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Research Article

Study on the aridity in the north-western (NW) part of Bangladesh through combined application of remote sensing, GIS and geophysical data

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Abstract

The present study deals with the conceptual development of a RS-GIS based Information and Decision Support System (IDSS) in view of geo-environmental monitoring of land surface features, functionalities and conditioning principally of agricultural lands of normal-semiarid categories. System operation involves necessary functional blocks for application of remote sensing data supplemented with climatic, geophysical and groundwater data and other ancillary information. Two adjacent but physiographically contrasted zones of (i) semi-arid Barind Tract and (ii) Ganges flood plain situated in the north-western part of Bangladesh have been studied and possible mechanisms of geo-environmental variability in the two sites have been investigated. Spatial data preparation procedure includes co-registration and georeferencing of each data layer against a reference layer in a platform of RS-GIS. Individual GIS thematic data layers have been generated for each of the data. Different biophysical parameter products have been generated through processing of Landsat TM and SPOT HRV data with conventional data and maps. Analysis of annual rainfall data shows substantially higher rainfall in both the study sites as compared to that of a typical semiarid region. Geospatial analysis and subsequent interpretation of generated RS-GIS multilayer inputs results in important findings, e.g., (i) slower subsurface infiltration due to relatively thick impermeable clayey top layer in Barind Tract, (ii) quicker surface runoff due to relatively high surface elevation, steeper slope and lower drainage density in the Barind Tract, (iii) uneven temporal distribution of annual rainfall (almost 80% within July-September), increasing runoff limiting rainwater for infiltration and (iv) increasing ground water exploitation and expansion of irrigated area consistent with (v) increasing trend of GWL depth. Biophysical characterization of satellite data applying radiative transfer analysis has been performed. Coupling of satellite derived vegetation cover information to rainfall amount depicts higher sensitivity of Barind Tract as compared to that of floodplain area. Derived surface albedo and surface temperature manifest quite contrasted seasonal behavior for different physiographic land units in the two study sites.

Keywords: LANDSAT TM, Albedo, Semi-arid Barind Tract, Vegetation cover, Spectral response.

Introduction

Land surface processes have become a great concern in the context of global change and increased natural hazards over the world (ADB, 2015; Houghton et al., 1990; Jager and Ferguson, 1991). Lands surface and atmosphere are subjected to continuous changes over time through land use modification and environmental degradation (Yang et al., 2020; Sinha, 1996; Dickinson, 1983). Such changes either human induced or natural have significant impacts on the world's climatic processes (IPCC, 2019; Ülker et al., 2018; Charney, 1975; Charney et al., 1977; William and Robert, 1982; Stohlgren et al., 1998). The phenomena like flooding, drought, cyclone, river erosion, etc. becoming increasingly hazardous. In one part, impacts of human activities due to exploitation of the earth's natural resources, various urban and industrial activities and on the other part, climatic and geophysical variability act interactively and thereby, cause continuous modifications on the ecological and environmental condition of a given geographical region. The scale, intensity and persistence with which human activities have affected the environment, the composition of the atmosphere as well as local and regional climate is a subject of extensive research giving rise to numerous publications (e.g., IPCC, 2019; Claussen et al., 2001; Lynn et al., 1995; Henderson-Sellers, 1995). Various studies provide evidences that fragmentation of the landscape can affect convective flow regimes and rainfall patterns locally and globally (e.g., Chase et al., 2000; Baidya and Avissar, 2002).

Arid and semi-arid regions cover a large portion of the total land areas in the world (about 12.5 per cent) where water deficiency is a common event. In arid land areas, rainfall is generally insufficient (below 200mm) but is enough to support pastoral activity. Rainfall in semi-arid land areas is relatively low and the amount generally ranges from 200 to 600 mm (Colwell, 1983). Such land areas generally exhibit high surface albedo, low soil moisture (He, et al., 2019), and relatively high temperature gradient between day and night with relatively low vegetation density.

The changes in earth's radiative budget due to changes in ecological and environmental conditions of a given area affect the whole ecosystem. Event like emission or removal of CO_2 to the atmosphere can be resulted in due to changes in land surface and thus, Earth's radiation balance can be changed. Changes in land surface can also change the radiation balance by altering the Earth's surface albedo. The urgent need for a proper understanding of the Earth system particularly of semi-arid land processes offers a major scientific challenge with a concern for intensified and accelerated research in this direction and requires a potential tool for regular and repeated observation of these phenomena over large areas.

Characterization of trends in semi-arid land ecosystem requires repeated monitoring of the area on a regular basis. The functional environment types as determined by their geology, landform and surface drainage, each type characterized by certain properties of soil and vegetation cover. The development of remote sensing techniques significantly improves the monitoring of land surface processes over large area (Reiji Kimura and Masao Moriyama, 2019; Verstraete and Pinty, 1991; Jacob et al., 2002).

The present paper deals with an investigation on the phenomena of aridity in the Barind tract area situated in the north-western part of Bangladesh in contrast to the condition in adjacent flood plain areas using remote sensing supplemented by meteorological and geophysical data. All the data have been analysed in the Geographic Information System (GIS) platform.

Physics of the Problem

The earth's biosphere and atmosphere together form a closely coupled dynamic system in which interaction between the soil, vegetation and atmosphere takes place through the exchange of mass and energy (Chen et al., 2015; Verstraete and Pinty, 1991; Dickinson, 1983; Pitman, 2003). Various physical processes are involved in such transfer mechanisms over an area (Jacob et al., 2002). Water is distributed through the process precipitation to the soil, where a portion of the water is infiltrated into the soil and the excess water causes run-off. Moreover, water in the soil and vegetation is evapo-transpirated to the atmosphere in the form of latent heat (energy). The change in any one component of the soil-vegetation-atmosphere (SVA) interface system affects the other components of the system. Rainfall, incident solar radiation, albedo, surface temperature, potential evapotranspiration, available surface water over the region, soil moisture, ground water condition are the most important components making significant contribution to the radiation and water budget of the area.

Water is one of the most essential components for sustaining live. Natural water cycle consists of continuous movement of water between the earth and the atmosphere. Water vapor from water and land surfaces circulates through the atmosphere and falls as rain or snow. When it reaches the earth, water either flows into streams and then into oceans or lakes, or it enters, or infiltrates the soil. Some water becomes soil moisture, which may evaporate directly or move up through the roots of plants and be released by leaves. Some water percolates downward, accumulating in the so-called zone of saturation to form the groundwater reservoir, the upper surface of which is the water table. Under natural conditions, the water table rises in response to inflowing water and then declines as water drains into natural outlets such as wells and springs.

The growing demand for water and the anticipated impacts of climate change necessitate a more reliable assessment of ecosystem components, water availability for proper planning and management. Climatic factors along with geographical context determine the amount and characteristics of annual rainfall over a given area. While, factors e.g., geo-environmental setting, rainfall characteristics, surface characteristics like drainage pattern, elevation, slope and topographic characteristics along with soil lithological properties and subsurface reservoir condition etc. collectively govern the partitioning of intercepted rainfall water into surface runoff, infiltration and surface water components. Water losses through the processes of evaporation and evapotranspiration are determined by the soil moisture content, amount of input solar radiation, ambient temperature, air humidity, vegetation cover, subsurface water reservoir condition etc. As such it is crucial to consider all the above-mentioned factors during analysis to understand the water or aridity condition of a given geographical area.

Description of the Study Area

The study area is geographically located in the north-western part of Bangladesh as shown in figure 1. Two adjacent study sites having different hydro-environmental conditions have been selected from two land categories.

The study site 1 is situated in the relatively dry Barind tract area. Barind Tract is the largest Pleistocene physiographic unit of the Bengal basin (Rashid et al., 2015) covering an area of about 7,770 sq km. This unit lies roughly between latitudes 24°20´N and 25°35´N and longitudes 88°20´E and 89°30´E. This area is characterized as a semi-arid environment (Riches and Maritime, 2008; Islam and Kanungoe, 2005; with relatively low vegetation and soil moisture content during dry period and higher vegetation cover and soil moisture content during wet period (Rahman et al., 2007).

The study site 2 is situated in the flood plain areas of the river Ganges, Mahananda and Atrai. In contrast to study site 1, relatively higher vegetation cover and soil moisture content characterize study site 2 during both wet and dry periods. The soils over these areas are generally classified into loam, sandy loam and clay. The study area has tropical monsoon climate like whole area of the country. Three most prominent seasons of the year in this area are winter, summer and monsoon are prominent. Winter season extends from November to February during which weather is relatively cool and almost rainless. Finally, the monsoon or rainy season extends from June to October, which is warm and humid. This period accounts for 80 per cent of the total annual rainfall.

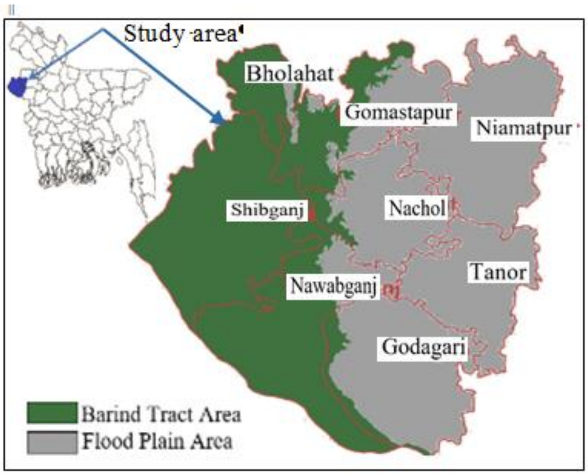

Figure 1: Location map of the study area situating in the NW part of Bangladesh consisting of two adjacent study sites: site 1 in the relatively dry Barind tract area and study site 2 in the flood plain areas of the river Ganges, Mahananda and Atrai.

Table 1. Rainfall values averaged over the last 30 years and last 10 years period in different Upazilas under the present study.

Upazila	Rainfall (mm) Averaged over	
	1966-1995 (30 years)	1986-1995 (10 years)
Tanor	1428	1518
Nachol	1424	1483
Niamatpur	1686	1669
Godagari	1378	1534
Shibganj	1520	1514
Nawabganj	--	1357
Bholahat	1464	1657

The land use of the area is mainly determined by the land elevation in relation to flooding during monsoon season and by the available soil moisture content in the dry season (Rahman et al., 2003; 2007). The Barind area is mainly a single crop area of transplanted Aman rice. During dry period, winter rice is cultivated in some of the places over this area by providing irrigation facilities. Thereby, exploitation of ground water has also been increased. The floodplain areas are mainly used as single and double cropped land with some areas as triple cropped.

