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Estimation of rainfall patterns in Bangladesh using different computational methods (arithmetic average, thiessen polygon and isohyet)

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Abstract

The present study was conducted to measure the total amount of annual rainfall all over the Bangladesh by different computational methods (Arithmetic average, Thiessen polygon and Isohyet). The rainfall data (1991-2011) of 34 rain gauges stations all over the Bangladesh were collected from Bangladesh Meteorological Department (BMD). Geographical Information System (GIS) tools were used in the present study to interpret the results. The Arc GIS 10.1 software (interpolation tool, Kringing) and different statistical analysis were carried out to get output results of different computational methods. GIS was used to show the patterns of rainfall all over the Bangladesh. The average rainfall of Bangladesh in the year of 1991 were 2876.029 mm, 2654.54 mm and 3066.47 mm by arithmetic average, thiessen polygon and isohyet method respectively whereas, in the year of 2011 the average rainfall by arithmetic average, thiessen polygon and isohyet methods were 2478.76 mm, 2213.046 mm and 2733.63911mm respectively. The annual average rainfall by all these three methods showed a decreasing trend science in 1991 to 2011 by considering all significant level of error in annual average rainfall that may be due to the physiographic stratification of the Bengal delta. The GIS interpolation tool (Kringing) also showed the decreasing patterns of annual average rainfall all over the Bangladesh. All these methods are not suitable to measure rainfall in different regions of the country. So, region-wise rainfall estimation must be done all over the country by these methods to find the actual scenario of rainfall patterns in Bangladesh.

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Introduction

The South Asian Association for Regional Cooperation (SAARC) is considered as the most susceptible to climate change that is badly disturbing the agricultural productivity, reducing the extent of natural amenities and restricting economic growth of the generations to come (Islam, 2009). According to the climate change experts of World Bank, the climate change effects to a nation depend on its economic condition and climate change already affects the South Asian countries and will go on to make stronger (Haq*et al.*, 1998; Ali, 1999).In recent years, Bangladesh attracts the universal consideration because as it is one of the severe vulnerable countries to rainfall unpredictability and major 'hotspot' for upcoming influences of climate change (IPCC, 2007). Climate changes have significant effects on the people and their manners as well as on agricultural possessions, accessibility of water and particularly those regions where economic activities rely mostly on agriculture (Altin*et al.*, 2012; Alam and Iskander, 2013). Bangladesh suffers different rainfall related natural and manmade disasters like flood, drought, landslide and many more (Islam *et al.*, 2010). Climate change alters the rainfall patterns on global (Hulme*et al.*, 1998; Lambert *et al.*, 2003; Dore, 2005) as well as local scales (Rodriguez-Puebla *et al.*, 1998; Gemmer*et al.*, 2004; Kayano and Sansígolo, 2008). Rainfall is considered as the most significant variable to recognize global warming as well as changes in the state of climate, therefore rainfall is extensively used to study the advanced climate sciences. The types and levels of rainfall's variation are vital issues for policy planner and policy maker regarding mitigation and adaptation measures to take against climate change. In Bangladesh, we are already facing several adverse impacts of climate change in different sectors. There have several published research (Ahasan *et al.*, 2010; Farhana and Rahman, 2011; Rahman *et al.*, 2012 and Alam and Afrin, 2014) regarding characterization and estimation of rainfall patterns of different regions of Bangladesh and they measured the trend of rainfall in specific periods/seasons of the year by different statistical and software based analysis. The present study was conducted to determine the overall rainfall patterns of Bangladesh by different computational methods (Arithmetic average, Theissen polygon and Isohyets) and compared their suitability to use in different regions of Bangladesh. The present study will enrich the knowledge of the country's policy planner and maker to response properly against the climate change's impacts of rainfall in Bangladesh.

