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Full Length Research Paper

Unusual rainfall shift during monsoon period of 2010 in Pakistan: Flash flooding in Northern Pakistan and riverine flooding in Southern Pakistan

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Floods due to "blocking event" in the jet stream during 2010 caused intense rainfall and flash floods in northern Pakistan which resulted to riverine flooding in southern Pakistan. In the beginning of July 2010, changes in summer monsoon rainfall patterns caused the most severe flooding in Pakistan history. Process control charts suggest that monsoon pattern was not normal which made one-fifth of the country to be inundated. In this study, our main concern was to check the upward shifts (floods) in the rainfall pattern of all provinces of Pakistan. Results indicate that there was significant and sudden shift in the rainfall pattern of monsoon in 2010 which might be due to prolong "blocking event" in the jet stream. In late July, rainwater from the highlands entered major rivers which affected nearby areas of the Indus River. More than 250 mm of rain fell over a 36-h period in late July. Abeyant policies by the Pakistan Irrigation Department (PID) caused destruction in Jacobabad which was not a normal Indus waterway. The first week of August marked the worst week of extreme flooding in southern Pakistan. Flood simulation overlay technique showed the affected areas of the country in comparison with normal waterways by using vector and raster data images.

Key words: Indus River, monsoon, flooding in 2010, rainfall pattern, Climate Change, Floods.

INTRODUCTION

Natural disasters are common in today's world. They happen as a result of sudden changes in the state of natural elements. Flooding is one of the catastrophic natural hazards that take place every year around the globe. Pakistan is a country built around the Indus- the green swathe that cuts north-south across the deserts of central and southern Pakistan and essentially defined by Indus River and its tributaries (Figure 1). There are two major hydro-climatic factors which are responsible for flooding in Pakistan (Indus River basin). The first factor is the melting of snow cover in northern Pakistan while second factor of flooding is attributed to monsoon period (Shamshad, 2011). Flooding in Pakistan during 2010 was due to unusual shifts in the rainfall pattern during monsoon season. Monsoon is the periodic rainfall season which is responsible for the heat stabilization and land-mass warming by series of precipitation and/or rain-storms. In Indian subcontinent, climate is being controlled by tropical monsoon period which is the seasonal reversal of winds between late June and late September. During early July to late August of 2010, northern Pakistan and northwestern India faced one of the biggest natural

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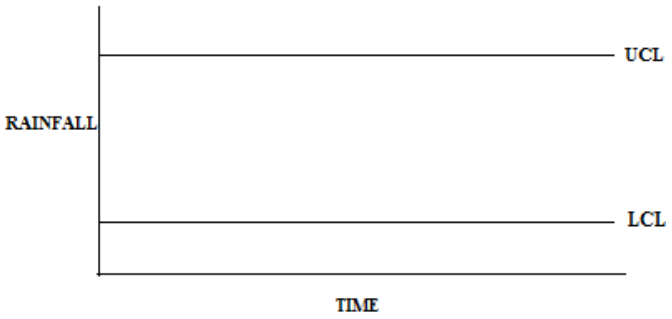

Figure 1. Basic theme of control chart with fixed upper and lower limits for floods and droughts.

disasters in the form of flash floods (Chi-Cherng et al., 2011), while riverine flooding were observed in southern Pakistan (Webster et al., 2011). Indus River, the longest river of Pakistan, was over-flooded during this period and was the main cause of riverine flooding in southern Pakistan as rainfall water receded downward towards Indian Ocean. Normal waterways of Pakistan along with the length of Indus River are shown in Figure 2. Tropical rainfall measuring mission satellites rainstorm structures also explained that rainfall behavior was not normal during 2010 in Indian Subcontinent (Houze Jr. et al., 2011).

In addition to this, the phenomenon of high rainfall was also correlated with another disastrous natural event called Russian heat wave-wildfire due to “blocking event” in subtropical Jet stream (William and Kyu-Myong, 2012). Jet streams are great rivers of air that ring earth at levels in the atmosphere ranging from 7 to 8 miles (11 to 13 km) above the surface. The subtropical jet stream is a permanent feature flowing west to east. Blocking event froze the meander of jet stream for approximately, 36 days because jet stream stops when an area of high pressure air forms, which is stronger enough to stop the normal flow of the jet stream from west-to-east as shown in Figures 4 and 5. This halting of jet stream allowed more fuel recharge (moisture content) from Arabian Sea and finally, resulted into unusual shift in the monsoon pattern and high rainfall in northern Pakistan because the upward movement of trade winds was to balance the effects of climate change in terms of pressure gradient (Figure 5). The whole picture reflects the intense precipitation and flash flooding in northern areas which, further, affected the downstream areas in terms of riverine flooding as rain water rolled across the length of country.

The study was conducted to show the variations and unusual shifts (upward and downward) during 2010 in the normal rainfall pattern of monsoon. Upward shifts explain flooding periods while downward shifts elucidate drought seasons in rainfall pattern. Permanence in downward shifts explains the desertous environment in some regions of southern Pakistan, that is, Thar Desert. Moreover, affected inundated areas were illustrated in polygons.

