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GIS BASED HYDROMETEOROLOGICAL ANALYSIS OF HEAVY RAINFALL EVENTS IN THE INDUS BASIN OF INDIA: OBSERVED AND FUTURE PROJECTIONS

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ABSTRACT:

Rainfall is the main source of fresh water, which is predominantly controlled by the monsoon in India. Due to large spatial and temporal variability in rainfall, some river basins suffer obsolete water scarcity, while, some basins fall in the category of water excess. Himalayan rivers are perennial as snowmelt contribution is also substantial compared to rainfall. Proper Management of excess rainfall is therefore of prime importance in flood control studies. In light of global warming scenarios, present study examines the recorded heavy rainspells and also rainstorms that may occur in future. The objective of the study is to use the latest technique of GIS to analyze the heavy rainspells in the Indus Basin during the period 1951-2009 using daily station data and also future projections from second generation regional climate model (PRECIS). Remote sensing datasets available in GIS format on different websites have been used to run the hydrological model using ArcMap 10.2 suit. Trend analysis has been employed to examine the temporal changes in seasonal, annual rainfall and extreme rainfall series. Meteorological conditions during the heavy rainspells have also been analysed using wind, geopotential height data. Such analysis will be very useful for hydrological and agricultural planning and also for proper management of water allocation and for flood control studies. Results indicated increase in extreme rainfall and also maximum water yield during rainstorm period because of reduction in the evapotranspiration. Teleconnections between extreme rainfall in the basin and meteorological parameters such as Geopotentional height, specific humidity and wind field in lower and middle atmosphere.

1. INTRODUCTION

Life on the earth is sustained by water. 97% of the earth surface is covered by water but most of it lies in the ocean and therefore can not be used directly for mankind due to salinity. Remaining 3% fresh water either lies in the form of permanent ice or underground.

Rainfall is the main source of fresh water, which is predominantly controlled by the summer monsoon. It is well known that, water availability in India is driven by the monsoon. The whole year's rainfall is concentrated in just few months. This problem of water scarcity has become more serious due to population growth, increase in water demand, vulnerability from climatic change and deterioration in water quality from domestic as well as industrial pollution loads. In the context of global warming scenario, understanding of the regional climatic changes over India is therefore directly linked to the understanding of the rainfall patterns in the region, its inter-annual and intra-seasonal variations. While there are regions which receive abundant precipitation and have lakes and rivers, there are also regions practically devoid of water. Floods and droughts occur frequently over extensive areas due to high variability of rainfall. Dams, barrages and other hydraulic structures across the rivers must be designed and built to withstand the maximum floods that can occur at a site. Proper management of the water resources for various purposes such as for domestic use, industrial use, irrigation, hydropower generation are of prime importance. PMP is the key design rainfall input in computing Probable Maximum Floods (PMF). If a spillway is not able to safely release the PMF, breaching of the dam wall due to over-topping can occur and cause heavy loss of lives and damages to property. Rainstorm analysis is the pre-requisite in the estimation of PMP. Considering the importance of the subject, an attempt has been made in this study to carry out rainstorm analysis in the Indus basin using past 50 years of observational data. In light of global warming scenarios, future projections of heavy rainstorms that may occur at the end of century have been discussed in detail. Such analysis is useful for proper planning, management, and design of different types of water resources projects in this river basin.