Materials and methods

Study area

Bangladesh is situated at 21°47'12" N and 92°36'36" E (Wikipedia, 2014) with south east subtropical monsoon climate region. Bangladesh has high seasonal variations with minor climatic variation covering a total 1, 47,570sq.km of land area (Wikipedia, 2014).Total 34 rain gauges stations were used for the collection of data which are situated unevenly all over Bangladesh, but mainly focused on major geographical feature areas and also major divisions. Fig 1 shows the elevation, location of the different rain gauges stations beside watershed and basin boundary in the study area.

Data and software

The data of 34 rain gauges station were collected from Bangladesh Meteorological Department (BMD).The Arc GIS 10.1 software was used for obtaining output result. Now a days GIS(Geographical Information System) is widely used for various purpose as: rainfall computation, rainfall trend and rainfall distribution. The software was mainly used for the calculation and preparation of bisectional area of thiessen and also preparation of isohyets all over Bangladesh.

Data preparation and Analysis

In arithmetic method there is no need to prepare the data. Thiessen and isohyet methods need data preparation and software input. Thiessen polygons are a simple and straightforward method where each un-sampled or interpolated location is given the value of the adjoining observation (Thiessen, 1911). The data collected from different BMD stations were prepared with latitude and longitude for projection.

The Fig 2 shows the data generation and analysis procedures.

Three major computational methods were used for calculating the average rainfall all over the Bangladesh. These are the following heads;

Arithmetic Average Method

This is the modest computational method and more widely used method. For the computation of rainfall by the arithmetic average method the rainfall data collected from BMD (34 meteorological stations) were summed up first. The following formula was used to obtain results:

$$A_{av} = \frac{P_{av}}{N}$$

Where, P_{av}=Total Rainfall,N= Total number of station

$$\text{Arithmetic Average} = \frac{\text{Total rainfall}}{\text{Total number of rainfall station}} \quad [i]$$

Thiessen Polygon Method

This is most common method of rainfall computation over an area. It is mainly used for smooth area. For constructing thiessen polygon using the data collected from BMD stations the Arc GIS' thiessen polygon tool was used to draw bisectional area for every station with respect to other station.

The Fig 3 exposes the thiessen polygon over Bangladesh in the year of 1991 and 2001.

