Title: Analyze the current and future trends of river flow in the Upper Indus Plain from its relationship with temperature and rain in the region

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Introduction:

Pakistan has already entered in the category of water scarce nations with a per capita availability below 1000 cubic meters defined as a world standard (Pildat, 2003). Increasing water scarcity in Pakistan demands a detailed analysis of hydrological data so that we can evaluate water availability and how the water trends have changed over time to predict the availability in future. Moreover, the GDP of Pakistan is largely dependent on agriculture, which in turn is dependent upon the water availability in rivers and the rain and temperature trends. Hence, it is very important to analyze hydrological data, more specifically the river flows, rain and temperature trends across the country.

Dataset:

The dataset of the upper indus river catchments was provided by Dr.Hassan Khan, Professor at Habib University. There are 4 main data sources:

1- Maximum temperatures in upper indus catchment areas

2-Minimum temperatures in upper indus catchment areas

3-Rainfall in upper indus catchment areas

4- River Flow in all 6 main rivers

This report analyzes the rain, temperature and river flow data for the area in the Upper Indus Plain of Pakistan for the time period 1981 – 2005. As shown in *Fig.1,* the rivers under consideration for this study are as follows:

- Chenab
- Ravi
- Satluj
- Indus River
- Kabul
- Jhelum

To investigate the River flows further, we will also investigate trends in the above variables by

1- Annually

2- Monthly

3- Seasonal

4- City wise (shortlisted 4 main areas around the Indus)

- Gilgit

- Astore
- Besham Qilla
- Nimmo Bazgo

Fig. 1: Rivers in the Upper Indus plain of Pakistan

Upon analyzing the trends of these rivers, following questions would be investigated and answered:

1. What is the current trend in the river flow of the rivers in the Upper Indus Plain in Pakistan?

   This question will be investigated by analyzing the data for temperature and rain separately then using that data to see the dependency of river flow on the variables.

   The research questions are as follows:

   - What is the dominating factor for river flow, rainfall or temperature?
   - Has global warming (the rise of the temperatures) affected Riverflow?

- How does the flow vary according to seasons?
- How does Temperature vary annually?
- Does higher temperatures cause more rain?

2. What is the predicted river flow of the rivers in the Upper Indus Plain in Pakistan?
   This question will be investigated by taking help from the past trends evaluated and using them to forecast the coming trends

Section 1: Analyzing current trend in the river flow of the Upper Indus Plain in Pakistan

Change in river flow can be a direct consequence of the change in temperature. Hence, to confirm that, it is necessary to first analyze the trends in temperature in the areas of Upper Indus Plain.