(i) *Rainfall Variability*

Figure 2 shows the variation of annual rainfall over the period 1965 to 1995 in four different Upazilas. Two areas are situated in the Barind Tract (semi-arid region) and another two are situated in the flood plain areas. Annual rainfall averaged over the thirty years period from 1966 to 1995 are about 142.8 cm and 142.4 cm respectively in the Tanor and Nachol Upazilas (both areas in the semiarid Barind Tract) and are about 151.8 and 148.3 cm respectively for a period averaged from 1985 to 1995 (ten years). Average annual rainfall of about 151.4 cm and 135.7 cm respectively have been noticed for the Shibganj and Nawabganj Upazilas under the flood plain area for an average from 1985 to 1995 (ten years). Annual average rainfall about 152.0 cm has been noticed for Shibganj Upazila for an average from 1966 to 1995 (thirty years). Rainfall is substantially higher in all the four areas as compared to rainfall over a typical semi-arid area that usually ranges from 20.0 to 60.0 cm (Colwell, 1983). No significant difference is noticed between rainfall characteristics of the two physiographically contrasted zones particularly in terms of amount of annual rainfall. From the figure it is evident that apart from April, rainfall gradually increases and reaches to a peak around June/July. As rainfall continues, surface water flows down slope toward an established channel or stream.

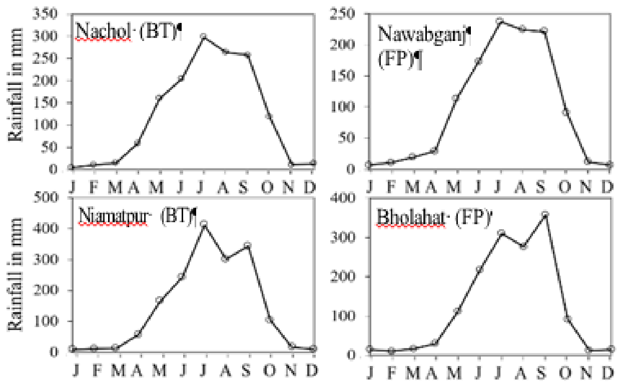

Figure 2: Variation of monthly rainfall averaged over five years period from 1991 to 1995 in the Nachol and Niamatpur corresponding to BT and Bholahat and Nawabganj Upazilas corresponding to floodplain areas. Here, BT and FP refer to Barind Tract and Flood Plain areas respectively.

(ii) Incident Solar Radiation

Incoming solar, or shortwave, radiation is an integral part of the surface energy balance and can often be the largest energy source at the earth's surface. The amount of energy available at the surface plays a central role in determining the partitioning among sensible, latent, and conductive energy fluxes at the surface. Similarly, the hydrologic budget is heavily influenced by solar radiation as evaporation is governed by net radiation. Furthermore, biological activity such as photosynthesis, and in turn carbon cycling, is dependent on the amount and type (whether direct or diffuse) of solar radiation (Monteith 1972).

Figure 3a shows the variation pattern of monthly mean incident solar radiation recorded at the meteorological station at Bogra situated just near to the study sites averaged over the period 1991 to 1995. Data have been collected from the Bangladesh Meteorological Department (BMD).

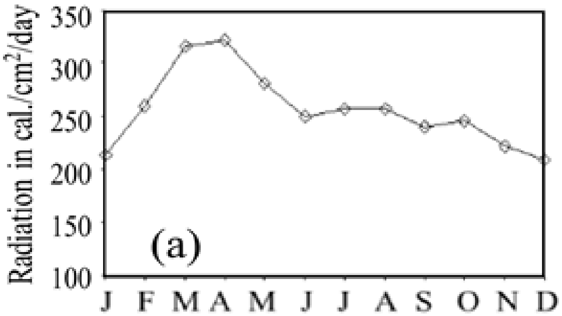

Figure 3a: Monthly variation averaged over five years period from 1991 to 1995 of (a) incident solar radiation. Data Source: Bangladesh Meteorological Department (BMD).

The amount of incident solar radiation follows an increasing trend from January and attains its maximum value during March-April period. Apart from April, amount of incident radiation decreases till it attains its minimum value in December.

(iii) Temperature Variability

Figure 3b shows the monthly variation of temperature in Degree-Centigrade averaged over five years period from 1991 to 1995 in the study area. Data Source: Bangladesh Meteorological Department (BMD). In general, relatively lower temperature is generally observed during December-January and relatively high temperature is observed during April-October

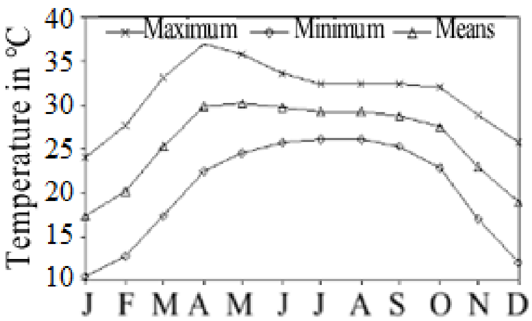

Figure 3b. Monthly variation of temperature in Degree-Centigrade averaged over five years period from 1991 to 1995. Data Source: Bangladesh Meteorological Department (BMD).

Experimental approach

Data used

Table 2 provides a list of data sets used for the present study. Data includes different satellite data, climatic and geophysical data, thematic maps, field-measured data and other relevant published information. Rainfall data have been collected from the Bangladesh Department of Meteorology (BMD). Information on the seasonal fluctuation of groundwater has been obtained by the application of geophysical prospecting particularly electrical and magnetic survey methods.

Table 2. List of satellite data sets used for the present study.

Satellite/Sensor	Date
Landsat TM	January 25, 2011, April 2, 2010; October 24, 2009
SPOT HRV	October 25, 2000
NOAA AVHRR	October 20, 2007

Methodology

Figure 4 shows the functional block of methodology adopted for the present work. All the digital images were geometrically corrected and geo-referenced to ensure proper mutual registration and geographic positioning. Digital numbers (DN) of each band (band 1 to 5 and band 7) in TM images have been converted into the at-satellite radiance ($mWcm^{-2}sr^{-1}\mu m^{-1}$) and reflectance (Sánchez-Aparicio, 2020; Hill and Strum, 1991; Tassan, 1992).

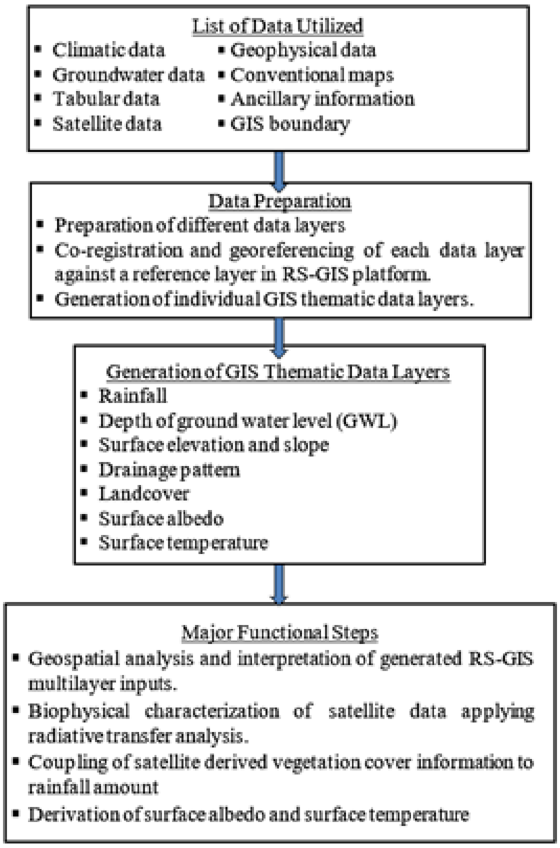

Figure 4. Functional block of planned methodology

The images have been corrected for atmospheric effects particularly for gaseous absorption due to water vapor, ozone, oxygen and carbon dioxide and scattering due to molecules and aerosols using SMAC (Rahman and Dedieu, 1994) and thereby, the at-surface reflectances have been obtained from Landsat TM multi-spectral data. Surface temperature was derived following the procedure developed by Markham and Barker (1986; 1987) using thermal infrared data of Landsat TM (band 6). In the present work, a supervised method of classification based on maximum likelihood algorithm available in the ERDAS Imagine software (ERDAS,

1997) has been employed to separate individual class elements in the digital images. This form of classification starts with the establishment of training samples, which are areas that are assumed or verified to be of a particular type or class. The classification algorithms then 'sort' the pixels in the image accordingly using a given statistical procedure (e.g., maximum likelihood algorithm as in the present case). A detailed description of the used classification technique based on maximum likelihood algorithm can be found in ERDAS (1997). Area-wise spatial statistics on different thematic parameters have been obtained using the GIS based analysis. GPS (Global Positioning System) based ground survey has been conducted to verify and rectify the results of digital interpretation.

Results and discussions

The phenomenon of aridity is defined by a shortage of moisture based on the average climatic conditions in a given region (Maliva and Missimer 2012; Agnew and Anderson 1992). In the recent time, the climatic aridity, dryness, and drought events are becoming a significant socio-environmental problem, and are affecting both ecosystem and the livelihood of populations in many regions, and especially in developing nations (Nyamtseren, Feng and Deo, 2018).

Geo-Environmental Characterization of the Area

Barind tract belongs to an old alluvial formation, which is usually composed of massive argillaceous beds of pale reddish brown, often turns yellowish on weathering; kankar and pisolitic ferruginous concretions occur throughout the mass.

(i) Slope and Terrain Characteristics

Landscape of Barind Tract area comprises of broadly dissected terrace, closely dissected terrace and level, intermittently terrace including wide spectrum of land categories like highland, lowland etc. (Rahman et al., 2007). Major portion of Barind Tract are under broadly and closely dissected terrace. The slope related to the area of a drainage basin (Norbert and Rothman, 2002) is one of the major factors affecting the partitioning of rainfall water through hydrological activities like overland flow, runoff volume of rainfall water and infiltration etc. (Gamesby, 2018). Particularly, the channel length and effective channel slope (Norbert and Rothman, 2002; Rahman et al., 2004) are important parameters in determining the response time of a watershed to precipitation events of given frequency. Steep slopes tend to result in shorter response time and increase the discharge while flat slopes tend to result in longer response time and reduce the discharge which compliances the streaming water principle, that is to flow the greatest downward slope (Riazanoff et al., 1992).

The Barind tract area is represented by a series of fault blocks appears as a terrace landscape. In general, the tract is hilly in the western side and dissected by narrow usually streamless valleys, there it is up-warped and slopes downwards both to the west and east (Rahman et al., 2003). Narrow valleys with slope variations dissect hilly areas. The maximum and minimum elevation above mean sea level is 21 meter in the northern side of the study area and 40 meter in north-eastern high Barind area respectively (Haque, 1997). In the east, the tract is nearly level, un-dissected, slightly titled to the south and passes under the adjoining flood plain sediments.

(ii) Analysis of Drainage Characteristics

Drainage network of Barind Tract and flood plain areas have been constructed from LANDSAT TM image of January 25, 2011 and SPOT HRV image of October 25, 2000. In both images, drainage areas exhibit comparatively dark and distinct appearances from the adjacent areas due to relatively high moisture level of the drainage roots and landform / terrain variations (Norton et al., 1979).