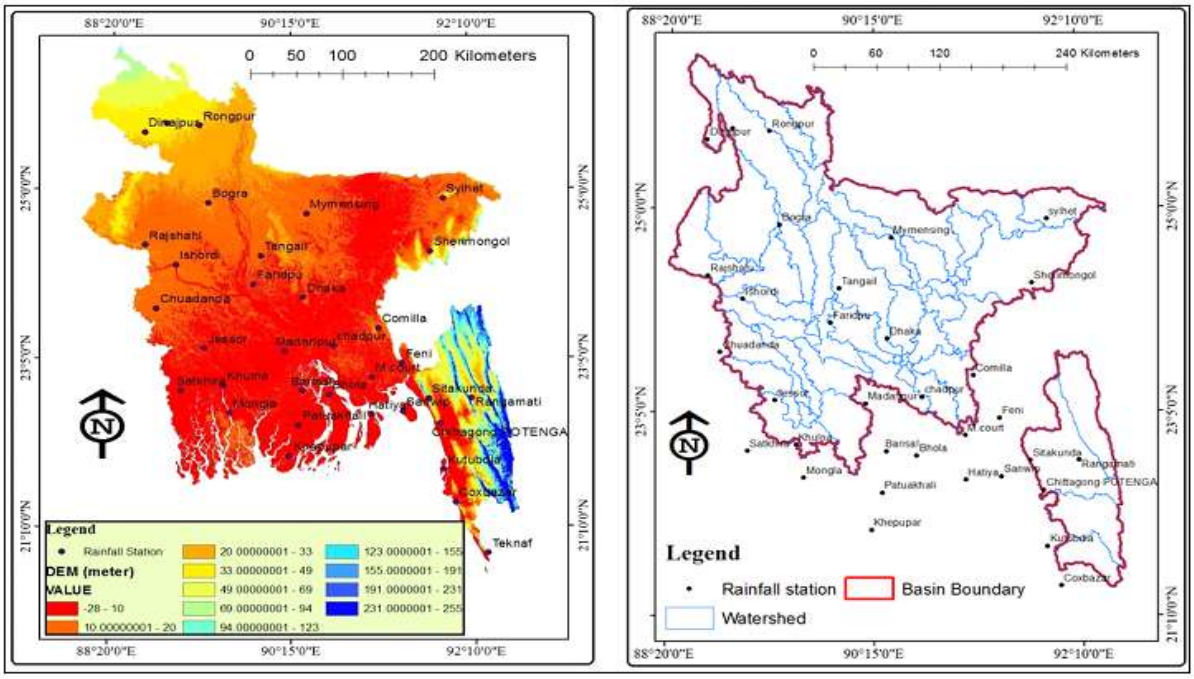

Fig 1: Study area with DEM (digital elevation model) value, Basin Boundary and watershed.

The bisectional area was same of the two Fig 3 (left) and (right) because, bisectional area created as a triangle of different station then joining these perpendiculars with triangle (Drawing the perpendicular bisectors of the triangle) and then the polygon was drawn (*Done by GIS 10.1 software*). As Perpendicular was drawn based on the location of stations and stations location was same (for 1991 and 2001 year). So the bisectional areas were same for both Fig 3 (left) and (right). The Table 2 exposes bisectional area individually (km²). But there are slight difference in color of different bisectional area for Fig 3(left) and (right), because the rainfall for same station is not same for every year. This is why there is color difference of every bisectional area, which states the rainfall distribution in every bisectional area was different from other bisectional area for every different year.

The formula used for computing the average rainfall all over the Bangladesh is given bellow:

$$P_{av} = \frac{A_1 \times P_1 + A_2 \times P_2 + \ldots\ldots\ldots A_n \times P_n}{A_1 + A_2 + \ldots\ldots\ldots A_n}$$

Or more simply it can be written as:

$$\text{Rainfall average} = \frac{\{\text{Total of } (P_a \text{or } P_b \times A)\}}{\text{Total of A}}$$

$$\text{Thiessen} = \frac{\{\text{Total of (Rainfall} \times \text{Bisectional area)}\}}{\text{(Total Bisectional area)}} \quad \text{[ii]}$$

Where,

$P_{a=}$ Rainfall (mm), 1991, $P_{b=}$ Rainfall (mm), 2011, A= Bisectional areas, (km^2).

Isohyet Method

For calculating the isohyets it is necessary to build isohyets over Bangladesh. Isohyet method is best for uneven area and by this method a good result can be found. By using the Arc GIS 10.1(by the contour with barrier tool) Fig 4was built easily, where contour interval was500mm.Rain gauges were split into low, medium, and high rainfall zones according to the long-term average annual rainfall isohyet map (Giambelluca *et al.* 1986): (a) 1,000 mm, (b) 1,500 mm, (c) 2,000 mm (d) 2,500mm, (e) 3,000mm, (f) 35,00mm, (g) 4,000 mm (h) 4,500mm, (i) 5,000mm (Fig. 4,Table 2and 3).

In Fig 4 (left side) it was clear that most of the area were covered by the 2000mm isohyets and then 3500mm isohyets, which means that most of the area was covered with the rainfall of 2000mm and then 3500mm.From the right side of the Fig 4 it was also clear that the isohyet that covered the maximum area was2000mm and after then 2500mm and the rainfall over maximum area was about 2000mm after then 2500mm respectively. But for the isohyet method, not only visualization or mapping was enough, from the map calculating area between isohyets. For the actual computation of rainfall over Bangladesh for base year of 1991 and 2011 using isohyets needed a calculation formula and the formula was:

$$\text{Rainfall average } (I_{av}) = \frac{\text{Total of [(Area between isohyets} \times \text{Value of Isohyet lines)(km}^2 \times \text{mm)]}}{\text{Total of area between isohyet lines (km}^2\text{)}} \quad \text{[iii]}$$

Results and discussion

The average rainfall of Bangladesh in 1991 calculated by arithmetic average, thiessen polygon and isohyet methods were 2876.029 mm, 2654.54 mm and 3066.47 mm respectively and in 2011, the average rainfalls in Bangladesh by using three computational methods (arithmetic average, thiessen polygon and isohyet) were2478.76 mm, 2213.046 mm and 2733.63911mm respectively. In the year of 1991 and 2011, there were three different values for those same years because of the suitability of different computation methods for different land area.

