanation in order to enable reader to have better understanding about this research. The analysis of the study is illustrated by the qualitative and quantitative assessment techniques.

A brief discussion about this study is presented in Chapter five. In this chapter an assessment was made to investigate whether the overall research objective of this study has been achieved or not. This chapter also summarizes the outcome this research with respect to other published research works.

The last chapter in this study is chapter six where an overall conclusion of the study is presented. This chapter also summarizes the research findings with respect to research limitations. Several recommendations are also made in this chapter for the improvement of the future research.

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