MATERIALS AND METHODS

In this study, rainfall data of 900 days for all the four provinces of Pakistan including Azad Jammu Kashmir (at each rainfall station) was collected from Pakistan Meteorological Department (PMD). Average rainfall rate, in millimetre, for each month was computed by taking average of daily measured rainfall of each station and the process was repeated for all the provinces viz: Azad Jammu Kashmir (AJK), NWFP, Punjab, Baluchistan and Sindh. Finally, rainfall data was summarized for all the stations to generate a single value for the representation of rainfall behavior. Data source was Pakistan Meteorological Department (PMD) which is located at Flood Forecasting Division, 46-Jail Road Lahore, Pakistan. Finally, data was plotted in excel sheet with upper and lower limits defined according to definition of floods and droughts. On average basis, rainfall rate for floods was fixed to 200 mm/month (> 100 mm/h) (Robert, 2004) while rainfall rate for droughts was fixed to 20 mm/month (< 25 cm/year). If rainfall rate remains less than 20 mm for longer periods of time, more than a year, succession of droughts will turn the green land into desert (Robert Maliva and Thomas Missimer, 2012). Basic ideology behind the experimentation was process control with fixed upper and lower control limits whose illustration is shown below:

The second objective of this research work was to integrate flood simulation model, remotely sensed data with topographic and spatial data in a GIS environment for flood risk mapping in the flood plain of Indus River in Pakistan. GIS based overlay analysis was done by using software MapPro Maker and Arc View 3.1. Data source for waterways of Pakistan was http://pakgis.blogspot.com/ which was further compiled in Arc View and adobe photoshop to mark the places (Figure 2). MapMaker Pro, compared to other packages, was more convenient and easy to use for analysis regarding GIS overlay technique based on raster and vector data images. Vector data images were used to illustrate normal water ways (red lines) which were merged with topographic raster data images showing abeyant behavior of water flow in Indus River and inundation in Pakistan (blue polygons) as shown in Figure 3. Lastly, layers were merged together based on themes union and MapMaker Pro was used for the impact analysis mainly for inundation.

RESULTS AND DISCUSSION

Daily rainfall data of 900 days from all the provinces elucidate more than 250 mm of rain fell over northern Pakistan in July 2010. Gradient coloring of line chart for each province is divided into red, yellow, green and brown zones. Red zone is the representation of intense rainfall which is beyond the upper control limit (UCL) whereas brown zone is the indication of droughts which are lower than lower control limit (LCL). Results illustrate that there was intense rainfall in three provinces, that is, Azad Jammu Kashmir, NWFP and Upper Punjab including federal (Figure 6). Maximum rainfall is observed in Azad Jammu Kashmir which is, approximately, at 4900 feet elevation and ultimately resulted into flash as shown in Figure 7 (Houze Jr. et al., 2011). Punjab also get intense rainfall (>250 mm) and faced riverine flooding in lower Punjab due to settlement of people on floodplain areas (Figure 8). Similar results are observed for NWFP

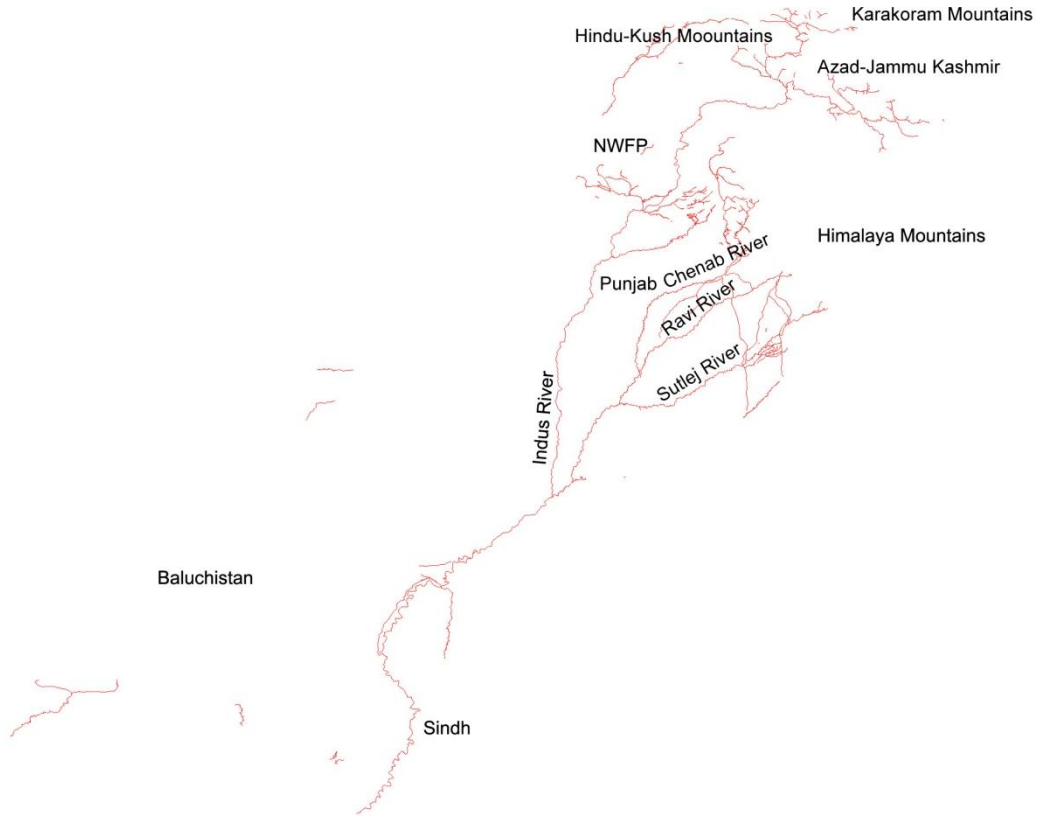

Figure 2. Normal waterways of Pakistan along with the length of Indus River.