Table1: Bisectional area (A) and measure Rainfall (mm), 1991(P_a) and 2011(P_b) for stations.

Station name	Rainfall mm,1991 (P_a)	Rainfall mm,2011 (P_b)	Bisectional areas,km^2 (A)	P_a× A (Rainfall ×Bisectional area),mm×km^2	P_b× A (Rainfall ×Bisectional area),mm×km^2
Dhaka	2850	1776	6263	17849550	11123088
Tangail	2748	1839	4562	12536376	8389518
Mymensing	3312	2147	1110	3676320	2383170
Faridpu	2156	1509	4470	9637320	6745230
Madaripur	2511	1613	4319	10845009	6966547
Sherimongol	2828	2050	6696	18936288	13726800
Sylhet	4620	3101	7250	33495000	22482250
Bogra	2291	1721	8878	20339498	15279038
Dinajpur	2021	1644	4864	9830144	7996416
Ishordi	1697	1736	4332	7351404	7520352
Rajshahi	1489	1475	5941	8846149	8762975
Rongpur	2263	1932	6506	14723078	12569592
Sydpur	1836	1890	4499	8260164	8503110
Chuadanda	1677	1622	3644	6110988	5910568
Jessor	2052	1361	4894	10042488	6660734
Khulna	1760	1948	2769	4873440	5394012
Mongla	1957	2247	5863	11473891	13174161
Satkhira	1768	2121	2859	5054712	6063939

Barisal	2392	1909	2378	5688176	4539602
Bhola	2744	2015	1494	4099536	3010410
Khepupar	3083	3092	2707	8345681	8370044
Patuakhali	2681	2414	2854	7651574	6889556
chadpur	2490	2128	3012	7499880	6409536
Teknaf	5133	4978	459	2356047	2284902
Chittagong	3675	3101	1864	6850200	5780264
Comilla	2914	1884	3333	9712362	6279372
Coxbazar	4177	4404	3172	13249444	13969488
Feni	4231	3194	3128	13234568	9990832
Hatiya	3362	3842	1656	5567472	6362352
Kutubdia	3415	3894	3066	10470390	11939004
M.court	3505	3234	2166	7591830	7004844
Rangamati	3023	2439	6883	20807309	16787637
Sandwip	5968	4260	478	2852704	2036280
Sitakunda	3156	3758	1800	5680800	6764400
Total	97785	84278	130169	345539792	288070023

Table 2: Value of Isohyets line (mm) and Area between isohyets for 1991over Bangladesh.

Value of Isohyets lines (mm)	Area between isohyet lines (km²)	Area between isohyet lines × Value of Isohyets lines (km² × mm)
1500	1096	1644000
2000	19706	39412000
2500	15966	39915000
3000	17160	51480000
3500	17778	62223000
4000	7566	30264000
4500	10087	45391500
5000	1907	9535000
Total	91266	279864500

Arithmetic average and isohyets methods are highly precise for computing average rainfall in the hilly regions and thiessen polygon method is suitable for calculating rainfall in the flat areas or less rugged areas. Traditional approaches for estimating areal and point rainfall have included station-average, Thiessen polygon, inverse distance weighting (IDW), and isohyet methods (Thiessen 1911; Shepard, 1968; McCuen, 1989).