2. STUDY AREA

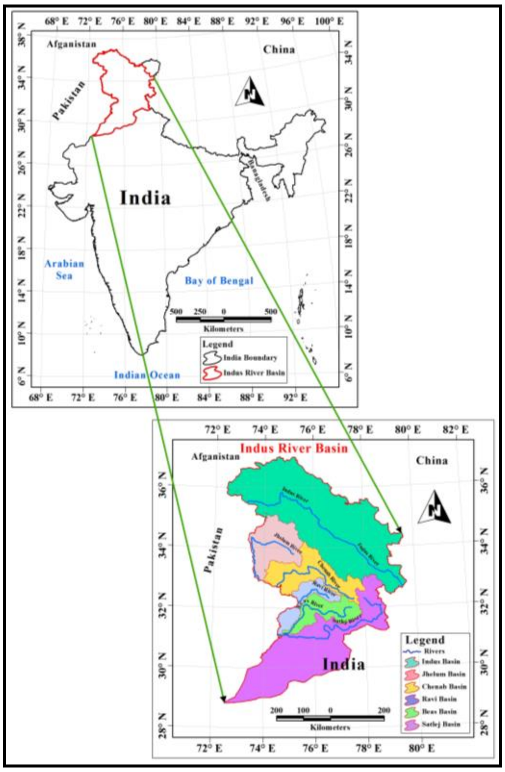


Figure 1: Location Map of Study Area

The Indus originates in the northern slopes of the Kailas range in Tibet near Lake Manasarovar. It follows a north-westerly course through Tibet. It enters Indian Territory in Jammu and Kashmir. It is a major river in Asia which flows through India and Pakistan and China. The geographical extent of the Indus basin in India is between 72° 28’ to 79° 39’ E. longitudes and 29° 08’ to 36° 59’ N. latitudes of the country with a maximum length of 756 km and width 560 km. The basin extends over an area of 11, 65,500 sq. km and lies in Tibet (China), India, Pakistan and Afghanistan. The drainage area lying in India is 3, 21,289 sq. km. which is nearly 9.8% of the total geographical area of the country. The total length of Indus from its origin to its outfall in Arabian Sea is 2,880 km, out of which 1,114 km flows through India. Its principal tributaries in India are the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej.

It is bounded by the Karakoram and Haramosh ranges on the north, on the east by the Himalayas, on the west by the Suleiman and Kirthar ranges and on the south by the Arabian Sea. The basin lies in the States of Jammu and Kashmir, Himachal Pradesh, Punjab, Rajasthan, Haryana and the Union Territory of Chandigarh. Figure 2 shows the map of the river basin with its statewise distribution and Tributaries of the Indus Basin while Table 1 gives the exact area of the basin covered in India.

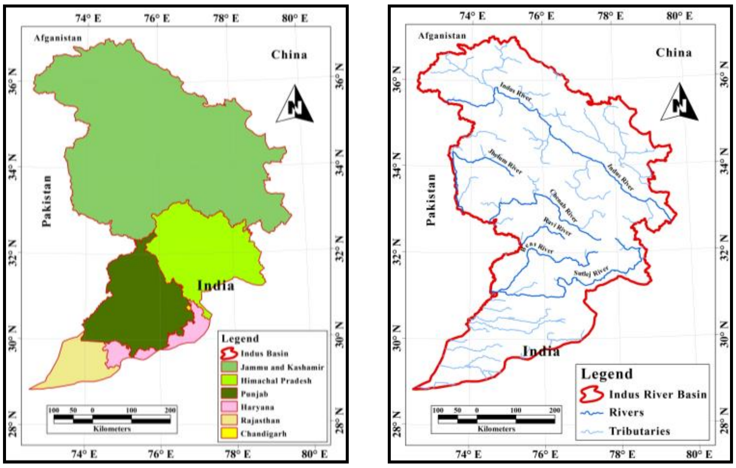


Figure 2: State-wise Area Distribution and Main River Channel and Tributaries of the Indus Basin

Table 1: Sub-Basins of the Indus River in India

Sr. No.	Tributary	Basin area in (sq.km.)	Length (Km.)
1	Jhelum River	34775 km^2	774 km
2	Chenab River	26755 km^2	960 km
3	Ravi River	14,442 km^2	720 km
4	Beas River	20,303 km^2	460 km
5	Sutlej River	19,827 km^2	1057 km

3. MAIN OBJECTIVES OF THE STUDY

a) To prepare mean monsoon seasonal and annual rainfall maps for the Indus basin and to examine temporal changes in seasonal, annual rainfall and extreme rainfall series.
b) Preparation of the isohyetal maps of 1 day of each of the selected severe rainstorms and to carry out Depth-Area Analysis,
c) Teleconnections between extreme rainfall in the basin and meteorological parameters such as Geopotentional height (gpm), specific humidity (gm/kg) and wind field in lower and middle atmosphere.
d) To examine water balance components during heavy rainstorm duration using hydrological model to delineated stream, tributaries, basin and sub basins, soil and land use classification.

4. DATA USED AND METHODOLOGY

4.1. Description of Data Sets Used

4.1.1. Observed Daily Gridded Rainfall and Mean Temperature Data Set

To study any climatic aspects about the daily rainfall characteristics, consistent data sets in time and space are more appropriate. Daily gridded rainfall data set at the resolution of 0.5^0 x 0.5^0, prepared by India Meteorological Department (IMD), Pune (Rajeevan, 2008) for the period of 1971 - 2005, have been used in the analysis. Irregularly spaced station data is thus transformed into regularly spaced grid data using certain interpolation method.

Daily gridded mean temperature data set at the resolution of 1^0 x 1^0, prepared by India Meteorological Department (IMD), Pune (Rajeevan, 2008) for the period of 1969-2005, have been used to run the hydrometeorological model.