Figure 4a shows the contour map of the study area overlaid with Landsat TM image of January 25, 2011. The landscapes of the study area include gentle slope hill shape, hummocky and river alluvium plain land. The surface drainage network of the area is mainly provided by tributaries, distributaries with numerous canals and channels along with a series of rivers namely the Ganges, Mahananda and Atrai.

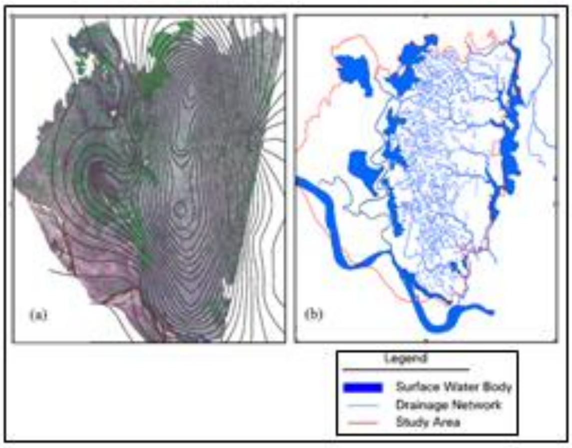

Figure 5. (a) Contour map of the study area overlaid with Landsat TM image of January 25, 2011; (b) Drainage pattern map of the study area as derived from Landsat TM and SPOT HRV data.

Water is generally drained into the river, cannel and local water reservoirs through foot slopes of hill and hummocky lands. Drainage network of Barind Tract comprises of tributaries, distributaries, numerous canals and channels, which passes through the valleys and adjoining low lands.

Figure 5b shows the drainage pattern map of the study area as prepared from Landsat TM and SPOT HRV data. The hierarchical lines reveal the drainage network of terrace landscape. The crest/ridge of up-warped surface with downward slope on both sides follows a line through broadly dissected terrace and closely dissected terrace. The ridge is undulating in nature and seems to be a series of hill shapes. Drainage networks in elevated Barind Tract starts from this ridge and distribute only intercepted rainfall water among the linked basins. Barind Tract area is never flooded and hence rainfall water is the only source of surface as well as runoff water. In reference to the surface water movement the drainage network of Barind Tract is unidirectional and distributary and the direction of distribution is towards basins.

In fact, the slope and elevation of the surface, soil type, rainfall characteristics and properties of the underlying surface largely influence the pattern and density of drainage of an area (Gamesby, 2018; King, 1984). The top layer of this elevated hill shape Barind Tract is a thick clay layer with relatively low permeability rate. Rainfall in this area has an uneven temporal distribution pattern over different seasons in a year.

In addition to the influence of underlain clay layer (Morisawa, 1968) and climatic regime (Small 1978) another parameter slope angle having spatial variation has clear influence on drainage network characterization like drainage branching, traveling lengths etc. A high drainage density associates a highly dissected drainage basin with a relatively prompt hydrologic response to rainfall events, while a low drainage density generally reflects a poorly drained basin with a slow hydrologic response (Luoto, 2007; Melton, 1957). In Barind Tract area dense drainage branching are observed at west and south-western side and slopes are also comparatively steep in these areas. Less drainage branching is observed at north, northeast and eastern side where slopes are comparatively gentle. Formation of drainage branching, nature and length of individual branch and their nodding with the next feeding line are different in different areas depending on surface topology and climatic regime (Small 1978). If we consider the ridge i.e., the starting point as a reference then it is found that the drainage network of eastern and south-eastern side travels more than the western part. Topology of eastern side followed by level, intermittently flooded terrace with relatively lower elevation angle.

Relatively steep slopes are found in small parts of Nawabganj, Tanor and Nachol Upazilas that direct surface drainage flow towards southwest direction and make easy passages for accelerated runoff for a given land use pattern under a given intensity of climatic variables. Long narrow watersheds generally offer lower peak discharges than do fan or pear-shaped basins. Soil properties like soil texture, structure, vegetation cover, biologic structures, initial soil moisture and surface condition define the infiltration capacity of a particular soil (Gamesby, 2018; Morisawa, 1968) which also influences surface runoff. Generally, surface, underlain by clay layer has a high drainage density (Morisawa, 1968). In Barind Tract up-warped surface with downward slope on both sides of crests followed by a thick clay layer with poor permeability high precipitation rate and surface slope helps expeditious and heavy drainage and slows down the infiltration rate.

(iii) Analysis of Lithological Properties

Rainfall water after intercepted by the surface undergoes processes like infiltration, runoff etc. Part of infiltrated water goes to subsurface storage. Figure 5 shows the Lithological map of the study area. Subsurface configuration of the study area has been inferred from geophysical data. Height of individual aquifer has been inferred from bore-logs information provided by Barind Multipurpose Development Authority (BMDA) (Khaleque, 1994; Haque, 1997). Scattered locations of bore-logs and corresponding lithological information have been preserved and presented as point data. From these randomized point data, a continuous (Raster) spatial map has been generated by the 'create surface' options provided by ERDAS Imagine Software.

Soil lithology is one of the important factors governing the hydrological movement of water in a ground aquifer system during both charging and discharging cycle. Borehole information of the study area suggests the existence of four compositional layers such as top clayey, fine sand, composite sand and black plastic clay with varying thickness. Information provides evidences of the presence of a relatively impermeable clayey layer at the top surface over the Barind Tract area. Table 3a provides the infiltration rates for different soils.

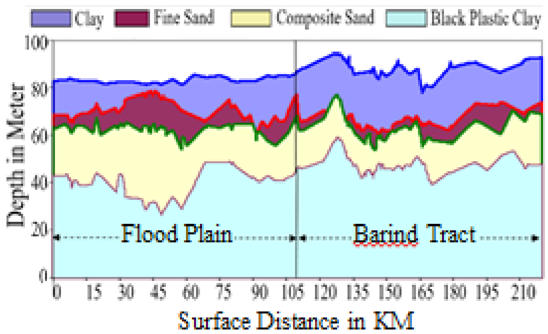

Figure 6: Lithological map of the study area. Subsurface configuration of the study area has been inferred from geophysical data (Data source: Barind Multipurpose Development Authority (BMDA) (Khaleque, 1994; Haque, 1997).

A long straight profile (219km) was drawn over the created lithological spatial map covering both Barind Tract and Flood alluvial plain land to study the variation of lithology. During profile area selection maximum attention has been paid to include area with maximum lithological variations. Location of each intersection point and its corresponding distance and lithological information such as compositional variation were collected and have been shown in figure 6. Compositional arrangement and thickness of sub-surface layers having different hydro-geological properties indicate the occurrence of water extraction and availability (Uwiringiyimana, et al. 2019; Dunne and Leopold, 1978).

Table 3a. Infiltration rates for different soils

Soil type	Infiltration rates mm/hr
Clay	0-4
Silt	2-8
Sand	3-12

The presence of such a low permeable clayey layer slows down the infiltration rate significantly. Maximum and minimum variations of thickness of top clay layer over Barind Tract area are nearly 29m and 10m respectively. The average of this top clay layer thickness variation is nearly 21m. And the variation of top clay layer over flood plain area is nearly 13m.

Under the poor permeable top clayey layer combined formation of fine sand layer with fine grain size and the composite sandy layer with mixed grain size is favorable for ground water reservoir and also for exploration. The thickness of the composite sandy layer directly influences the ground water storage quality. From figure 6 it is seen that thickness of ground water reservoir is relatively poor in Barind Tract area. Storage capacity of Barind Tract ranges from 1 to 8 except some scattered areas and in flood plain areas ranges from 9 to 19.

Table 3b. Values of permeability and transmissivity values at different locations in the study area according to the data provided by BWDB obtained through aquifer test analysis of different Upazilas (Administrative unit) of Barind Tract (Hoque, 1997) along with Upazila-wise areas under Barind Tract and floodplain.

Upazila	Area (hectare) under		SWL from Ground Surface (m)	Permeability K (m/day)	Transmissivity T (m2/day)
	Barind Tract	Flood plain			
Godagari	40251 (90.2%)	4371 (9.8%)	6.88	15-18	600
Nawabganj	7283 (15.6%)	39469 (84.4%)	4.67	57	1200
Gomastapur	15304 (48%)	16572 (52%)	6.23	17	300
Shibganj	0 (0%)	52815 (100%)	7.24	25	700
Niamatpur	4434 (100%)	0 (0%)	9.40	14	400
Nachol	25584 (89.3%)	3075 (10.7%)	11.60	12	224

The thickness of quantifying zone of aquifer is comparatively thin in Barind Tract with thick low permeable elevated undulating top clayey layer which prompt the surface runoff and its slippery nature in moist condition also protect the infiltration rate. Eventually, the combined effects of high rainfall within a short time period and the presence of relatively impermeable soil layer at the top surface results in relatively lower charging of the groundwater reservoirs. Multi-fold mechanisms like high-rate precipitation, comparatively thick clay layer with low permeability rate, low storage capacity and elevation apparently controlling the hydro-environment of Barind Tract area (Rahman et al., 2003). Table 3b provides values of the geophysical parameters characterizing hydrological properties of the soil particularly of permeability and transmissivity corresponding to different Upazilas under the present study.

Analysis of Hydro-Environmental Impacts

Climatic characteristics of this area as conditioned principally by incident solar radiation, rainfall and temperature etc. have significant impacts on the SVA system influencing the water and energy transfer processes. Most of these parameters have seasonal and long-term variations. Rainfall characteristics particularly (i) Intensity (rate of rainfall); (ii) Duration; (iii) Frequency (statistical probability of how often rainfall occurs); and (iv) Temporal distribution are relatively important in determining surface runoff and infiltration in a given geographical area.

Ecosystem of the study area undergoes dynamic changes over time and space due to interaction of seasonally varying atmospheric temperature, precipitation and surface radiation with various land types. The observed changes in the hydro-environmental condition of the area can be broadly classified into two main categories (i) periodic changes related to the seasonal variation of vegetation cover, soil moisture, rainfall and temperature and (ii) non-periodic changes related to variations in land use, land cover, soil properties, rainfall and temperature changes over relatively long period of time. Table 4 provides a list of Upazila-wise distribution of different surface features for the two study sites as derived from Landsat TM images of April 2, 2010 and October 24, 2009 representing dry and wet periods respectively.

In the study area, water is generally provided to the soil layer through rainfall, ground water irrigation and to some extent through seepage from adjacent water bodies. While, water reaching the surface is returned to the atmosphere as vapor through the process of evapotranspiration that ultimately governs the loss of surface water and soil moisture in a given geographical area. Various factors influence the rate of moisture losses through evapotranspiration over an area of which surface temperature; soil moisture content and air humidity are considered to be mostly important. In the study area, water is generally provided to the soil layer through rainfall, ground water irrigation and to some extent through seepage from adjacent water bodies.