Table 3: Value of Isohyets line and Area between isohyet for 2011 over Bangladesh

Value of Isohyets lines (mm)	Area between isohyet lines (km²)	Area between isohyet lines × Value of Isohyets lines (km² × mm)
1500	2148	3222000
2000	16283	32566000
2500	11689	29222500
3000	3190	9570000
3500	3046	10661000
4000	6950	27800000
4500	3024	13608000
Total	46330	126649500

Table 4: Results of different methods

Computation Methods	Year 1991	Year 2011
Arithmetic	2876.029412	2478.764706
Thiessen	2654.547488	2213.046294
Isohyet	3066.470537	2733.639111

All the parts of Bangladesh are not hilly region and rain gausses stations are not uniformly distributed or the whole country is not flat. In Bangladesh the rain gauges stations are distributed in a combination of uneven, flat and hilly regions that results the variation of average rainfall with different computation methods. The isohyets method may give more precise result than other methods. In mountainous regions; evaluating rainfall distribution is more complicated because rainfall patterns are influenced by high changes in topographical relief over relatively short distances (Mair and Fares, 2011).

By considering all kinds of physiological, morphological and error conditions, it is evident that, the average rainfall in Bangladesh is decreasing from the year 1991 to 2011. From fig 4 it is also clearly seen that the rainfall pattern in Bangladesh is decreasing science 1991 to 2011 significantly. By arithmetic method where it was 2876.02 mm in 1991 but in 2011 it reaches to 2478.76 mm. Not only arithmetic but also every method as thiessen polygon and isohyets method reveals that the average rainfalls are decreasing. The kriging (GIS interpolation tool) also discloses that the total rainfall all over Bangladesh is decreasing. The Thiessen method produced the highest error, whereas OK (ordinary kriging) produced the lowest error in all but one period (Mair and Fares, 2011). A trend analysis over Dhaka city during the last 67 years (1953-2009) shows a decreasing trend of rainfall about 0.0154 mm per year (Murshed *et al.,* 2011). In fig 6, the red color indicates the high rainfall areas and dark green color indicates the low rainfall areas. From the year of 1991 to 2011 the dark green color is increasing over the red color. In Fig6 (left side) yellow color is also replaced by the green color. In 1991, the rainfall of Bangladesh was in the range of 742 to 5828 mm but in 2001 it was in the range of 835 to 4968 mm (fig.6). So, the rainfall all over Bangladesh is in decreasing trend.

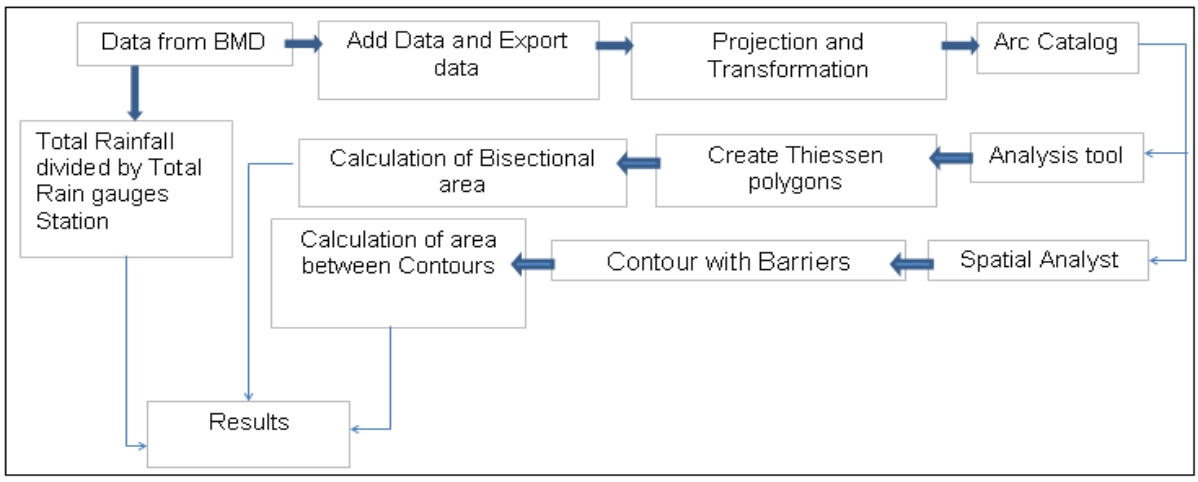

Fig. 2. Data Generation and Analysis Procedure.