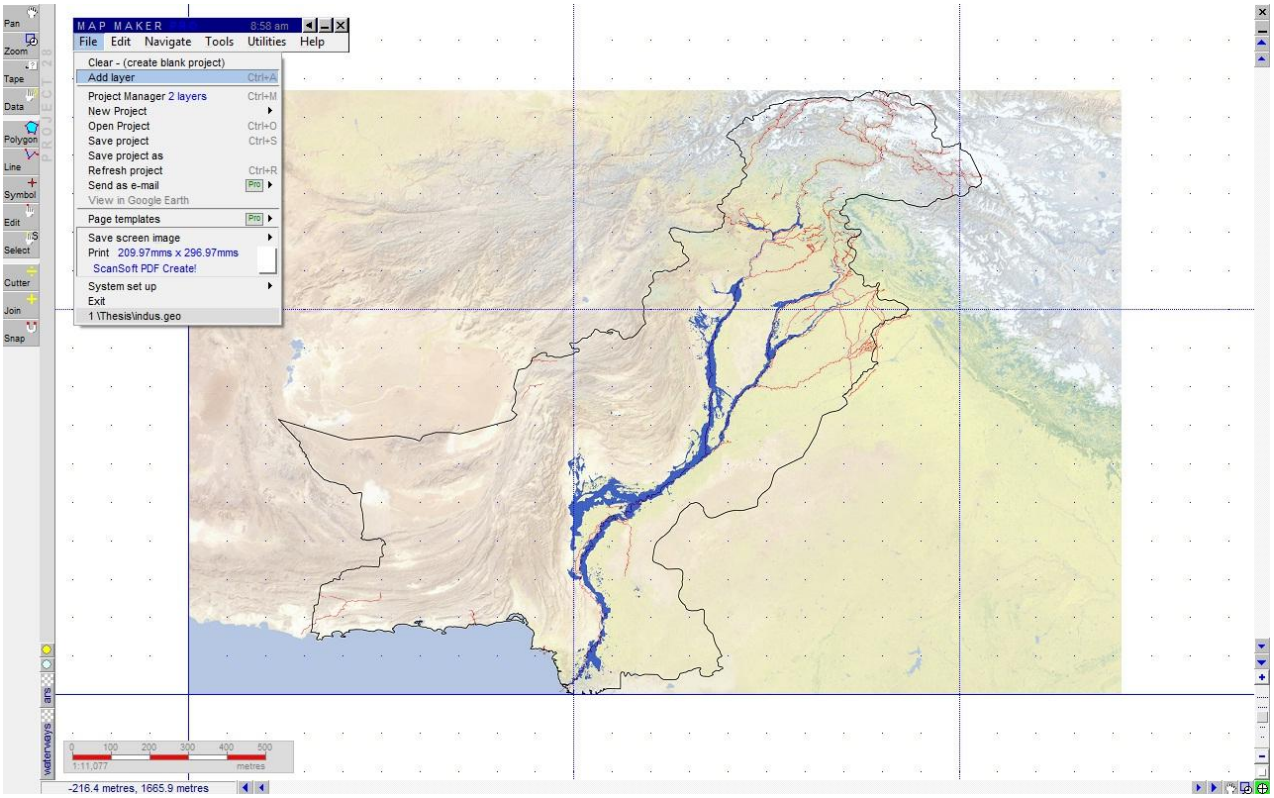

Figure 3. Water Inundated areas (blue polygons) with normal waterways (red lines).

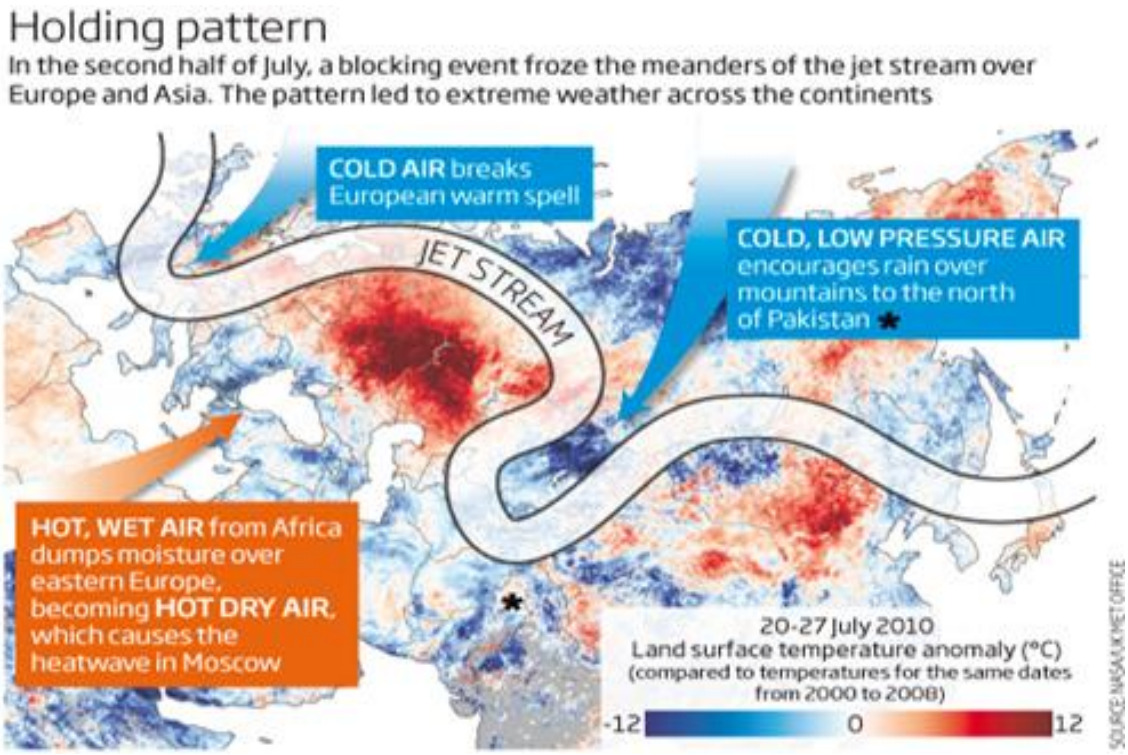

Figure 4. Frozen meander of jet stream showing blocking event
(Source: http://www.newscientist.com/article/mg20727730.101-frozen-jet-stream-leads-to-flood-fire-and-famine.html)