During rainy season, soil receives adequate moisture through precipitation. As the temperature during November to January time period is relatively low (figure 3a), the evaporation rate remains at its minimum value and thereby, the surface layer retains good amount of moisture. Under normal condition of sub-surface reserve just a short period after monsoon, surface layer absorbs adequate water from the sub-surface layer. During this period rainfed Aman rice cultivated in most of the areas of Barind Tract. The presence of vegetation during Aman season helps soil layer in maintaining soil moisture to a satisfactory level and tends to keep the surface temperature low enough to maintain the balance.

A gradual rise of surface temperature apart from January results in a gradual increase of evaporation. After harvesting of Aman rice in December, soil becomes exposed to direct sunlight. But as the air temperature is relatively low (figure 3b) at that time, the moisture loss due to evaporation is also low. Such a condition is maintained up to February or beginning of March.

At the end of March, the temperature begins to rise up and precipitation remains at its minimum level. Such an increase in surface temperature eventually increases the evaporation rate and thereby, causes soil to dry up and surface water to decrease rapidly. The maximum rate of evaporation is generally observed during April/May when surface temperature generally attains its maximum value.

Here it is to be mentioned a semiarid region is generally characterized by a mean annual precipitation between 20.0 and 70.0 cm (Gallart et al., 2002). While the areas under the present study generally receive an average annual rainfall higher than 130.0 cm (table 1) which is much higher than typical annual rainfall as documented by various researchers (Gallart et al., 2002)

i) Variation of Surface Water Coverages

Among various sources, surface water is relatively cheaper and can be utilized in abundance without creating any major drawbacks to the environment and ecology in a given geographic area. Surface water reservoirs hold water for future usages. Charging of ground water reservoirs is also an important function of surface reservoirs. Amount of surface water in a geographical area at a given time is dependent on the characteristics of the reservoirs particularly on the water holding capacity of the reservoir, its position above sea level, on the surface characteristics (topographic characteristics, drainage pattern, soil properties etc.) of the adjacent areas and on the magnitude and temporal distribution of annual rainfall.

During July to September when rainfall amount largely exceeds the infiltration rate, a significant portion of the rainwater drains into the river through the process of surface run off. As a result, river water level generally increases during this period and attains their peak value around July or August (Azam and Rahman, 2004).

Efficiency of a given area to convert intercepted rainfall water into either (i) surface water or (ii) ground water by holding it for future usage under a given amount of annual precipitation is extremely important. Elevation and topographic characteristics of an area principally determines the capacity to hold the intercepted rainfall. Figure 7 shows the fluctuation of surface water over the study area during two characteristically different seasons, namely dry and wet seasons. Information on seasonal water areas have been obtained through classification of Landsat TM images.

In the flood plain areas, a significant variation in surface water areas is found between dry and wet periods. During wet season, water area increases appreciably in this area due to submersion of relatively depressed land areas. Excessive rainfall often causes flooding of the flood plain areas. In Shibganj Upazila (flood plain dominated areas) situated in the flood plain area, change in surface water areas is very much significant between wet and dry periods. An increase in water area of about 23 per cent of the total Upazila area is noticed under an annual precipitation of 146.3 cm which is significant.

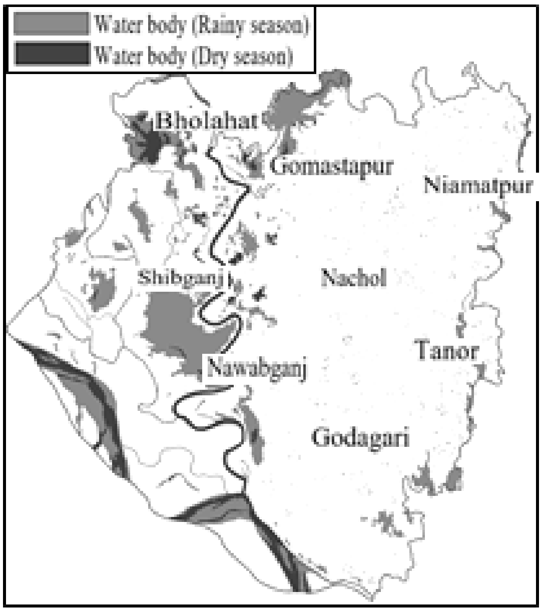

Figure 7: Spatial distribution of surface water over the study area during summer (dry) and rainy (wet) season as obtained through classification of Landsat TM images of April 2, 2010 and October 24, 2009 respectively.

Table 4. Upazila-wise area of different surface features in rainy (wet) and summer (dry) seasons as derived from multi-temporal Landsat TM images of October 24, 2009 and April 2, 2010.

Name of Upazila	Season	Area (hectare) corresponds to Bare soil	Water	Mango orchard	Crop	Other
Nachol	Summer	24,862	359	490	1,713	1,079
	Rainy	5,398	731		20,913	
Niamatpur*	Summer	35,248	125	--	2,960	1,579
	Rainy	5,532	75		25,215	
Tanor*	Summer	17,663	20	--	2,086	633
	Rainy	3,360	62		11,577	
Godagari*	Summer	37,414	881	972	3,808	909
	Rainy	13,990	2,077	"	22,152	
Nawabganj	Summer	33,319	3,026	4,255	5,589	359
	Rainy	27,282	8,644	"	6,082	
Bholahat	Summer	4,658	1,190	2,433	4,363	--
	Rainy	3,138	1,322	"	5,645	
Shibganj	Summer	29,998	1,705	14,635	7,403	--
	Rainy	31,417	4,681	"	2,642	

However, Barind Tract area is not affected by floodwater due to its relatively high elevation and topography. Surface does not hold rain water except scattered distributed ponds over the area. While major part of the rainfall water moves away to other regions through surface runoff. As such no significant changes in water areas are noticed in Barind Tract area between wet and dry periods. In Nachol Upazila under Barind Tract area, the change in surface water area is almost insignificant between wet and dry periods. Increase in water area of only about 2.5 per cent of the total Upazila area is noticed in wet period as compared to that of dry period under an annual precipitation amount of 155.3 cm. Thus, conversion efficiency of flood plain area appears to be much higher than that of Barind Tract area.

Land characteristics particularly elevation and topography of the area seems to play a determining role in the variation of surface water area. Rainfall generally acts as a unique source for charging ground water reservoirs and surface water bodies like river, pond etc. as well. Here it should be pointed out that both the study sites receive comparable amount of annual rainfall. However, due to variation in land characteristics of Barind Tract and flood plain areas, the water holding capacity of flood plain areas is much higher than that of Barind Tract area. In these areas, surface water generally serves a two-fold purpose. Firstly, it provides water for domestic usage and for irrigation to maintain agricultural activities particularly during dry season. Secondly, it helps charging of ground water reservoirs just underneath and nearby areas. The distributary characteristics of drainage system of the Barind Tract area offer relatively quicker surface runoff of the intercepted rainfall water. While, the flood plain areas have predominantly accumulated nature of drainage system.

(ii) Seasonal Changes of Land Cover

Changes in land use and land cover (LULC) cause bio-geophysical changes to the land surface that disturb the Earth's surface energy balance, which have noticeable impacts on ecological and environmental systems (Gibson and Palmer, 2019). Table 4 provides Upazila-wise distribution of different surface features over the study area as obtained through digital classification of the Landsat TM images of April 2, 2010 and October 24, 2009 corresponding to summer (dry) and rainy (wet) seasons respectively. Landform characteristics and hydro-climate mainly determine the agriculture and other vegetation activities over the area. In particular, agricultural functionality of the area is greatly influenced by a number of factors: depth of flooding in relation to land elevation during wet season and soil moisture content during dry season seemed to be the two major determinative variables governing the landuse of the study area (Rahman et al., 2007).

In the Barind Tract area, unavailability of water and acute deficit in moisture content in soil layer during summer is a general characteristic. As a result, major part of Barind Tract area (about 90 per cent) under the present study is found to be under bare soil or fallow land category in summer (Table 4). About 9.6 per cent of the area is found to be under different vegetation classes. While during wet period (October 24 2009), about 76 per cent of the land area in Barind Tract under the present study is covered by vegetation of which 72 per cent belongs to Aman rice area. The basin soils of the floodplain areas are subjected to varying degree of flooding during wet season. Whereas, in the flood plain areas cover change is moderate and the vegetation cover varies from 36 per cent to about 44 per cent, i.e., an increase of only about 6 per cent is noticed (Table 4). In general, flood plain areas are mainly used as single and double cropped land with some areas being triple cropped. While Barind area is mainly used for a single crop of transplanted Aman (Rahman et al., 2007).

(iii) *Thermo-Environmental Variability*

Land surface temperature (LST) is an important reference index used to measure the land environment and has important impacts on regional material and energy cycles, ecological system balance and human production and life (Yan et al. 2020). LST is one of the primary components that influences the surface and surface cover activities, crop yield, aridity level and evapotranspiration rate. The invention of thermal technology and the advancement of technology can easily capture the surface temperature through satellites (Sánchez-Aparicio et al. 2020). Surface temperature has been obtained from Landsat TM images following combined methods of Markham and Barker (1987) and Smith and Choudhury (1991).

Figures 8(a) and 8(b) show the spatial distribution pattern of surface temperature over the study area as derived from Landsat TM images of April 2, 2010 and October 24, 2009 for dry season and wet season respectively. Surface temperature has been obtained from Landsat TM images following combined methods of Markham and Barker (1987) and Smith and Choudhury (1991). reveals a significant variation in surface temperature over the study area due to differences in thermal responses to incident solar radiation for different functional environments.

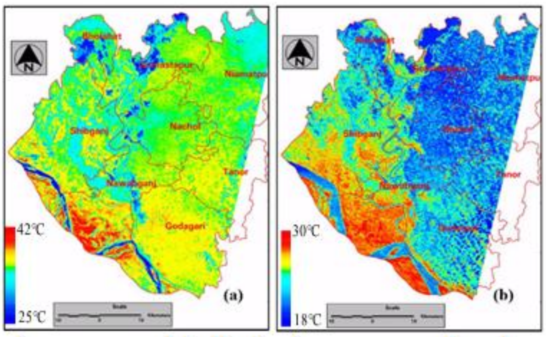

Figure 8: Spatial distribution pattern of surface temperature over the study area as derived from Landsat TM image of (a) April 2, 2010 for dry season and (b) October 24, 2009 for wet season.

Maximum surface temperature is observed over dry sandy areas situated on the bank of the river. In case of bare soil temperature is found to be relatively higher for the drier soil as compared to that of moist soil. In the densely vegetated areas, temperature is found to be relatively lower whereas, in the areas having lack of vegetation exhibits relatively higher temperature. Thus, surface temperature appears to be one of the important indicators of biophysical condition of land-surface and surface cover (Dan and Wang, 2019; Lambin and Strahler, 1994). From the figure it is evident that in most of the areas of Barind Tract surface temperature belongs to medium to relatively high value in the observed temperature range. Maximum surface temperature in the semi-arid Barind Tract zone in dry season is about 41°C and minimum is 26°C. Surface temperature of denude soil is found to be relatively higher ranging from 29°C to 39°C depending on the soil moisture condition. Northern corner of Niamatpur (maximum) and middle of Nachol areas show temperature from 29°C to 32°C. Major areas of Godagari, Tanor and few scattered areas of Gomastapur show temperature variation from 35°C to 39°C. While, major areas of Nachol, Niamatpur and Gomastapur demonstrate temperature variation ranges from 33°C to 35°C.