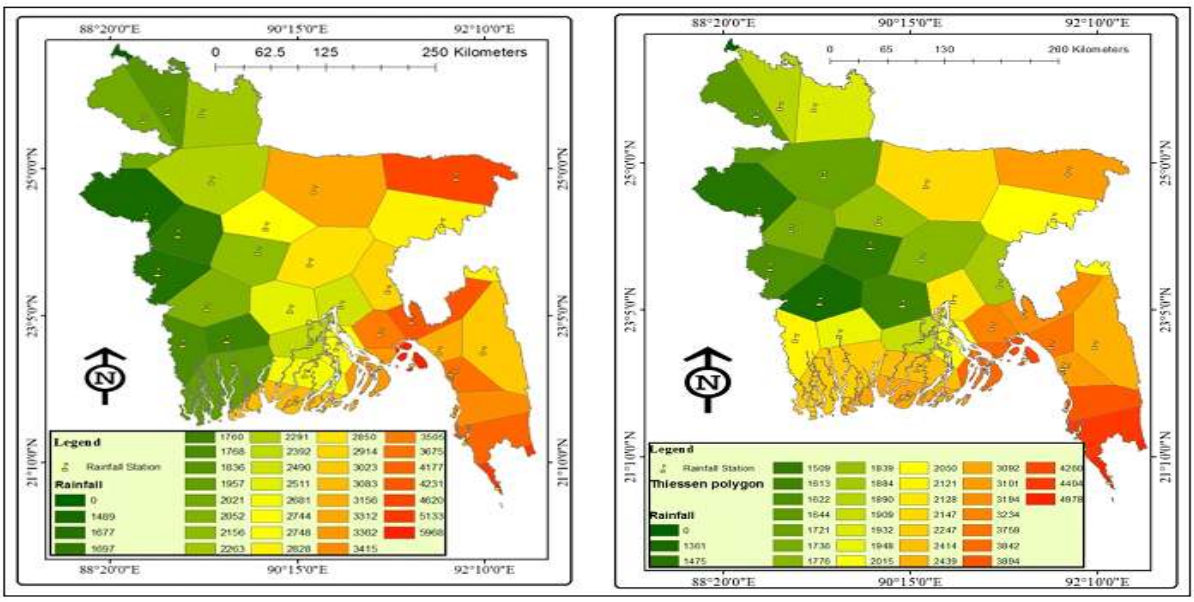

Fig. 3. Thiessen polygon (bisectional area with rainfall distribution) 1991(left), 2011(right).

It is totally means that the total rainfalls all overall Bangladesh is in decreasing pattern and varies according to Physiographical condition the country. The north-eastern part of Bangladesh has a number of topographical features like rivers, hills and hillocks, haors and high flood plain and the rainfall varies from 1500 mm in the western part to more than 5000 mm in the north-eastern part of the country (Hasan *et al.*, 2015). In the study it is exposed that the rainfall estimation of different region using different methods is different (Table 1 and 3) and height rainfall in sylhet and Chittagong region and lowest in rajshahi division.