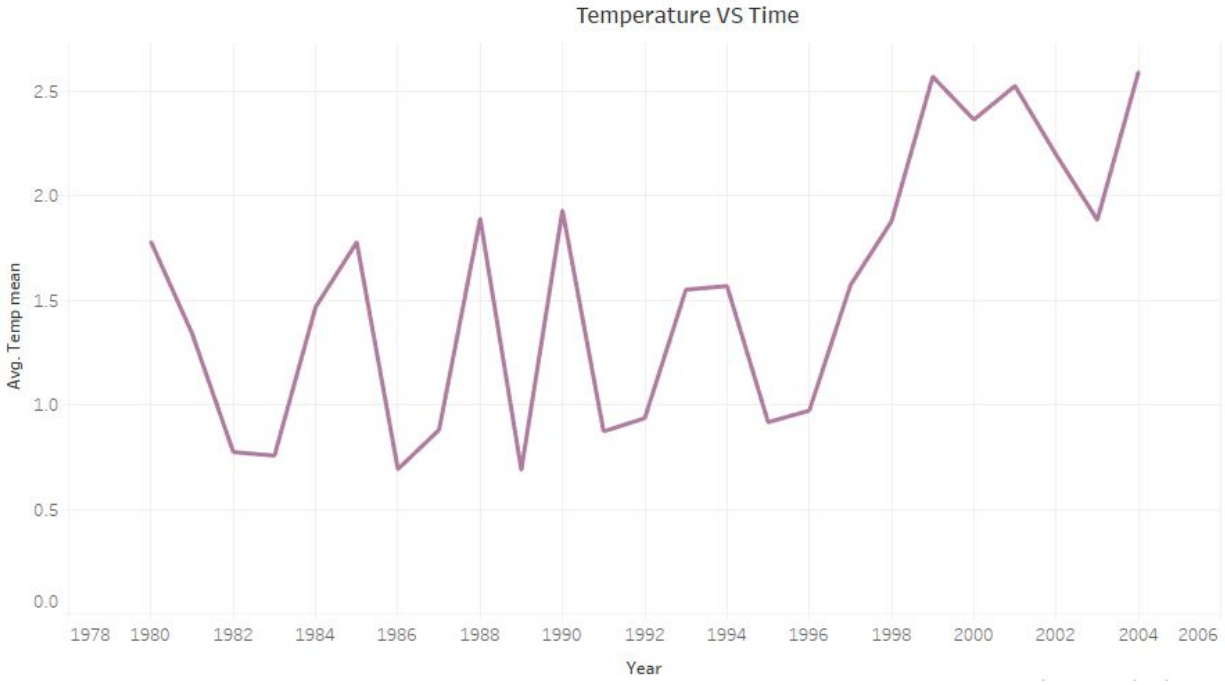

Fig. 2: Yearly trends in temperature from 1980-2004

As seen from the figure, an overall increase in the temperature is being observed which specifically started to peak from 1996 onwards. This is also validated by the description given by Mr. Rab Nawaz currently serving as the Sindh regional director of World Wide Fund for Nature-Pakistan (WWF-P) to Dawn News in 2015.

Secondly, in an ideal situation, one should expect peaks and troughs in the yearly temperature trends due to change in weather. It is interesting to note that just before 1996, when the temperature finally peakes, the highest average temperature noted in 1992 till 1994 was between 1.552-1570 which is a bit lesser then what the general trend was in the past years (around 1.781-1.932) from 1978-1990 which also an increasing trend. This observation from 1992-1994 can be answered by the melting of glaciers in the Upper Indus Plain due to the 0.2 increase in the highest average temperature over the years. When glaciers melt, the initial consequence is a lower temperature for a small amount of time and then a sudden rise in temperature. However, this is just a hypothesis now which will further be validated in the upcoming analysis.

Lastly, From 1996-1999, there has only been an increase in temperature and no troughs can be seen even due to weather changes, this means that even the weather changes could not stop the increase in temperature in these years. After 1999, some troughs are observed which point to stability in higher temperatures.

After having a look at yearly trends, it also makes sense to analyze monthly and seasonal trends to understand temperature trends in much detail.