While overall response of flood alluvial plain land is under low to medium temperature range. Low land and low land cropping areas of Bholahat Upazila, low land cropping areas of northern part of Gomastapur Upazila, eastern side of Mahananda river, small water bodies in Barind Tract and water of Ganges and other river shows the lowest temperature. In this season boro rice is generally cultivated over vast areas under irrigation support.

Dense crops with good health, irrigated areas and water having the properties of high specific heat offer resistance to temperature rise and thereby, tends to maintain relatively lower surface temperature. In general irrigation, precipitation and dew increase leaf wetness (Goel and Norman, 1990) and often lower the surface temperature, backward radiation and increase net radiation (Dan and Wang, 2019; Linacare, 1972). Permanent vegetated areas of Nawabganj, Shibganj and Bholahat Upazila show moderate temperature. North-east corner, eastern side and central part cropping areas and homestead vegetation of Barind Tract also shows moderate temperature. With the increase of soil moisture, thermal conductivity and heat capacity of soil generally increases (Kalma, 1971) which directly influence the heat flow and temperature change of soil (Dan and Wang, 2019; Goel and Norman, 1990). Eventually, in dry season comparatively less moist area in the southern part of the Barind Tract area and some areas of flood plain exhibit relatively high surface temperature.

In the alluvial flood plain minimum and maximum observed temperatures are 26°C and 40°C respectively. For bare soil with normal soil moisture, surface temperature ranges from 33°C to 37°C. Surface temperature in permanent vegetated areas varies from 28°C to 32°C. In dry season plants in permanent vegetated areas holds relatively matured yellowish leaf with minimum water content. Buckley (2019), Ceccato et. al. (2001), Hunt et. al. (1989), Bartholic et al. (1972) and Jackson (1982) explained in their study that lack of leaf water content restricts stomatal functioning that ultimately increases leaf temperature. Both in Baind Tract and flood alluvial plain land cropping areas show relatively lower surface temperature ranging from about 26°C to 31°C.

Relatively dry Barind Tract and moist flood plain areas offer different temperature responses to a given amount of incident solar radiation. Particularly, variations in moisture and vegetation cover in the two areas mainly introduce the observed variability in thermal responses. Barind Tract area offers relatively high surface temperature, since soil of the area is relatively drier as such surface temperature increases in response to incident solar irradiation.

Eventually, surface temperature of the area appears to be a function of surface type such as soil, vegetation or water, level of moisture content, physiographic undulation etc. All these factors are pertinent to thermal properties e.g., thermal conductivity and heat capacity, volumetric air-filled porosity (Hiraiwa and Kasubuchi, 2000) of the surface as well as of meteorological factors, e.g., incoming solar radiation, ambient air temperature and relative humidity etc.

While in wet season, relatively higher moisture content in the soil layer due to high rainfall supports the growth of agricultural crop in the area and keeps surface Regular measurements are being performed on the depth of water table at different positions over the study area by the Water Development Board (WDB), Bangladesh. Figure 8a shows the locations of different GWL measuring stations of WDB in different Upazilas covering the study area.temperature to relatively lower values. The presence of agricultural crops over most of Barind Tract areas maintains surface temperature to its minimum values. Relatively small difference in surface temperature is observed between water and land particularly in the vegetation covered areas. Maximum and minimum surface temperature varies within range 10°C to 30°C (difference is 12°C) in wet season. While in dry season the range becomes 25°C to 42°C (difference is 17°C).

Dynamics of Ground Water Level (GWL)

Water plays a vital role in the activities of ecosystem components in this geographical area. Besides surface water, ground water is the other major source of water in this area of Bangladesh for agricultural, drinking, municipal, and industrial usages and plays a vital role particularly during dry season and drought periods. Ground water reservoirs are subjected to continuous charging and discharging processes in a hydrological cycle. Charging of a particular aquifer takes place by downward percolation of surface water from precipitation and infiltration from rivers and lakes. The incident rainfall intercepted by the surface is distributed mainly through infiltration and surface runoff. Such distribution process is primarily dependent on the characteristics of the soil and properties of vegetation overlying the surface. A given type of soil has its own characteristics of vertical and horizontal transmissivity that ultimately determine the amount of infiltration and surface runoff from rainfall water. Discharge generally takes place by evaporation and transpiration, by overflows in surface streams and by percolation to neighbouring aquifers. Another way of discharging of ground water is the uplifting of water using power pumps for irrigation of agricultural lands.

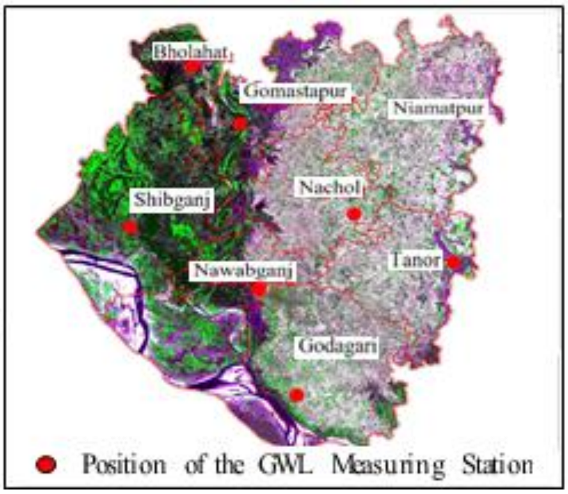

Figure 9a: Positions of the GWL measuring stations in different Upazilas (Smallest administrative unit in Bangladesh) covering the study area.

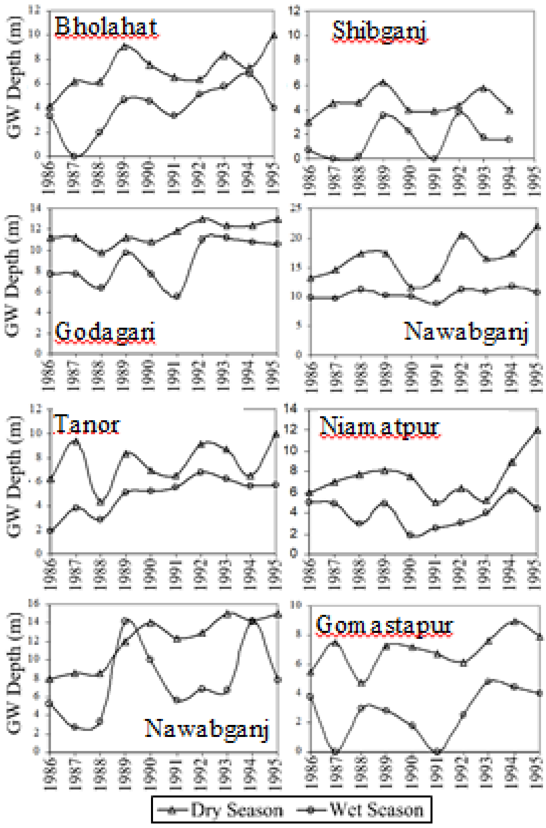

Figure 9b: Plot of time series data of annual and seasonal fluctuation of ground water (GW) depth in meter in different Upazilas under the present study. Data have been provided by the Water Development Board (WDB), Bangladesh.

Figure 9b shows plot of time series data of annual and seasonal fluctuation of ground water (GW) depth in meter in different Upazilas (administrative units in Bangladesh) under the present study in two different seasons namely dry season and wet or rainy season over a period from 1986 to 1995 indicating the charging status in the two seasons. Data have been provided by the Water Development Board (WDB), Bangladesh.

As a general observation, a gradual increase in the depth of ground water has been noticed over the observation period. The comparison of depth of ground water values exhibits higher depth of WL during dry season as compared to that in wet season for all the Upazilas under the present study.

(i) Sensitivity to Rainfall

The hydrodynamic cycle of Bangladesh is mainly controlled by rainfall activities in and around the country. Both surface and groundwater reservoirs in these areas receive annual charging from rainfall that varies from year to year. The main source of replenishment of ground water in this area is annual rainfall. However, ground water reservoirs also receive a portion of charging water through surface seepage from the adjacent water bodies particularly those are situating near to river or large water body.

Referring to figure 2, it is evident that almost 80 per cent of the total annual rainfall occurs in this region during July-September, i.e., within a short time period. Such an intensification of rainfall during the mentioned period initiates the process of surface runoff as soon as precipitation exceeds the requirement of: (i) Vegetal interception; (ii) Infiltration into the soil; (ii) Fill up of surface depressions (puddles, swamps and ponds). Ultimately, the condition results in relatively high surface runoff and allows lesser time for infiltration of rainfall water into the deeper soil.

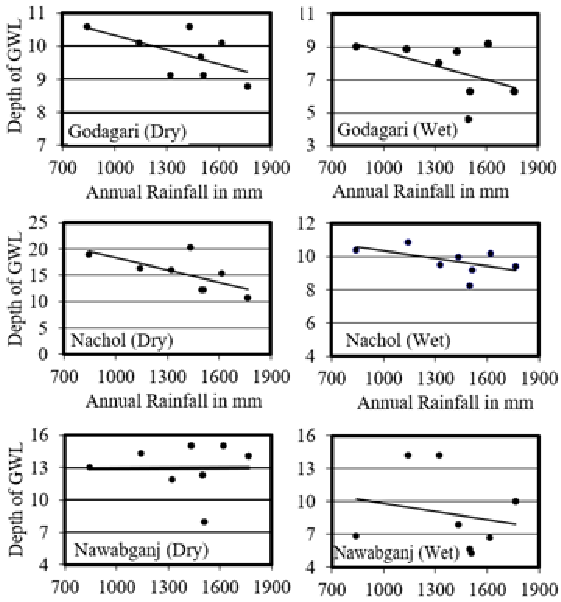

Figure 10: Plot of depth of ground water table as a function of annual rainfall for different Upazilas under the study area

Figure 10 shows a plot of annual rainfall as a function of depth of GWL for different Upazilas over the present study area. The GWL shows a negative correlation with annual rainfall amount for most of the Upazilas. Such relationship between rainfall and GWL also reveals possible indications that replenishment of ground is mainly accomplished through rainfall. It is also observed that the relatively high variability of ground water table due to rainfall over the dry region and lesser sensitivity to rainfall variation over the flood plain areas. It is observed that the response of GWL to rainfall is not identical all over that study area and a dependency of such event is observed on the lithological setting of the area.