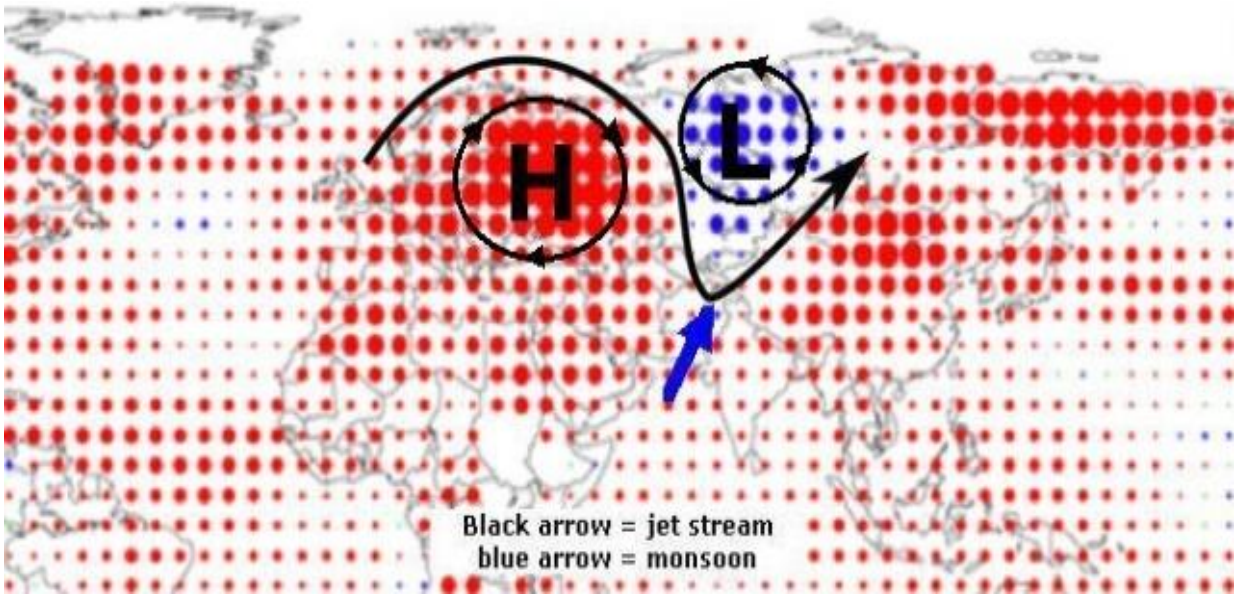

Figure 5. Pressure gradient created in subtropical jet stream during blocking event
(Source: http://www.newscientist.com/article/mg20727730.101-frozen-jet-stream-leads-to-flood-fire-and-famine.html)

as shown in Figure 9. Upward shift during 2010 was very abrupt and sudden as compared to monsoon periods of 2008 and 2009. The sudden, significant and unusual shift in July 2010 is attributed to changes in rainfall pattern which lead to extreme rainfall events at Gilgit-Baltistan and AJK as explained by Lau et al. (2012). Lau et al. (2012) have also correlated this phenomenon of extreme rainfall with excitation of Rossby wave train of Russian

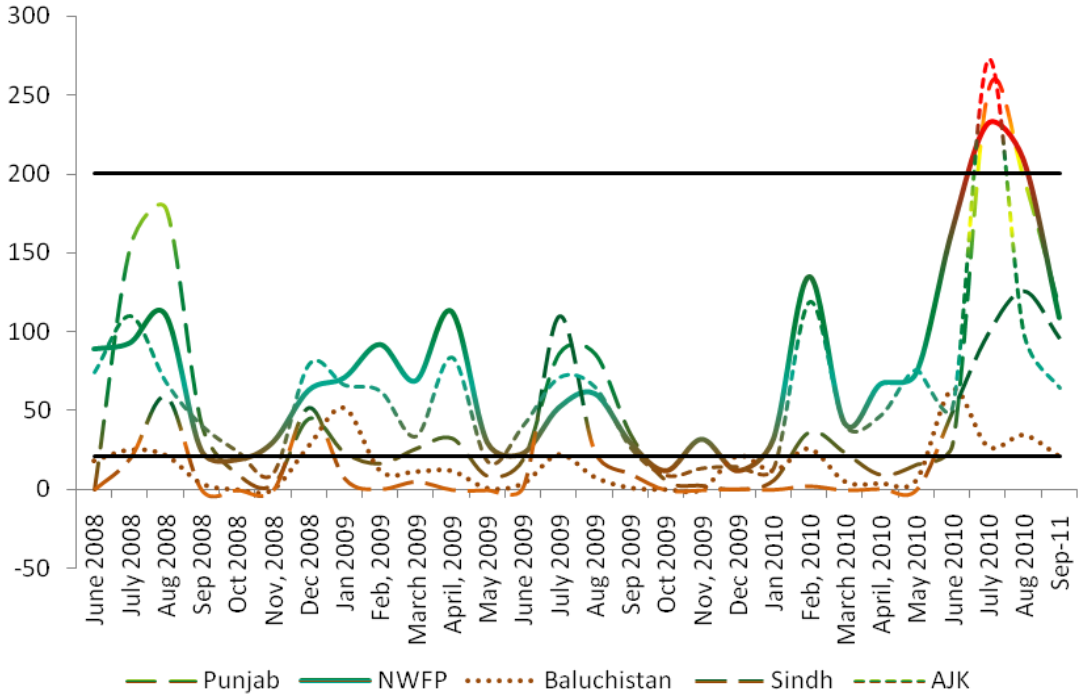

Figure 6. Rainfall data of all of the provinces for 900 days showing high rainfall in July 2010