4.1.2. PRECIS Model Simulated Data Set (Providing Regional Climate for Impact Studies)

Future projections of rainfall characteristics are essential for long term planning of hydraulic structures. Regional climate models, that well capture the local features affecting the climatology of an area, are the basic tools used to estimate future climate scenarios. Daily rainfall simulations at the end of 21st century, as generated by regional climate model PRECIS have been used here to project the future scenarios of hydroclimatic features. The model has been developed at Hadley centre UK and run at IITM (Indian Institute of Tropical Meteorology) to generate future scenarios.

4.1.3. NCEP - NCAR Reanalysis Data Sets

NCEP-National Centers for Environmental Prediction (NCEP) reanalysis data at pressure levels 850 hpa and 500 hpa on various parameters such as zonal / meridional wind (m/s), Geopotential height (gpm) and specific humidity (g/kg) at the resolution of 2.5^0 lat. x 2.5^0 long. for the rainstorm period 23th - 25th Sept. 1988 and 3th - 5th *Sept. 1995* retrieved from the Web site: *http://www.esrl.noaa.gov/psd/* is used in the analysis.

4.2. Methodology Used to Carry Out Analysis

To display various maps of the study area, it is essential to digitised map of the study area to display all the results of the analysis. For this, digitisation of the boundary points of the river basin have been carried out first using the scanned map of the Indus Basin. All the graphs in the analysis are prepared using the ArcGIS interface.

Daily rainfall data sets mentioned above are used in the analysis and using certain criteria, heavy rainstorms occurred in the past 50 years in the Indus basin are selected. Envelope curve for each of the observed, baseline and future projections are made. Spatial patterns of meteorological parameters namely, Geopotential height, Specific humidity at lower atmosphere (850 hpa) and Middle Atmosphere (500 hpa) are made and these maps have been examined to see their teleconnections with extreme rainfall pattern during the heavy rainstorm. Trend analysis of certain rainfall parameters such as seasonal and extreme 1-day rainfall has been carried out to study the temporal changes in these parameters in the Indus basin.

5. RAINFALL CLIMATOLOGY AND TEMPORAL CHANGES IN RAINFALL FEATURES OF THE INDUS BASIN

5.1. Introduction of Monthly, Seasonal and Annual Rainfall

Precipitation in the Indus basin varies over different catchments. The precipitation inclusive of snow is much heavier in the hills than in the plains. The Himalayas are a major barrier for the natural flow of the southwest monsoon. Precipitation in general increases from low land valleys to higher mountain slopes upto certain heights. The windward slope gets more precipitation than the leeward side. However, based on available information from different research publications over northwest Indian region, different portions of the Indus basin broadly get affected by the climatically.

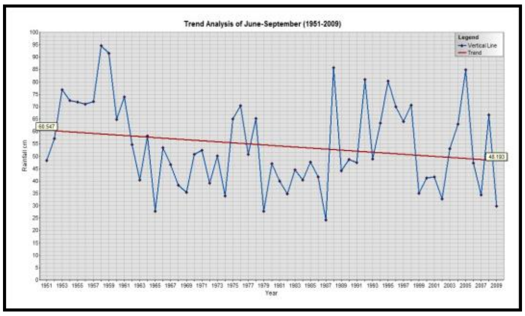
5.2. Meteorological Situations Responsible for Causing Heavy Rainfall over Indus River Basin

The basin under study is characterized by different climatic conditions from tropical to alpine. The upper portion of the basin receives good rainfall during the winter season due to the passage of weather disturbances known as “Western Disturbances” which moves along and across the Himalayas from west to east.

5.3. Temporal Changes in the Rainfall Features

The aim of the present study is to analyze rainfall time series over a wide time interval and a wide area, detecting potential trends and assessing their significance. Trend analysis is a mathematical technique that uses historical results to predict future outcomes. In the present study temporal changes in the Pre-monsoon, Monsoon and annual rainfall of the Indus basin have been examined using trend analysis over the time period 1951 - 2009.

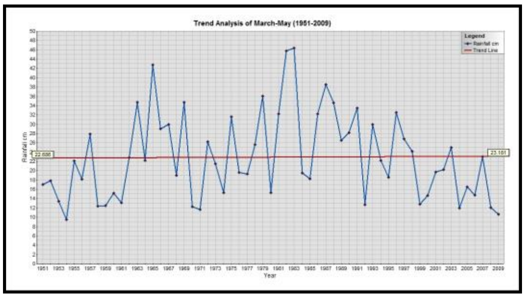
5.3.1. Trend Analysis of Summer Monsoon Rainfall (June-September)



Monsoon season is the chief rainy season in the basin. Average monsoon rainfall of the basin is 52 cm. Time series plot shows that maximum seasonal rainfall of 94 cm. occurred in the year 1958. While lowest rainfall of 24 cm. occurred in the year 1987 which is a sever drought year in India. High rainfall values observed in 1958, 1988 and 2005 above 84 cm. Decreasing trend is seen for monsoon rainfall in the basin.