In the wet season, rainfall rate is relatively high and often exceeds the rate of infiltration and thus, surface runoff takes place. As soon as the level of water in the river becomes higher than that of the aquifer layer, water flows towards the surface reservoirs. Consequently, the river water recharges the aquifer. During dry season, amount of rainfall is almost insignificant and large-scale evaporation lowers the water level of the reservoirs. Thus, surface water level gradually drops down and usually reaches to a level below the GWL. Under such condition, flow reversals occur, consequently water from the aquifer layer is discharged towards the river network infiltrating through the banks of the bounding streams. Both in Barind tract and flood plain areas, water level gradually declines during dry season and rises during wet period following the temporal distribution pattern of rainfall amount. The response of GWL to rainfall amount is different in different Upazilas under the present study demonstrating different degrees of sensitivity. The sensitivity seems to be very much higher in Godagari Upazila. In these areas, presence of large surface water bodies like *Bil* to hold rainwater is very rare, but in some areas foot slopes of hill and hummocky land producing bowl shape low land water-logged areas are seen.

All the subsurface reservoirs receive charges instantly during rainfall. In flood alluvial plain in rainy season flood water and rainfall are the two major sources for surface water as well as ground water charging. Number of low lands/bils holding precipitated and flood water in these areas helps long term charging of water reservoirs in these areas. In dry season GWL of Barind Tract areas specifically in Niamatpur, Nachol, Tanor and Godagari has noticeable dependency on rainfall amount. In these areas, rainfall and a limited irrigation return are the sources for ground water charging.

(ii) *Influence of Nearby Surface Water Bodies*

For the areas near to the river or large water bodies, plot of rainfall against depth of GWL does not exhibit any noticeable dependency. Areas in flood alluvial plain and its adjacent sides (Bholahat, Gomastapur, Shibganj and Nawabganj) have minimum influence of variability of annual rainfall amount on GWL in dry season. These areas generally receive large support from overlying large annual water-logged areas with minimum rainfall and irrigation return for ground water charging. Gomastapur is under Barind Tract area but there is a large surface water body adjacent to this area and the ground water receives maximum support from this source and hence the dependency on rainfall amount is minimal.

Meteoric water charges ground water reservoir through downward percolation through a complex physical process and shows high interannual variability (Jasechko et al. 2014; Lerner et al., 1990; Simmers et al., 1992). Such variations in GWL as a function of climatological cycle have been reported by various authors (e.g., Zeng, 1999; Matsuyama, 1992; Quesada et al., 2004). In general, the GWL depth is a function of land characteristics principally of surface topography, drainage pattern, soil properties, magnitude and temporal distribution of annual rainfall. In addition, human interference particularly utilization of water for irrigation also disturbs the stability of GWL.

Highest amount (about 80 per cent of total annual rainfall) of rainfall and moderate temperature characterizes the rainy season and minimum amount of rainfall with relatively high temperature characterizes the dry season. Ground water reservoir charges maximum in rainy season when maximum (almost 80 per cent) rainfall occurs and minimum in dry season from minimum rainfall and minimum irrigation return.

GWL depth exhibits significant variability in the spatio-temporal domain and is maximal in the Barind Tract. In Nachol Upazila, depth of GWL is maximal both in dry and rainy season. In flood alluvial plain land at Bholahat and Shibganj Upazila GWL is at comparatively moderate depth. Ground aquifer charges from surface water in these areas. From the rainy season hydrographs, it is seen that the charging conditions are better in Shibganj and Niamatpur of flood alluvial plain land and Barind Tract respectively.

Variation in GWL depth is determined by the balance between charging and discharging of a reservoir over a given time period. Seasonal variation adds a fluctuating component around the average water level. Balance between inflow and outflow has significant spatial and temporal variability depending on the amount of annual rainfall, amount of water drawn from the reservoir and on the infiltration properties of the soil. Ground water cycle is often influenced to a large degree, either raising or lowering the average water level due to human interference. In these areas, GWLs usually attain their highest value from August through October and lowest in April and May. A rapid increase in water level is generally noticed in May that continues until July. The rate of rise decreases apart from July, and in many areas GWLs remains almost stationary from August to October that might be an indication that aquifer has been charged to its full capacity. Hydrographs of figure 9b demonstrates an overall declining trend of GWL from 1986 to 1995 indicating a condition when discharge usually becomes higher than charge. Depletion of water table is an increasing concern for the global food supply. Both the factors - human intervention and variation in climate affect the groundwater recharge, including excess withdrawal and abstraction of groundwater (Hasan et al. 2018).

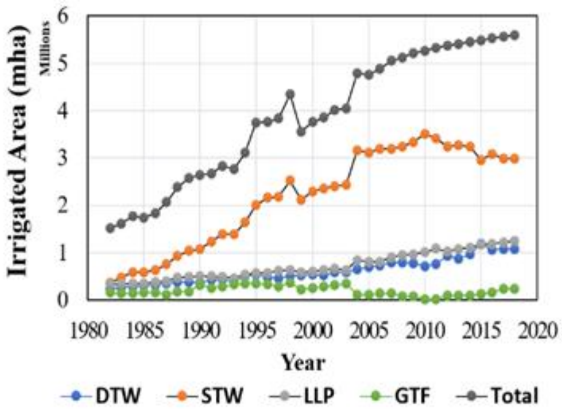

Figure 11. Yearly variation of areas in Bangladesh in million hectares during the period 1969 to 1993 of irrigated crop area along with different means of irrigation (B.B.S., 1998, 1997, 1987): Deep Tube Well (DTW), Shallow Tube Well (STW), Low Lift Pump (LLP), Gravity Flow Method (GFM).

(iii) *Effect of Ground Water Exploitation for Irrigation*
During last two decades, significant advancement in crop production in this country has been achieved through expansion of dry season crop cultivation principally utilizing large-scale ground water irrigation (Salam, 1998). Figure 11 demonstrates the yearly utilization of irrigation facilities in the country using different means for a period from 1982 to 2018. From this figure it is evident that yearly irrigation support for cultivation of agricultural crops has been increased almost linearly over the mentioned period still there is a trend of gradual yearly expansion.

Presently, irrigation is mainly utilized for Boro rice (71 per cent) and wheat (9 per cent) cultivation, which jointly occupies about 80 per cent of the irrigated land in the country. Here it should be mentioned that an extensive irrigation scheme initiated in 1985 covering about 12,67,400 acres of land in 17 Upazilas of Nawabganj, Rajshahi and Naogaon districts by facilitating groundwater exploration (Haque, 1997).

Ground water exploitation is gradually increasing in the country to provide increased support for bringing new areas under rice cultivation. Minor irrigation through low lift pumps mainly by tubewells (Shallow tubewells (STWs), Deep tubewells (DTWs) and Force mode tubewells (FMTWs)) has been emphasized since 1972 (Haque, 1997). As a result, significant expansion of minor irrigation with STWs in the private sector has been noticed during the period 1979 to 1984. About 0.20 million ha of land was brought under irrigation with 43,000 operating STW's during the period 1981-1982. This figure indicates that increase in irrigated area is mainly due to the increase of power pumps that utilize ground water.

Variation in GWL (figure 8b) demonstrates principal sources of dependency on the use of ground water in these areas that is consistent with the observation of Glennon and Maddock (1994). Over exploitation of ground water due to irrigation purposes has resulted in an average declination of about 3 m of GWL (Haque, 1997) and further declining might be harmful for the ecosystem of the area. Such threatening consequences of many riparian ecosystems in arid and semiarid regions of the world due to ground water declination have been extensively reported by Stromberg et al. (1996).

Feature-based Impacts on Surface Albedo

Table 5 provides the seasonal albedo values of selected surface features over the Barind Tract and flood plain areas as derived from Landsat TM images of October 24, 2009 and April 2, 2010 representing rainy (wet) and summer (dry) season respectively. The surface albedo values as well as seasonal land cover statistics for the study sites have been obtained through analysis of multitemporal Landsat TM data.

Position under observation			Albedo	
Feature	Land type	Geographical coordinate	Summer season	Rainy season
Water	Low land (Shibganj)	88° 14' 59.46" 24° 44' 58.95"	11.0	3.7
	Pond, Barind (Godagari)	88° 22' 38.57" 24° 31' 38.54"	13.0	6.1
	Padma River (Godagari)	88° 18' 42.28" 24° 28' 44.99"	13	12.1
Soil	Barind Tract (Tanor)	88° 28' 39.12" 24° 36' 17.27"	29.0	17.9
	Flood plain (Gomastapur)	88° 17' 05.25" 24° 49' 48.51"	30.0	18.9
	Flood plain (Shibganj)	88° 15' 30.63" 24° 45' 01.23"	35.0	24.1
Sand	Flood plain Padma River (Nawabganj)	88° 17' 44.70" 24° 27' 29.15"	48.0	11.5 (water)
		88° 16' 57.46" 24° 28' 00.80"	45.0	4.2
Aman Rice	Barind Tract (Godagari)	88° 23' 22.62" 24° 31' 35.75"	38 (soil)	10.9
	Flood plain (Gomastapur)	88° 13' 44.57" 24° 46' 19.61"	19.0 (Boro)	11.7
Boro Rice	Flood plain (Gomastapur)	88° 19' 23.72" 24° 50' 30.53"	17.0	15.5 (clay)
	Barind Tract (Niamatpur)	88° 33' 14.75" 24° 54' 26.53"	18.0	13.9 (Aman)
Mango Orchard	Flood plain (Shibganj)	88° 10' 05.68" 24° 40' 42.95"	18.0	11.9
		88° 14' 59.12" 24° 41' 07.12"	19.0	10.0

Land and land cover type like vegetation status, underlying soil moisture content, soil type, soil texture and structure controlling the magnitude of albedos through developing a complex pathway (He, et al., 2019). In the sandy areas particularly near the riverside, albedo value (derived from Landsat TM data) is relatively high throughout the year as sand usually has high reflectivity and low moisture content. Albedo value as high as 40 per cent to 48 per cent is observed in summer. Albedo value as high as 29-35 per cent is found over the soil area during dry season (Table 5). Moreover, due to absence of vegetation, exposed soil area comes to a direct contact with the sunlight causing an accelerated and exhaustive evaporation of the soil moisture and thereby, the surface rapidly becomes dry.

In dry season lack of soil moisture due to the absence of significant rainfall over the area increases the surface albedo significantly. On the other hand, occurrence of significant rainfall during wet period keeps the moisture content of the soil layer to a satisfactory level for a certain period of time even after the rainfall event. Emergence of vegetation over the area is noticed after getting sufficient rainfall. The combined effect of high soil moisture and emergence of vegetation during wet season significantly reduces the surface albedo.

The semi-arid Barind Tract area and flood plain area observe almost similar tropical climatic conditions. However, differences in landform and variation in local geology over the two areas mainly introduce variation in soil moisture level that ultimately governs vegetation growth over the area and the observed variability in surface albedo values. As such, the variation in the surface albedo value appears to be dependent on the type of landform (Rahman et al., 2007).