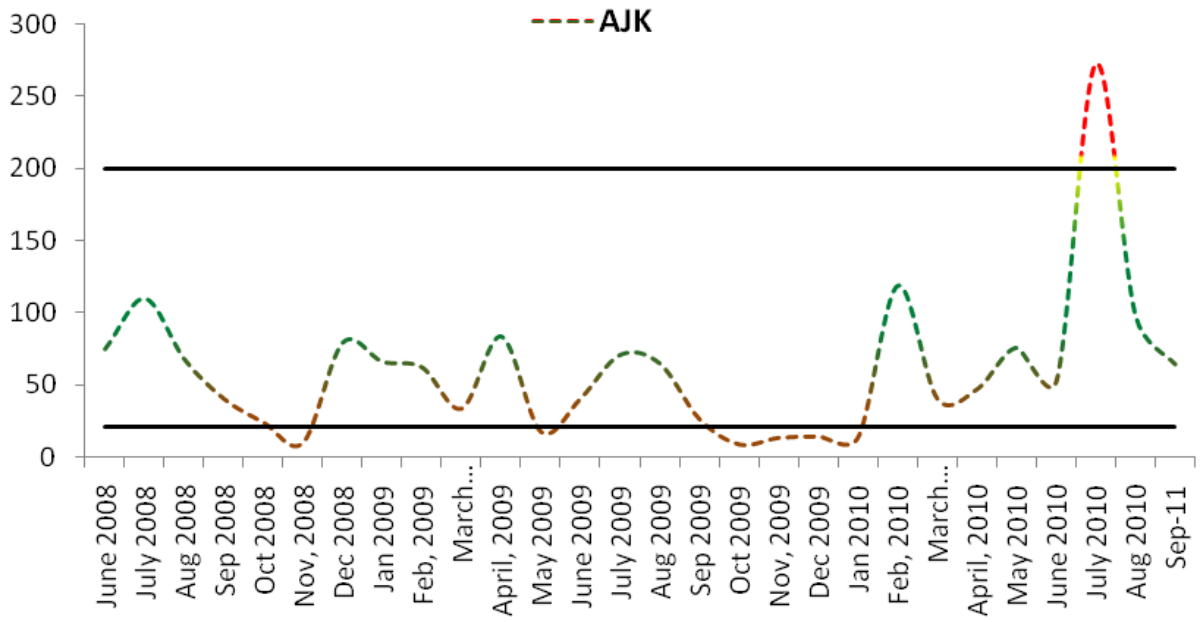

Figure 7. Rainfall data of Azad Jammu Kashmir for 900 days showing high rainfall in late July to early August 2010.

wildfires. Rossby wave train is meandering over Gilgit-Baltistan and northwestern China-Tibetan Pleatue region which reflects the association of two natural disasters occurring at the same time. Due to these reasons, intense rainfall and extreme flooding was observed in northern Pakistan which led to a big calamity in the history of Indian Subcontinent. According to previous records, extreme rainfall events of flooding have happened between 26th and 30th August 1929 and 31st July to 3rd August 1976 (Shamshad, 2011) but their impacts were not as much as in 2010 (OCHA, 2010). Monsoon rainfall season of 2010 is reported to be greatest natural disaster in previous 110 years history of the continent (UN Report).

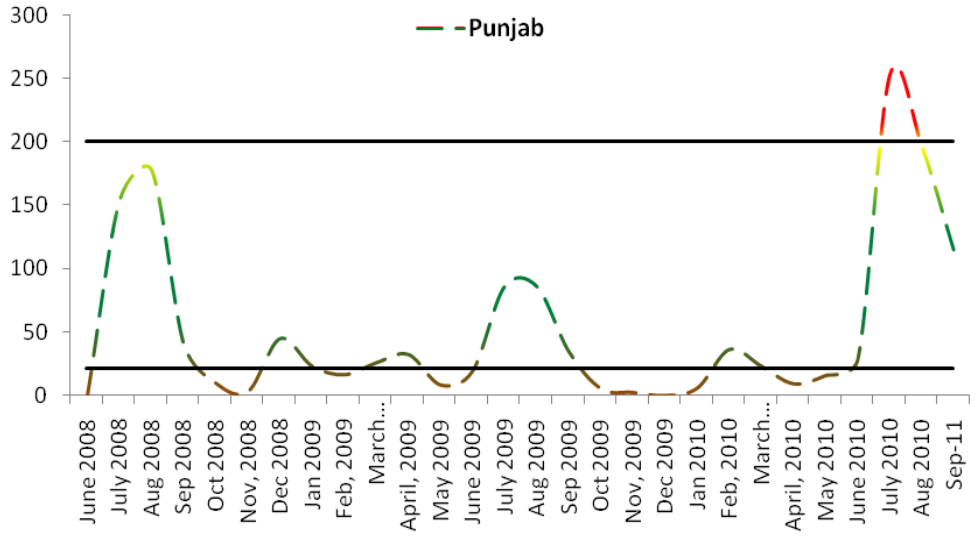

Figure 8. Rainfall data of Punjab for 900 days showing high rainfall in late July to early August 2010

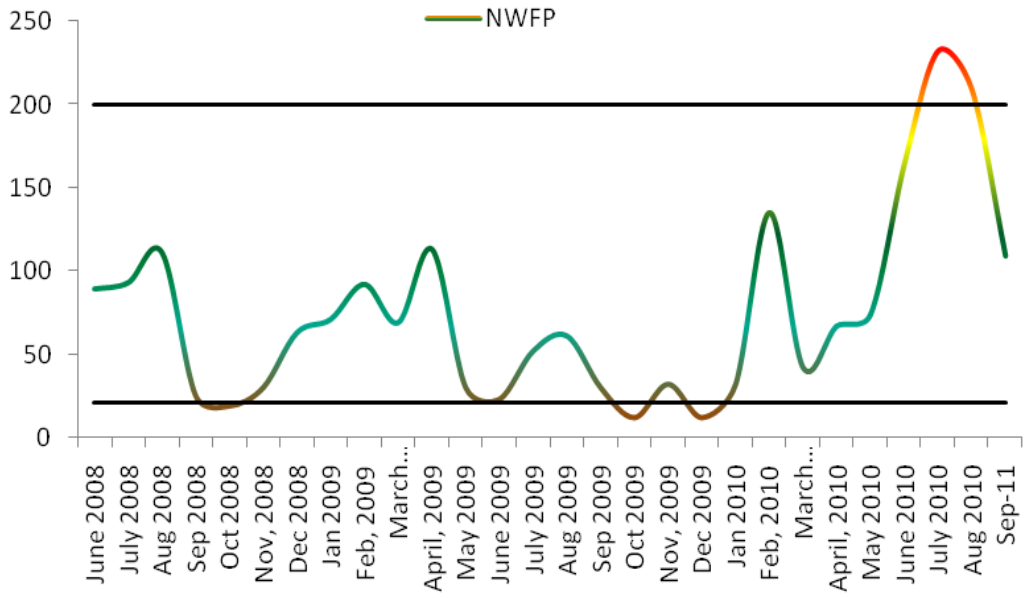

Figure 9. Rainfall data of NWFP for 900 days showing high rainfall in late July to early August 2010