Figure 3: Monsoon Rainfall Series and Fitted Linear Trend over the Period 1951-2009

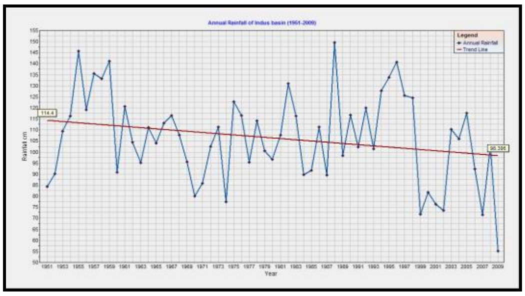
5.3.2. Trend Analysis of Pre-Monsoon Rainfall (March-May)



Pre-monsoon season is the second largest seasonal receiving good amount of rainfall. Figure 4 indicates pre-monsoon rainfall is slightly increasing (statistically insignificant) over the period 1951 - 2009. Maximum being in the year 1983 (47 cm.).

Figure 4: Pre-Monsoon Rainfall Series and Fitted Linear Trend over the Period 1951 - 2009

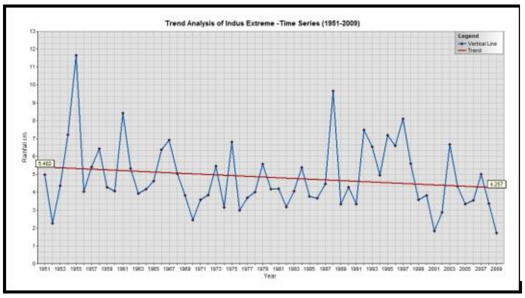
5.3.3. Trend Analysis of Annual Rainfall (Jan.–Dec.)



Average annual rainfall of the basin is 103 cm. Maximum of 150 cm has been observed in the year 1988, which is a flood year in India. Substantial decreasing trend has been noticed in annual rainfall.

Figure 5: Annual Rainfall Series and Fitted Linear Trend over the Period 1951 – 2009

5.3.4. Trend Analysis of Extreme Time Series Rainfall



The high rainfall values observed in 1955 and 1988 (> 9 cm.) and low rainfall values are seen in the years 1952, 1970, 2001, and 2009 (< 3 cm.). Such analysis is useful for planning, designing, and management of different types of hydraulic structures for optimum utilization of water resources in the basin. Such studies are crucial for the river basins like Indus which is located in highly orographic area where different rain bearing systems like south-west monsoon and western disturbances affect the basin.

Figure 6: 1day Extreme Rainfall Series and Fitted Linear Trend over the Period 1951 – 2009

6. RAINSTORM ANALYSIS

6.1. Selection of Heavy Rainstorms

Time series of basin rainfall on daily scale formed from observed, baseline and future scenario of daily simulations are used for the selection of heavy rainstorms. Screening these daily time series, days with rainfall exceeding 5cm (10% of the basin seasonal rainfall) have been first sorted out. Here the following criteria are used for the selection of heavy rainstorms: “Center value of the rainfall exceeds 25 cm. and the areal spread of the rainstorm should be at least 25000 sq.km. Peripheral isoline considered is that of 5cm”. To depicts the spatial patterns of these selected rainstorms over the Indus basin based on:

a. Observed data sets
b. Baseline representing present day climatology (used for validation of model simulations)
c. Future Projections

6.1.1. Rainstorms Selected from the Observational Data

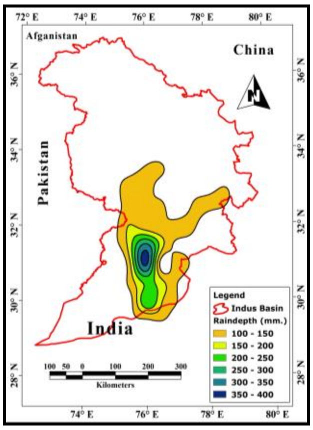


Figure 7: Isohyetal Pattern of 24th Sept. 1988 Rainstorm

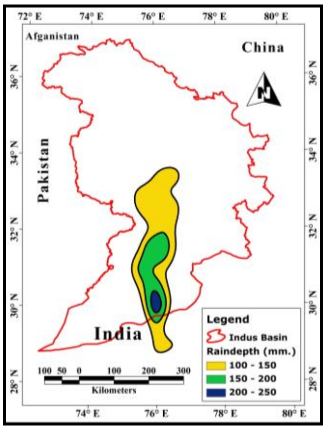
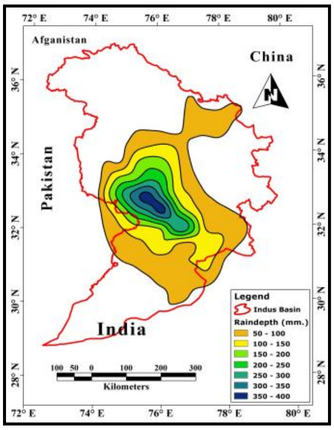