The albedo values corresponding to summer and winter seasons are higher than those corresponding to the rainy season (table 5). The Barind Tract area mostly represents bare soil both in summer and winter, and Aman crop in the rainy season.

Conclusions

Sustainable utilization of available land resources is an issue of immense importance in food production and food security under changing climate, global warming under pressure of increasing food demand often causing irreversible damages to the land resources and associated geo-environment worldwide. Proper monitoring considering various geo-environmental facts and factors, their limitations and assessment of impacts utilizing appropriate technology is extremely important.

The present study deals with the conceptual development of a RS-GIS based Information and Decision Support System (IDSS) in view of geo-environmental monitoring of land surface features, functionalities and conditioning principally of agricultural lands of normal-semiarid categories. System operation involves necessary functional blocks for application of remote sensing data supplemented with climatic, geophysical and groundwater data and other ancillary information. In view of testing and application on the mentioned theme, a pilot study has been carried out under the present work. The overall concept and associated methodology exercised under this work includes a number of parameters capable of providing an up-to-date scenario of the functioning geo-environment. Time series remote sensing data have been analysed to characterize the aridity in the Barind tract area situated in the northwestern part of Bangladesh. Two adjacent but characteristically different land areas, (i) semi-arid Barind Tract areas and (ii) Ganges flood plain areas have been selected for the present study where different hydro-environmental conditions prevail over the year.

Spectral characteristics of both floodplain and semi-arid Barind tract areas have been studied. The study reveals that the radiometric responses of Landsat TM are characteristically different for the two study sites having different environmental conditions and the semi-arid Barind tract areas are spectrally readily separable from the other neighbouring areas. The study provides evidences of high surface albedo, relatively low vegetation cover and soil moisture in the Barind areas and much higher vegetation cover and soil moisture in the flood plain areas during dry season (December to June). While relatively low surface albedo with relatively high vegetation cover in both Barind tract and flood plain areas during rainy season (July to November) is evident. Seasonal variation of surface albedo is significantly higher in the Barind tract area in comparison to that for flood plain areas. Spatiotemporal analysis of Landsat TM derived spectral curve shows appropriate seasonal trends and an overall trend towards increased vegetation over the Barind tract area that is consistent with field observation over the study interval.
The study demonstrates that radiative transfer processes through such system are mainly controlled by the amount of vegetation, water availability and soil characteristics. Unlike in most of the semi-arid land areas (where, amount of rainfall is considered to be the most important factor causing aridity), the temporally non-uniform distribution of rainfall with almost 80% occurring during July-September less infiltration rather than surface runoff of the intercepted rainwater, the presence of relatively impermeable thick top clayey layer over Barind tract and above all, the nature of the landscape seems to play vital role in causing aridity over this area.

Analysis on rainfall data over the past 50 years shows substantially high annual rainfall in the two study sites as compared to that of a typical semiarid land. Rainfall in these areas appears to be the main source of replenishment of ground water due to losses principally caused by large scale irrigation, domestic usage and surface evaporation.

Lithological data analysis on subsurface configuration reveals the existence of a relatively impermeable clayey top layer with comparatively higher thickness over the Barind area. The presence of such a layer also slows down the infiltration process significantly. Information on the ground water table reveals that the semi-arid Barind tract area has relatively higher depth of the ground water table in comparison to that of the flood plain areas.

The semi-arid Barind area shows relatively higher seasonal variability of the depth of groundwater level in comparison to that of the flood plain areas. It is also observed that annual rainfall has a direct impact on the variation of GWL particularly for the areas situated far away from the rivers. The response of ground water to annual rainfall shows relatively higher sensitivity of the

Barind tract areas as compared to that of flood plain areas. Further study is required to be conducted with more data for validation and operational utilization of this idea.

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References

Agnew C., Anderson W (1992). *Water in the Arid Realm.* Routledge, London. 18 (1), 143-143.

Asian Development Bank (ADB) (2015). Global Increase in Climate-Related Disaster, *ADB Economics Working Paper Series, Asian Development Bank,* Philippines. ISSN 2313-6537.

Avner Ayalon, Miryam Bar-Matthews., Eytan Sass (1998). Rainfall-recharge relationships within a karstic terrain in the Eastern Mediterranean semi-arid region, Israel: δ 18O and δD characteristics. *Journal of Hydrology,* 207(1–2), 5 June 1998, 18-31.

Azam, R., H. Rahman (2004). Application of satellite based geo-information technology for monitoring natural disasters in Bangladesh. *United Nations International Workshop on the Use of Space Technology for Disaster Management,* Germany, 18–22 October 2004.

B.B.S. (1987). *Yearbook of agricultural statistics of Bangladesh.* Published by the Bangladesh Bureau of Statistics, Dhaka, Bangladesh, pp. 718.

B.B.S. (1997).*Statistical yearbook of Bangladesh.* Published by the Bangladesh Bureau of Statistics, Bangladesh, 690.

B.B.S., 1998, *Yearbook of agricultural statistics of Bangladesh.* Published by the Bangladesh Bureau of Statistics, Dhaka, Bangladesh, 331.

Baidya, R.S., Avissar, R. (2002). Impact of land use/ land cover change on regional hydrometeorology in the Amazon. *Journal of Geophysical Research*, 107, 8037, doi:10.1029/2000JD000266.

Bartholic, J.F., L.N. Namken, C.L. Wiegand (1972). Aerial thermal scanner to determine temperatures of soils and of crop canopies differing in water stress, *Agronomy Journal*, 64,603–608.

Buckley, T. N. (2019). How do stomata respond to water status? New Phytologist, 224 (1), 21-36.

Ceccato, P., Flasse S., Tarantola S., Jacquemoud S., Grégoire JM. (2001). Detecting vegetation leaf water content using reflectance in the optical domain. *Remote Sensing of Environment* 77, 22-33.

Charney, J.G. (1975). Dynamics of deserts and drought in the Sahel. *Quart.J. Roy. Meteor. Soc.*, **101**, 193-202.

Charney, J.G., Quirk, W.G., Chow, S.M., J. Kornfield (1977). A comparative study of the effect of albedo change of drought in semi-arid regions. *Journal of Atmospheric Science*, **34**, 1,366-1,385.

Chase, T.N., Peilke Sr., R.A., Kittel, T.G.F., Nemani, R.R., Running, S.W. (2000). Simulated impacts of historical land cover changes on global climate in northern winter. *Climate Dynamics*, **16**, 93-105.

Chen, Z., Yu, G., Ge, J., Wang, Q., Zhu, X., Xu, Z. (2015). Roles of Climate, Vegetation and Soil in Regulating the Spatial Variations in Ecosystem Carbon Dioxide Fluxes in the Northern Hemisphere. *PLoS ONE* 10(4): e0125265. doi:10.1371/journal.pone.0125265.

Claussen, M., Brovkin, V., Ganapolski, A. (2001) Biogeophysical versus biogeochemical feedbacks of large-scale land cover change. *Geophysical Research Letters* 28(6), 1011-1014.

Coleman, J.M. (1969). Brahmaputra River: Channel processes and sedimentation. *Sedimentary Geology*, **3**, 129-239.

Colwell, R.N. (1983). *Manual of Remote Sensing, Second Edition,*. Published by the American Society of Photogrammetry, Virginia, 2440.

Dan Li, D., Wang, L. (2019). Sensitivity of Surface Temperature to Land Use and Land Cover Change-Induced Biophysical Changes: The Scale Issue. *Geophysical Research Letters,* 46 (16): 9678-9689.

Dickinson, R.E. (1983). Land surface processes and climate - surface albedos and energy balance. *Add. Geophysics,* 25, 305-353.

Dunne, T., Leopold, L.B. (1978). *Water in environmental planning.* San Francisco: W. H. Freeman and Company, New York, 818.

ERDAS Field Guide (1997-1999). *ERDAS,* Inc. Atlanta, Georgia.

Gallart F., Solé A., Puigdefábregas J. Lázaro R. (2002). Badland systems in the Mediterranean. In Bull JL and Kirkby MJ (eds) *Dryland Rivers: Hydrology and Geomorphology of Semi-arid Channels.* Chichester: Wiley, 299-326.

Gamesby, R. (2018) *Drainage Basins as open systems*

Glennon, R. J., T. Maddock (1994). III, In Search of Subflow: Arizona's Futile Effort to Separate Groundwater from Surface Water, Ariz. Law Review, Univ. of Ariz. Coll. of Law, 36, 567-610.

Goel, N., S., Norman, John M. (1990). Remote Sensing and Biophysical Measurements of Soils and Vegetation. *Remote Sensing Reviews*, **5**, 1-12.

Haque, N., Md. (1997). Study of groundwater condition in the western part of greater Rajshahi district. M. Sc. Dissertation, Department of Applied Physics and Electronics, University of Rajshahi, Bangladesh, 111.

He, T.; Gao, F.; Liang, S.; Peng, Y. (2019). Mapping Climatological Bare Soil Albedos over the Contiguous United States Using MODIS Data. Remote Sensing. 11, 666.

Henderson-Sellers, A. (1995). Human effects on climate through the large-scale impacts of land-use change, in Future Climates of the World: a modeling perspective. *World Survey of Climatology*, 16, Elsevier, Amsterdam.

Hill, J., B., Sturm, (1991). Radiometric correction of multitemporal Thematic Mapper data for use in agricultural land-cover classification and vegetation monitoring. *International Journal of Remote Sensing,* 12, 1471-1491.

Hiraiwa, Y., Kasubuchi, T. (2000). Temperature dependence of thermal conductivity of soil over a wide range of temperature (5-75°C), *European Journal of Soil Science,* 51, 211-218.

Houghton, J.J.T., Jenkins, G.J., J.J. Ephraums (1990). Climate change: The IPCC Scientific Assessment5, Cambridge University Press, Cambridge, 365.

Hunt, S., King BJ., Layzell DB. (1989). Effects of gradual increases in oxygen on nodule activity in soybean. *Plant Physiology*, 91, 315-321.

IPCC, (2019). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Islam, M., M., P. Kanungoe (2005). Natural recharge to sustainable yield from the Barind aquifer: a tool in preparing effective management plan of groundwater resources. *Water Sci Technol* (2005) 52 (12): 251–258.

Jackson, RD. (1982). Canopy temperature and crop water stress. In: Hillel D, ed. *Advances in irrigation,* Vol. 1. New York, NY: Academic Press, 43–85.

Jacob, F., Olioso, A., Gu, X., F., Su, Z., Seguin, B. (2002). Mapping surface fluxes using airborne visible, near infrared, thermal infrared remote sensing data and a spatialized surface energy balance model. Agronomie, 22, 669–680.

Jager, J., H.L. Ferguson (1991). Climate change: Science, impacts and policy. Proceedings of the Second World Climate Conference, Cambridge University Press, Cambridge, 578.

Jasechko, S., Birks, S.J., Gleeson, T., Wada, Y., Fawcett, P.J., Sharp, Z.D., McDonnell, J.J., Welker, J.M. (2014). Water Resources Research. 50 (11), 8845-8867.