In southern Pakistan, Baluchistan and Sindh, rainfall was not as much intense as it was in the northern areas but losses were reported in term of riverine flooding. Hereby, rainfall data show that there are consecutive periods of droughts in Baluchistan and Sindh which have converted the land of these provinces into desert (Figures 10 and 11). In Baluchistan, very low rainfall was observed even in monsoon periods due to its north-western geography which has very low influence on monsoon. Whereas, province Sindh faces seasonal rainfall as compared to Baluchistan but at lower extent though it is also desertous arid environment due to droughts in rest of the periods. However, in 2010, high rainfall in highland mountainous areas caused flood water to recede into the low lying areas and finally rolled across the length of the country. This created high water level in Indus River with the passage of time. Prior to destruction in floodplain areas, GIS based raster data images and GIS overlay technique illustrates the destruction of those areas which are not along normal waterways. This was due to poor water management policies of Pakistan government which lead to the destruction as in the case of Jaccobabad as shown in Figures 3 and 12. By overlaying the waterways of vector data image on inundated areas of raster data image, flood affected areas have been shown in blue polygons as compared to normal waterways in red lines. Intense monsoon rainfall season affected one fifth of the total area of Pakistan affected due to primary and

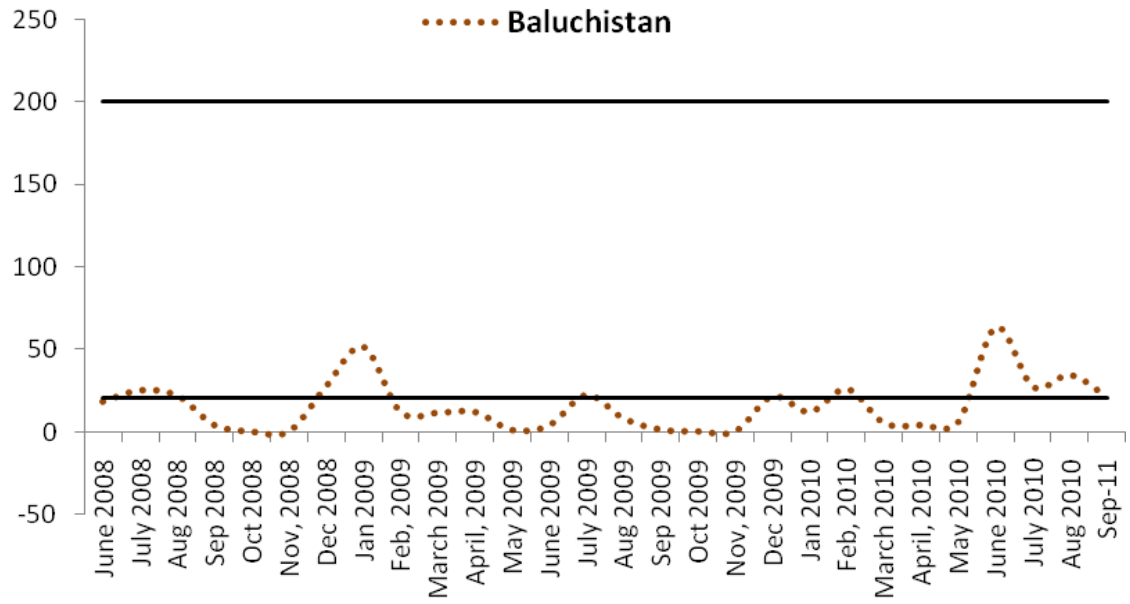

Figure 10. Rainfall data of Baluchistan for 900 days showing continuous droughts in rainfall pattern elucidating the desertous nature of the region

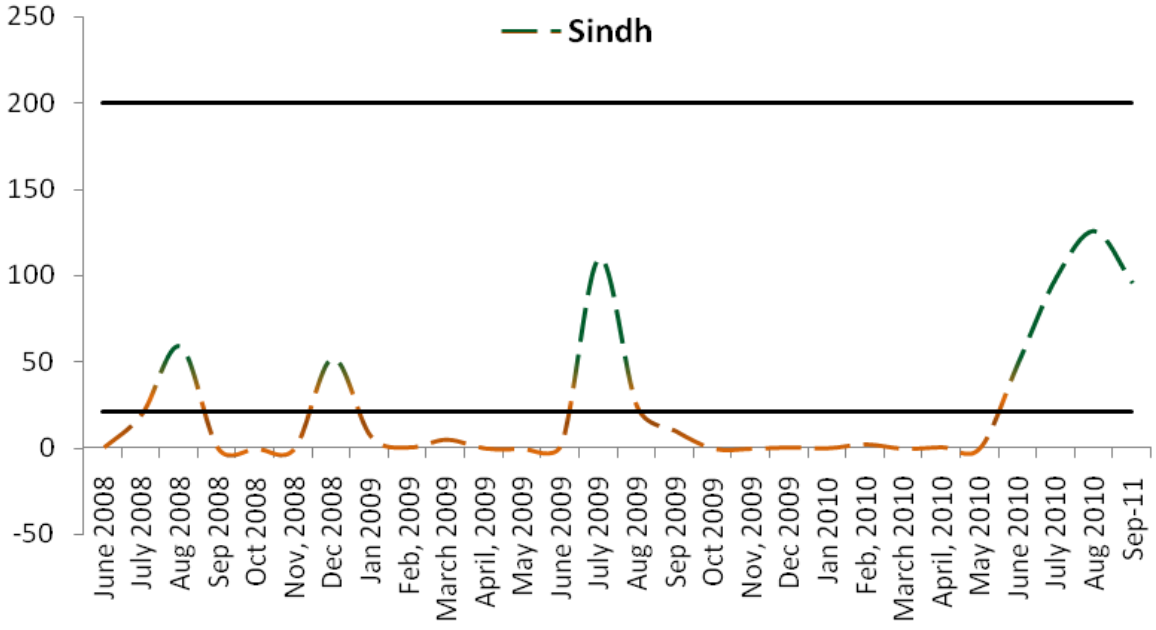

Figure 11. Rainfall data of Sindh for 900 days showing droughts in general rainfall pattern with three consecutive monsoon periods.

secondary effects (OCHA, 2010).