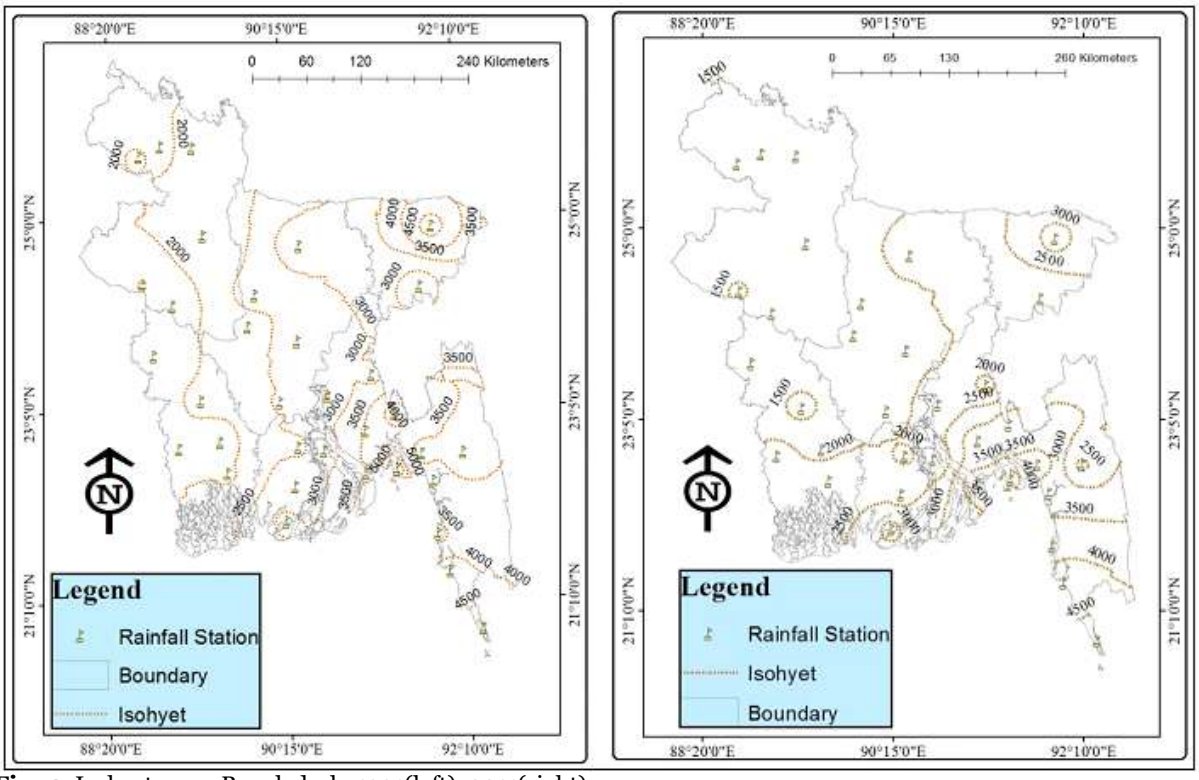

Fig. 4. Isohyets over Bangladesh, 1991(left), 2011(right).