Figure 8: Isohyetal Pattern of 04th Sept. 1995 Rainstorm

Flood of September 1988 is one of the highest historic floods for the rivers Sutlej and Beas. The flood was caused by extremely heavy rains across the border in the upper catchments of the river Sutlej, Bias, Ravi and Chenab. Source of precipitation was the tropical low pressure system which could be located over Rajasthan on 24^{th} September. This observed rainstorm was oriented elliptically in South - North direction.

This rainstorm was observed in the southern part of the Indus basin. Rainstorm recorded center raindepth of 25 cm. The rainfall during 04th September 1995 was caused due to the passage of a low pressure area which originated from the Bay of Bengal on September. Rainstorm was oriented in North-South direction. This rainstorm covers less area of the Indus basin as compared to 1988 rainstorm.

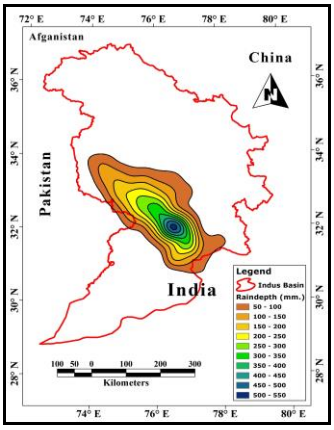
6.1.2. Rainstorms Simulated by RCM as Baseline Projections



The examination of baseline rainfall data showed that rainstorm of Sept 1965 was severe most. This rainstorm covered 40% area on Indus basin. Rainstorm extents from South-East to North-West direction. The rainstorm highest raindepth (350 - 400 mm.) has covered very small area but 50 - 100 mm. rain depth has covered the large area. This rainstorm is located in the central part of Indus Basin. This is the baseline simulated rainstorm also from September month. This rainstorm extent from South-East to North-West direction. The 50% rainstorm lies outside the Indus Basin.
This is the baseline simulated rainstorm also from September month. This rainstorm extent from South-East to North-West direction

Figure 9: Isohyetal Pattern of Baseline Rainstorm Present Climate - Sept 1965

6.1.3. Rainstorms selected from the future projections of rainstorms at the end of 21st Century (2071 – 2100)



Spatial patterns of the rainstorm simulated by the model as future projections is shown in Figure. Figure indicates that rainstorm extents from East to North West direction. The entire rainstorm lies in the Indus basin (peripheral Isoline is of 5 cm). Wind direction, Air pressure, humidity and weather conditions support to the occurrence of this rainstorm. This rainstorm located in the central part of the Indus basin. The Himalayas act as a major barrier for the natural flow of the southwest monsoon. Most of the rainstorms selected, shown by model are seem to be occurred in the month of September. Map depicts projected rainstorm condition for future scenarios at the end of 21st century on Indus Basin. Nearly 70% rainstorm area lies inside the Indus basin. Map depicts projected rainstorm condition for future scenarios at the end of 21st century on Indus Basin.

Figure 10: Isohyetal Pattern of Future Projections of Rainstorms at the end of 21st Century (2071 - 2100)

6.3. Estimation of Average Raindepths and Envelope Depth-Area Curves

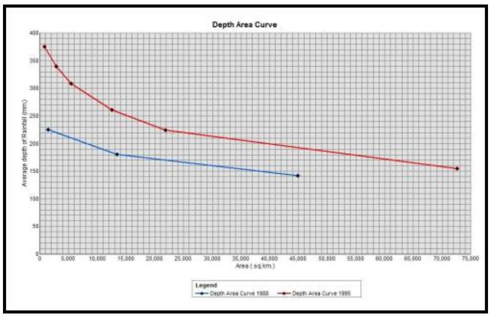
Different methods of estimation of areal averages are mentioned here.

6.3.1. Isohyetal Method

This is commonly used method for averaging precipitation over an area under study, is the isohyetal method. Rainfall values are plotted at their respective stations on a basin map and isohyets are drawn at suitable interval. **The same method has been applied in the analysis**.