In early August 2010, two weeks of devastating monsoon rains transformed the landscape of Pakistan by pushing rivers over their banks, inundating villages, washing away bridges and roads, destroying crops and killing livestock. According to reports by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA, 2010), more than 14 million people were affected in the middle of August. By comparing the water level in Indus River during monsoon season of 2009 with monsoon 2011, the Indus River appears as a thin river towards north of Sukkur with a skinny meandering waterway as compared to water level of Indus River in 2010 (Figures 13 and 14). In 2010, the river completely filled the river valley, merged the braided streams north of Sukkur, and pushed water over riverbanks in places.

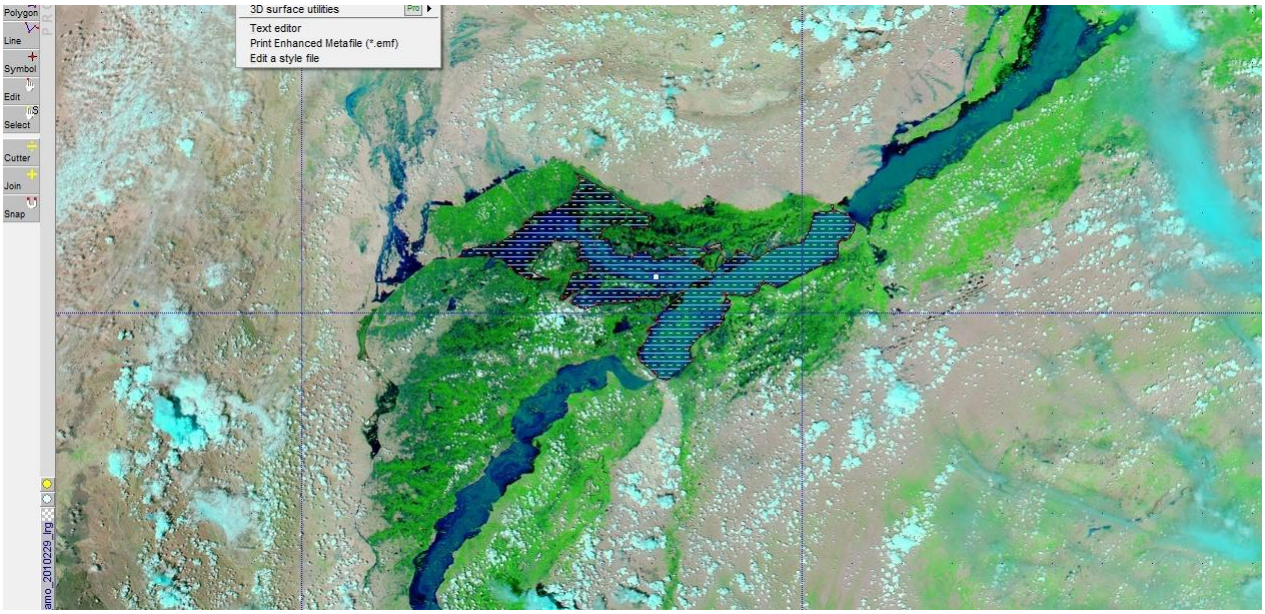

Figure 12. Water Inundation and destruction in Jaccoabad during late August 2010.