Kalma, J.D. (1971). *The Annual Course of Air Temperature and Near-surface Soil Temperature in a Tropical Savannah Environment, Agricultural Meteorology*, 8, 293-303.

Keeling, C.D., Bacastow, R.D. and T.P. Whorf, 1982, Measurements of the concentration of carbon dioxide at Mauna-Loa Observatory, Hawaii, Carbon Dioxide Review, Edited by W.C. Clark, Oxford University Press, 377-385.

Khaleque, M.A. (1994). Geophysical study of time variation of the depth of aquifer and its thickness in parts of Barind Tract, north-west of Bangladesh, Ph.D. Thesis, University of Rajshahi University, Rajshahi, Bangladesh, 195.

King, R.B. (1984). Remote Sensing Manual of Tanzania, Land Resources Development Centre, pp.59.

Kirkby, M.J. (1969). Infiltration, through flow, and overland flow, ch. 5(1) in R.J. Chorley, ed., Water, earth and man, Methuen.

Lambin, E.F.,Strahler, A.H. (1994). Indicators of land-cover change for change-vector analysis in multitemporal space at coarse spatial scales, *International Journal of Remote Sensing,* 15, 2099-2119.

Lerner, D. et al. (1990). Groundwater Recharge. A Guide to Understanding and Estimating Natural Recharge. *International Association of Hydrogeologists. International Contributions to Hydrogeology* 8, Hannover, Heise 345.

Linacare, E.T. (1972). Leaf temperatures, diffusion resistances and transpiration, *Journal of Agricultural Meteorology*, 10, 365-382.

Lynn, B.H., Rind, D. R. Avissar (1995). The importance of subgrid-scale mesoscale circulations generated by landscape heterogeneity in general circulation models (GCMs). *Journal of Climate*, 8, 191-205.

M.R. Hasan, M.G. Mostaf, Nafiur Rahman, Md. Saiful Islam, Md. Moynul Islam (2018). Groundwater Depletion and its Sustainable Management in Barind Tract of Bangladesh. *Research Journal of Environmental Sciences, 12: 247-255.*

Maliva, R., Missimer, T. (2012). Arid Lands Water Evaluation and Management, Environmental Science and Engineering, DOI: 10.1007/978-3-642-29104-3_2, Springer-Verlag Berlin Heidelberg.

Mandakh Nyamtseren, Qi Feng, Ravinesh Deo (2018). A Comparative Study of Temperature and Precipitation Based Aridity Indices and Their Trends in Mongolia., *International Journal of Environmental Research*

Markham, B.L., Barker, J.L. (1986). Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures. *EOSAT-Landsat Technical Notes,* 1(Lanham, Maryland: EOSAT), 3-8.

Markham, B.L., Barker, J.L. (1987). Thematic Mapper bandpass solar exoatmospheric irradiances. *International Journal of Remote Sensing,* 8, 517-523.

Matsuyama, H. (1992). The water budget in the Amazon River basin during the FGGE period, *Journal Meteorological Society of Japan.,* **70**, 1071–1083.

Md. Bazlar Rashid, Md. Sultan-Ul- Islam and Md. Badrul Islam, 2015, River morphology and evolution of the Barind Tract, Bangladesh. Journal of Nepal Geological Society, 2015, Vol. 49, pp. 65-76

Melton, M.A. (1957). An analysis of the relations among elements of climate, surface properties and geomorphology. Tech. Rep. II Project NR 389-042 O.N.R. Dept. Geol. Columbia Univ.

Miska Luoto (2007) New Insights into Factors Controlling Drainage Density in Subarctic Landscapes. *Arctic, Antarctic, and Alpine Research,* 39:1,117-126

Monteith, J. (1972). Solar radiation and productivity in tropical ecosystems. *J. Appl. Ecol.,* 9, 747–766, doi:10.2307/2401901.

Morisawa, M. (1968). Streams. Their dynamics and morphology, McGraw-Hill Book Company, New York, 175.

Münch, Z.; Gibson, L.; Palmer, A. (2019). Monitoring Effects of Land Cover Change on Biophysical Drivers in Rangelands Using Albedo. *Land, 8*, 33.

Norbert, S., Rothman, D. H. (2002). A causal relations between topographic slope and drainage area, *Geophysical Research Letters*, 29, 1633.

Norton, C.C., Mosher, F.R., Hinton, B. (1979). An Investigation of surface albedo variations during the Recent Sahel Drought. *Journal of Applied Meteorology*, 18, 1252-1262.

Pitman, A.J. (2003). The evolution of, and revolution in, land surface schemes designed for climate models, *Int. J. Climatol*., 23, 479-510.

Quesada, C.A., A.C. Miranda, M.G. Hodnett, A.J.B. Santos, H.S. Miranda, et al. (2004). Seasonal and depth variation of soil moisture in a burned open savanna (campo sujo) in central Brazil. *Ecol. Appl.*, 14, S33-41.

Rahman, H., G. Dedieu, (1994). SMAC: A Simplified Method for the Atmospheric Correction of Satellite Measurements in the Solar Spectrum. *International Journal of Remote Sensing*, **15**, 123-143.

Rahman, H., Rahman, S., Rahman, M.S., M. Ahmed, (2004). Satellite Image Based Information Retrieval on the Geo-environment in the Northwestern Part of Bangladesh: Effects of Image Resolution. *Proceeding of the 7th International Conference on Computer and Information Technology (ICCIT),* 26-28 December 2004.

Rahman, S., Rahman, H., M. Keramat (2003). Monitoring Hydro-Environmental Condition and Its Evolution in the North-Western Part of Bangladesh using Combined Remote Sensing, GIS and Geophysical Data. *Presented in the International Conference on 'The Role of Natural Resources and Environment in Sustainable Development in South and Southeast Asia (NESDA)'* held in Dhaka, Bangladesh during January 17-20, 2003.

Rahman, S., Rahman, H., M. Keramat (2007). Study on the Seasonal Changes of Land Cover and Their Impacts on Surface Albedo in the North-Western Part of Bangladesh using Remote Sensing. *International Journal of Remote Sensing* **28**, 1001-1022.

Reiji Kimura Masao Moriyama (2019). Determination by MODIS satellite-based methods of recent global trends in land surface aridity and degradation. *Journal of Agricultural Meteorology,* 75(3), 153-159.

Riazanoff, S., Julien, P., Cervelle, B. and Chorowicz, J. (1992), Extraction et analyse automatiques d'un réseau hiérarchisé de talwegs. Application à un modèle numérique de terrain dérivé d'un couple stéréoscopique SPOT, *International Journal of Remote Sensing*, **13**, 337-364.

Riches, C.R., C. Maritime (2008). The High Barind Tract: a challenging drought-prone agricultural environment. *International Rice Research Institute (IRRI)*, 3-6. ISBN: 971-220-229-1.

Salam, A. (1998). Ana agro-hydro-climatic and environmental analysis on the changes in cropping style in Bangladesh and their impacts on rice crop yield: *A combined remote sensing and GIS approach.* M. Tech. Thesis, Andhra University, India, 93p.

Sánchez-Aparicio, M., Andrés-Anaya, P., Del Pozo, S. Lagüela, S. (2020). Retrieving Land Surface Temperature from Satellite Imagery with a Novel Combined Strategy. *Remote Sensing,* 12(2), 277.

Schneider, N., Eugster, W., B. Schichler (2004). The impact of historical landuse changes on the near-surface atmospheric conditions on the Swiss Plateau Nicolas Schneider, *Earth Interactions,* 8, 1-27.

Simmers, I. et al. Eds. (1992). Selected papers on aquifer overexploitation. Puerto de la Cruz. Tenerife, Spain April 15-19 1991. *International Association of Hydrogeologists.* .

Sinha, S.K. (1996). Global change scenario – Current and future, with reference to land cover changes and sustainable agriculture in the South East Asian context. Regional land cover changes, sustainable agriculture and their interactions with global change (*Proceedings of the South Asian Regional Workshop on Regional land cover changes and sustainable agriculture in South Asia, India, 16-19 December, 1996*), Edited by V. Ravichandran, 208.

Small, R.J. (1978). *The study of landforms.* Second Edition, Cambridge University Press, Cambridge, 502.

Smith, R.C.G., Choudhury, B.J. (1991). Analysis of normalized difference and surface temperature observations over southeastern Australia. *International Journal of Remote Sensing*, **12**, 2021-2044.

Stohlgren, T. J., T. N. Chase, R. A. Pielke, T. G. F. Kittel, J. S. Baron (1998). Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. *Global Change Biol.*, 4, 495–504.

Stromberg, J.C., R. Tiller, B. Richter (1996). Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. *Ecological Applications* 6:113–131.

Tassan, S (1992). An algorithm for the identification of benthic algae in the Venice lagoon from Thematic Mapper data. *International Journal of Remote Sensing*, 13, 2887-2909.

Ülker, D., Ergüven, O., Gazioğlu, C. (2018). Socio-economic impacts in a Changing Climate: Case Study Syria. *International Journal of Environment and Geoinformatics*, 5(1), 84-93, doi. 10.30897/ ijegeo.406273

Uwiringiyimana, J., Sent. Y. Lubczynski., M. W (2019). Hydrogeophysics for designing the hydrogeophysical conceptual model of a sub-catchment in Maqu, Tibet-China. Dissertation for Master of Science degree, Department of Geo-Information Science and Earth Observation, University of Twente.

Verstraete, M.M., B. Pinty (1991). The potential contribution of satellite remote sensing to the understanding arid lands process. *Vegetation*, **91**,59-72. Walesh, S. G., 1989, *Urban Surface Water Management*, New York, John Wiley.

William, W., Kellogg., Robert, Schware (1982). Climate Change and Society, Western Press, Boulder, Colorado, USA, p2.

Yang, P., Van der Tol, C., Yin, T., Verhoef, W. (2020). The SPART model: A soil-plant-atmosphere radiative transfer model for satellite measurements in the solar spectrum. Remote Sensing of Environment, Volume 247, 111870, ISSN 0034-4257.

Yang, Z., L. (2004). Modeling land surface processes in short-term weather and climate studies. *Observation, Theory and Modeling of Atmospheric Variability*, edited by X. Zhu, X. Li, M. Cai, S. Zhou, Y. Zhu, F.F. Jin, X. Zou, and M. Zhang, World Scientific Series on Meteorology of East Asia, World Scientific, New Jersey, pp. 288-313.

Yibo Yan, Kebiao Mao, Jiancheng Shi, Shilong Piao, Xinyi Shen, Jeff Dozier, Yungang Liu, Hong-li Ren., Qing Bao (2020). Driving forces of land surface temperature anomalous changes in North America in 2002–2018. *Sci Rep* 10, 6931.

Zeng, N. (1999). Seasonal cycle and interannual variability in the Amazon hydrologic cycle. *Journal of Geophysical Research*, 104, 9097–9106.