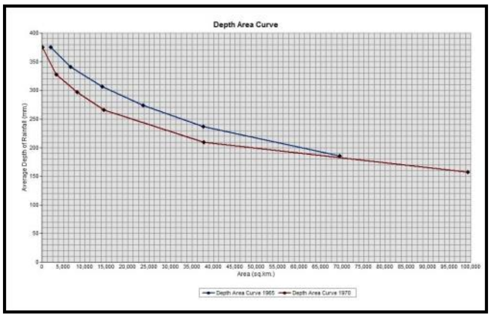
6.3.2. Depth-Area Curve

Various hydrologic problems concerning river valley projects require analysis of time as well as areal distribution of storm precipitation. For this purpose comprehensive study of all the rainstorms that have occurred within or in nearby area of the basin, is made by the procedure explained above, and the envelope curves are obtained by Depth-Area-Duration analysis for an area. The envelope curves have been created here in Arc Map Software in GIS techniques. Out of these curves, only curves corresponding to heaviest and most intense rainstorms are utilized for constructing the Envelope curves. Envelope curve as one which envelopes all the Depth-Area curves and which corresponds to highest depths corresponding to different areas.



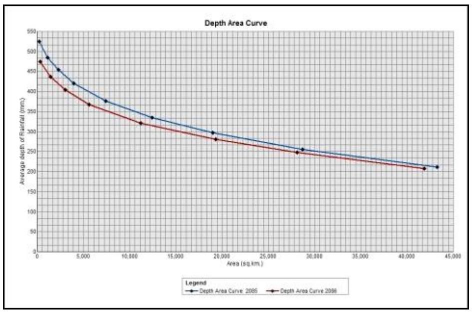
The above graph presents rainstorm analysis envelope curve in 1988 and 1995 year. In 24th Sept. 1988 observed the very highest rainstorm and lowest one is observed in 04th Sept. 1995 rainstorm in the Indus basin. The 1988 rainstorm analysis envelope curve identify cumulative frequency 72588.42 sq. km. area covered and that time 1995 rainstorm analysis envelope curve identify of rainfall cumulative frequency 44835.20 sq. km. area covered.

Figure 11: Depth Area Curve on Observed Rainstorm from 1988 & 1995



The graph shows the envelope curve for baseline rainstorms. One of the rainstorms identifies large raindepth but area covered is less. In 1970 baseline the very highest rainstorm and lowest one is baseline in 1965 rainstorm in the Indus basin. The 1965 rainstorm analysis envelope curve identify cumulative frequency 69411.22 sq. km area covered and that time 1970 rainstorm analysis envelope curve identify of rainfall cumulative frequency 43244.99 sq. km. area covered.

Figure 12: Depth Area Curves on Baseline Rainstorms from 1965 & 1970



The graph shows envelope curve of projected rainstorms during 2085 & 2086 year. The 2085 rainstorm covered an area of 43244.99 sq. km. area and that of 2086 rainstorm covered the area of 41873.74 sq. km. Envelope curve as one which envelopes all the Depth-Area curves and which corresponds to highest depths corresponding to different areas

Figure 13: Depth Area Curve on Future Rainstorm from 2085 & 2086

7. METEOROLOGICAL SITUATIONS IN THE ATMOSPHERE DURING RAINSTORM PERIOD IN THE INDUS RIVER BASIN

7.1. Introduction

Present study investigates the meteorological conditions, in detailed, prevailing during heavy rainfall over the Indus basin. Spatial patterns of different meteorological parameters in the lower atmosphere (850 hpa) and middle atmosphere (500 hpa) are made and studied to examine their interrelationship with that of heavy rainfall in the basin. Data on Meteorological parameters such as geopotential height which shows pressure patterns, Specific Humidity which tells about the moisture availability in the atmosphere and wind field which indicate the direction of moisture inflow in the area of low pressure.

7.2. Geopotentional Height:-

The term 'Geopotential Height' as it applies to the area of the weather can be defined as the height above sea level of a pressure level. For example, if a station reports that the 500 mb height at its location is 5600 m, it means that the level of the atmosphere over that station at which the atmospheric pressure is 500 mb is 5600 meters above sea level. Geopotential height contours are represented by the solid lines. The small numbers along the contours are labels which identify the value of a particular height contour. This example depicts the 500 mb geopotential height field and temperatures (colour filled regions). Geopotential height is valuable for locating troughs and ridges which are the upper level counterparts of surface cyclones and anticyclones.

7.2.1. Spatial Patterns of Geopotential Height of 1988 Rainstorm

a) 24^{th} Sept. 1988

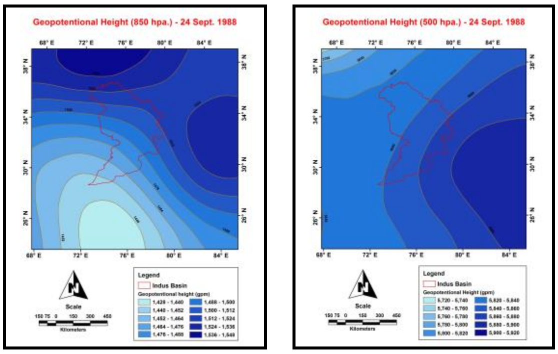


Figure 14 shows Geopotential height patterns at (850 hpa & 500 hpa) over and nearly Indus basin during the rainstorm period of 24^{th} Sept. 1988. Low pressure area at lower tropospheric level located at the location (24^0 N and 76^0 E) pressure. Such low pressure is not extended in the middle atmosphere. Light blue color shows low pressure region while dark blue color indicate high pressure region. On 24^{th} September this low pressure area moved near to the Basin and lies at (25^0 N and 74^0 E). Large portion is covered by this low pressure area.