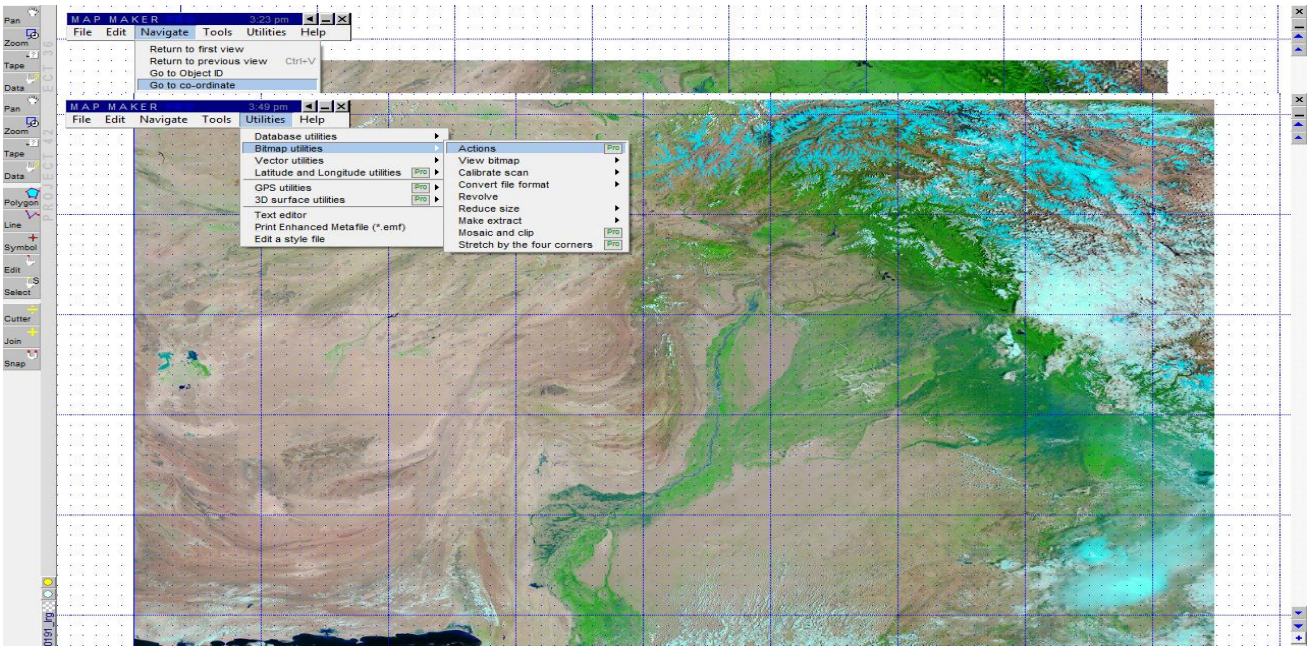

Figure 13. Monsoon Period of 2009 (18 August) showing water in Indus River. Source: NASA Earth observatory.

Northwest of the river valley, around the city of Sibi, standing water is evident on what appears to be normally arid ground as shown in Figure 14. Rainfall and flooding was also observed in 1929 and 1976, but the effects of flooding were not as much as they were in 2010. This might be due to the fact that population settlement on flood plains was not as much as it was in 2010. With the increase of population, people started living on flood plains to acquire the available resources but heavy rainfall heavy and flooding in 2010 destroyed their infrastructure, property, homes and lives.

Conclusion

In environmental studies, climate change is of prime importance because it can directly and indirectly affect the environment. Climate studies always played a major

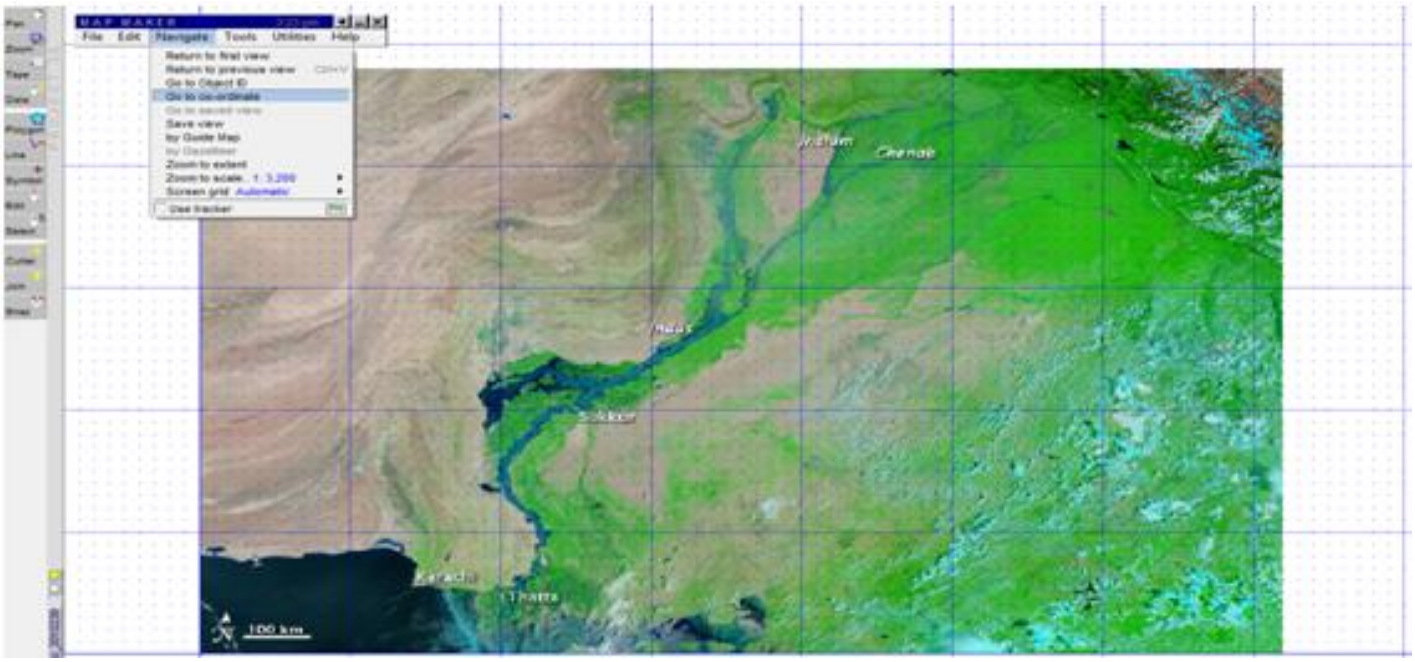

Figure 14. Monsoon period of 2010 (30 July) showing water in Indus River. Source: NASA Earth observatory.

role in the interpretation of hydrological cycle especially when changes are in rainfall behavior. Changes in monsoon of 2010 affected major portion of Pakistan due to flash and riverine flooding. In this study, we have tried to investigate the rainfall behavior for 900 days with three consecutive monsoon periods in which third monsoon period was very significant. By fixing the upper and lower control limits according to the definitions of floods and droughts, major shift in rainfall pattern was detected in 2010 which was due to blocking event in the jet stream. Jet stream halting created low pressure which allowed more fuel recharge from Arabian Sea and, hence, lead to severe rainfall in northern Pakistan. On the other hand, lower control limit for droughts supported the desertous environment of southern Pakistan which was affected due to riverine flooding. From the GIS based approaches, we can say that riverine flooding in Sukkur and Jacobabad was mainly due to heavy monsoon rainfall in highland areas of northern Pakistan. In conclusion, flash flooding in northern Pakistan was due to freezing of subtropical jet stream whereas riverine flooding in southern Pakistan was attributed to high water level in Indus River as rain-water moved across the length of the country. Poor water management policies by Pakistan government also contributed to destruction in major cities of the country.

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