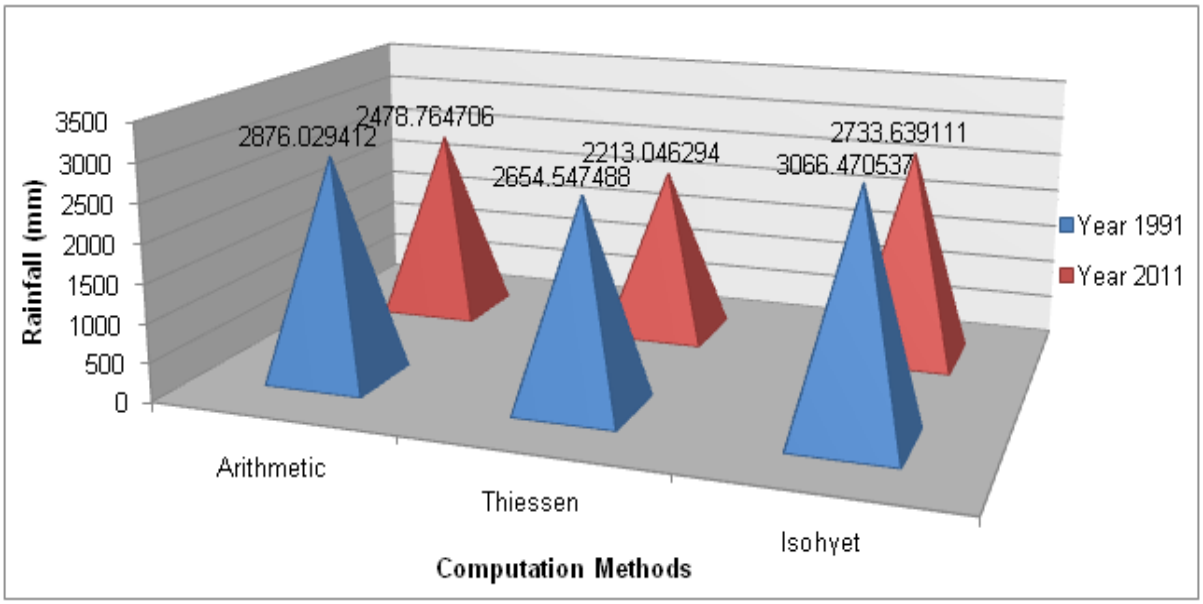

Fig. 5. Rainfall computation results chart.

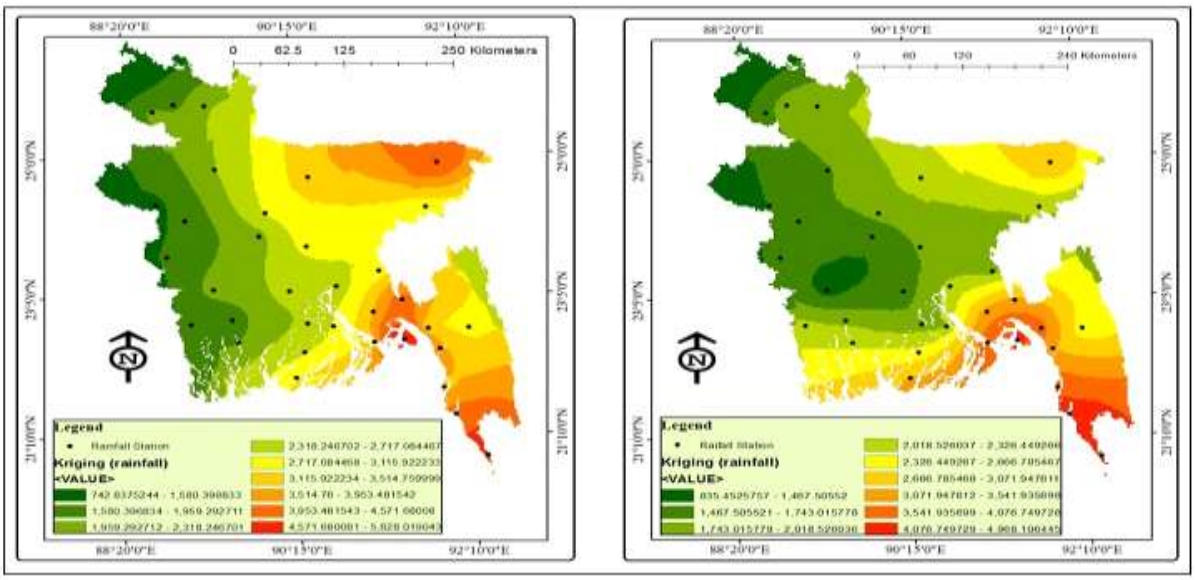

Fig. 6. Rainfall distribution in Bangladesh 1991 and 2011 using Kriging (left to right).

Conclusion

The present study determines the average rainfall of Bangladesh by three different computational methods (arithmetic average, thiessen polygon and isohyets). Though there are some errors in average rainfall because of the country's physiology but if we consider the highest peak values among different methods, the average rainfall did not exceeds 2800 mm in 2011 where it exceeded 3000mm in the year of 1991.Though it is not much devastating but is an alarm for the feature that the country is in the door of great drought. In far feature drought will be knocked in Bangladesh if this trend is continue.

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