Figure 14: Geopotentional Height of 850 hpa. & 500 hpa. on 24^{th} Sept. 1988 in the Indus Basin

7.2.2. Spatial Patterns of Geopotential Height of 1995 Rainstorm

a) 04^{th} Sept. 1995

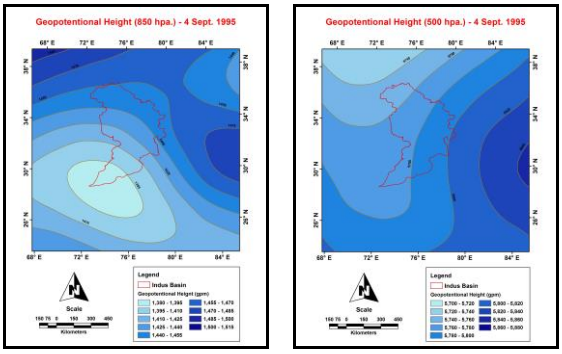


Figure 15 depicts the rainstorm period 4^{th} Sept. 1995 at lower and middle atmosphere. Minimum geopotential height located at 26^0 N and 77^0 E is of the order of 1400 gpm. These indicate the low pressure area located at this region. Vertically it is seen upto 500 hpa indicating intense low located over this area. Another low pressure area is associated with western disturbance moving eastward and approaching the basin. Combined effect of these two low pressure areas caused very heavy rainfall in the basin. The low pressure area moved the North West direction on the 4^{th} Sept. 1995 and thereafter reduced its intensity.

Figure 15: Geopotentional Height at 850 hpa. & 500 hpa. on 04^{th} Sept. 1995 in the Indus Basin

7.3. Specific Humidity

Humidity is the amount of water vapor in the air. Water vapor is the gas phase of water and is invisible. Humidity indicates the likelihood of precipitation, dew, or fog. There are three main measurements of humidity: absolute, relative and specific. Specific humidity means mass of water vapor in a unit mass of moist air, usually expressed as grams of vapour per kilogram of air. The specific humidity does not vary as the temperature or pressure of a body of air changes, as long as moisture is not added to or taken away from it. The specific humidity of saturated air increases rapidly with increasing temperature. Specific humidity is at a maximum in the tropics and declines as one moves pole ward reaching minimum values in each polar region.

7.3.1. Spatial Patterns of Specific Humidity 1988 of Rainstorm

a) 24^{th} Sept. 1988

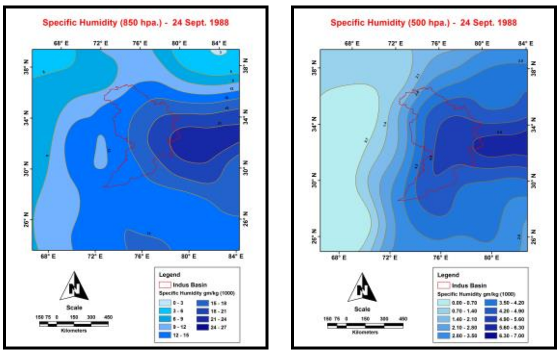


Figure 16 indicates high values of the specific humidity over the basin on 24^{th} September indicate the maximum moisture availability for precipitating over the basin. Middle atmosphere does not show any change in the specific humidity pattern.

Figure 16: Specific Humidity (850 hpa. & 500 hpa.) on 24^{th} Sept. 1988 in the Indus Basin

7.3.2. Spatial Patterns of Specific Humidity 1995 of Rainstorm

a) 04th Sept. 1995

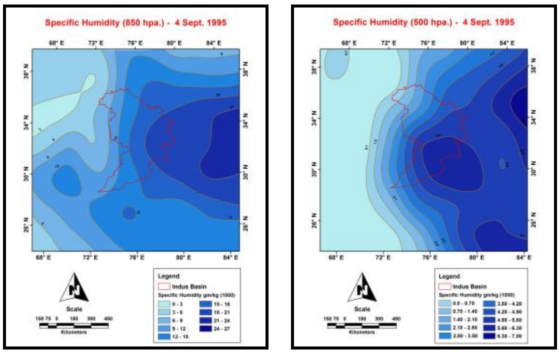


Figure 17: Specific Humidity (850 hpa. & 500 hpa.) on 04th Sept. 1995 in the Indus Basin

Figure 17 indicate that moisture availability was more on 4th Sept. causing heavy rainfall over the basin. On 4th Sept. this maximum moisture region moved towards eastward due to westerly winds.

7.4. Wind Patterns (Wind Speed and Wind Direction)

7.4.1. Spatial Wind Pattern of 1988

a) 24th Sept. 1988

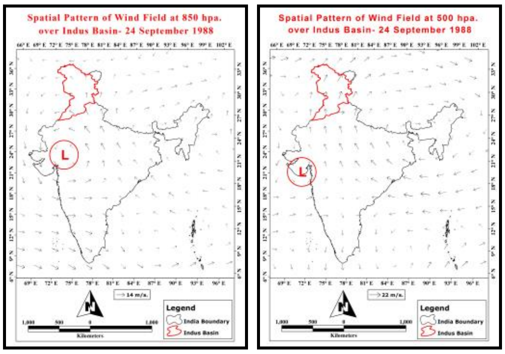


Figure 18: Spatial Wind Pattern (850 hpa. & 500 hpa.) on 24th Sept. 1988 in the Indus Basin

Figure 18 represent the wind field in low pressure area is located along Gujarat and Rajasthan region moved further northward and stagnated there for 2 days and then it dissipates causing heavy rainfall over the basin on 24th Sept. Heavy Rain occurred on 24th Sept. even after the moving away (east wards) of the upper air westerly trough due to the sustained low level cyclonic circulation over Rajasthan. Recurvature of this low pressure area caused by the presence of Tibetan anticyclone.

It can be seen from these figures that under the effect of the strong westerly trough which resulted in the strong moisture incursion from the Arabian Sea.

b) 04th Sept. 1995

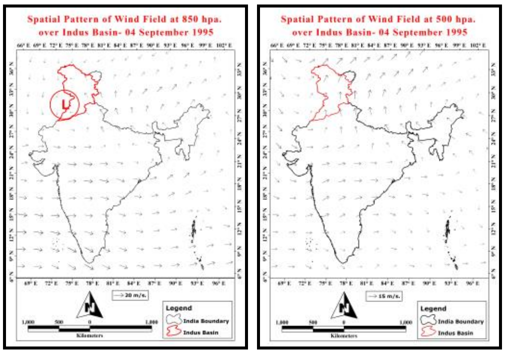


Figure 19: Spatial Wind Pattern (850 hpa. & 500 hpa.) on 04th Sept. 1995 in the Indus Basin

Figure 19 represent the wind field in lower as well as middle atmosphere during the rainstorm of 1995. Cyclonic circulation is seen over Gujarat which has been extended in middle atmosphere. Westerly trough is also seen in the middle atmosphere strengthening the rainfall activity in the basin. On 4th September low pressure area dissipates and appears only in lower troposphere.

8. SUMMARY AND CONCLUSIONS

Main Objective of the study is to use the latest technique of GIS to analyze the hydrometeorological. Remote sensing datasets on global land/soil freely available in GIS format on different websites are downloaded and use to run the hydrological model. ArcMap 10.2 version which is available at IITM, Pune is used.

Present study attempts to examine the projected hydro-climatic features of the major river basins in India in warming scenarios, which is done by analyzing the daily rainfall simulations from second generation regional climate model (PRECIS). Such studies are very useful for hydrological and agricultural planning and also for proper management of water allocation within these river basins.

The study emphasizes the rainstorm analysis (observed and future projections) which is the key feature of the analysis. Another key feature of the study is to display and analysis the meteorological parameters to study their interrelationship with extreme rainfall over the basin.

Outcomes of the analysis of the seasonal, annual and extreme rainfall patterns in the Indus basin located in the northern parts of India. Mean monsoon seasonal and annual rainfall maps for the Indus basin are prepared and temporal changes in seasonal, annual rainfall and extreme rainfall series are examined. Trend analysis of certain rainfall parameters such as seasonal and extreme 1-day rainfall has been carried out to study the temporal changes in these parameters in the Indus basin.

Main focuses on the rainstorm analysis and its importance in hydrological point of view. Time series of basin rainfall on daily scale formed from observed, baseline and future scenario of daily simulations are used for the selection of heavy rainstorms.

The teleconnections between extreme rainfall in the basin and simultaneous meteorological situations in lower and middle atmosphere. Spatial patterns of 3 meteorological parameters namely, Geopotential height, Specific humidity and wind field are made and these maps have been examined to see their impact in causing extreme rainfall over the basin.

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