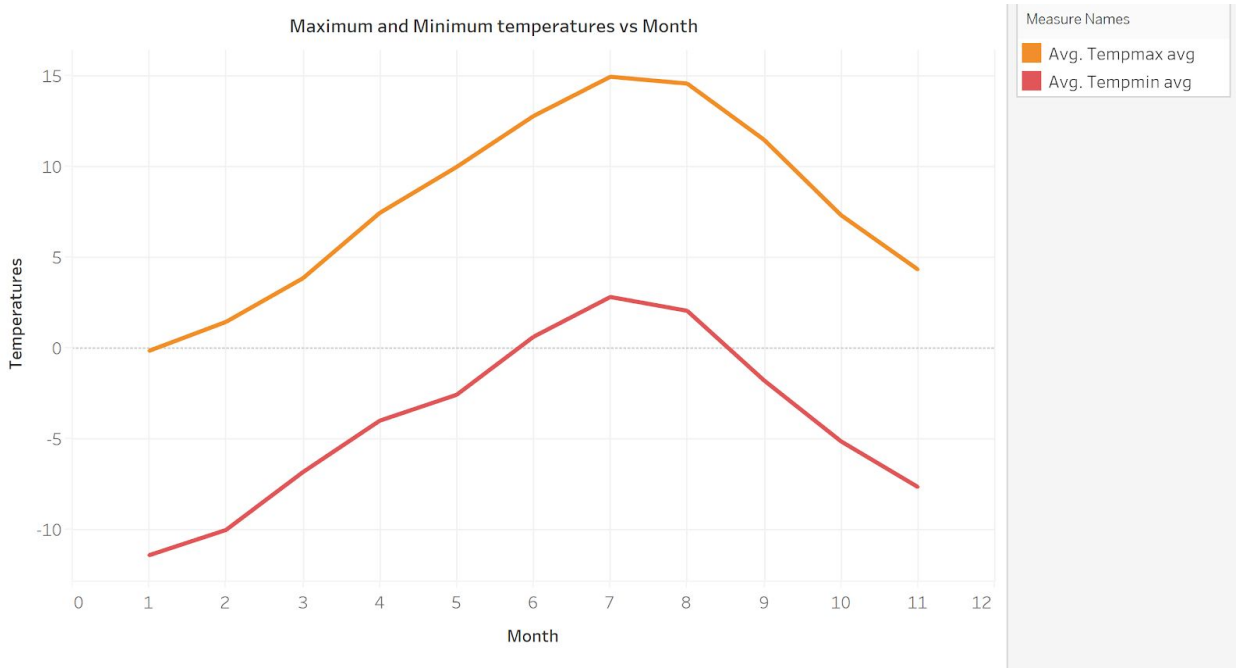

Fig. 3: Monthly trends in temperature

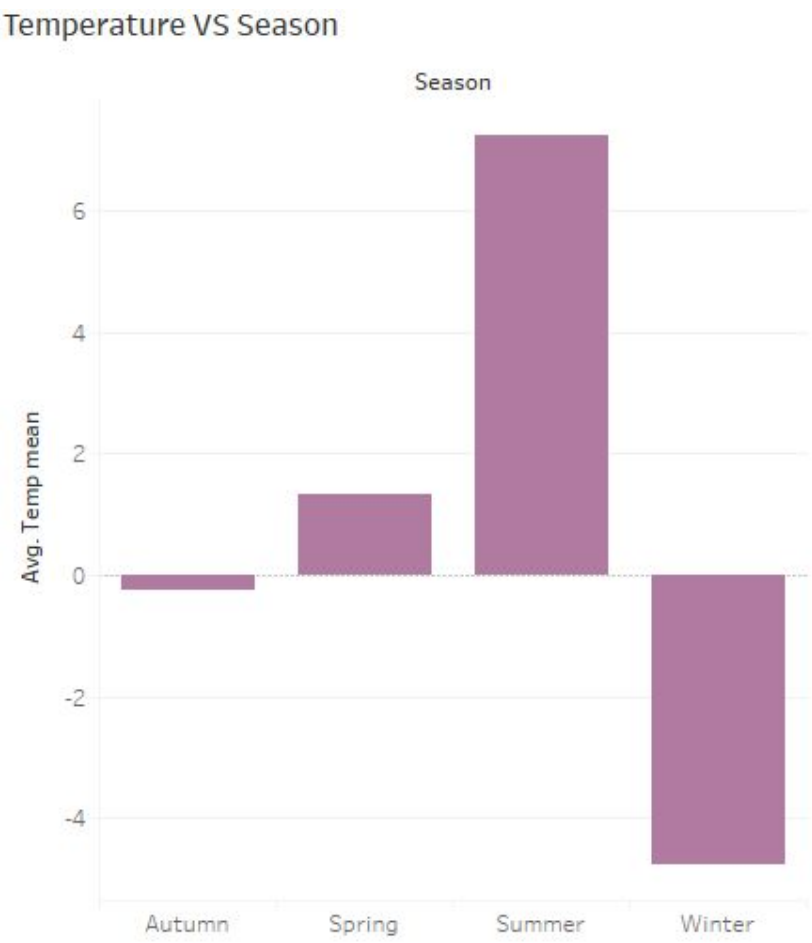

Fig. 4: Seasonal trends in temperature

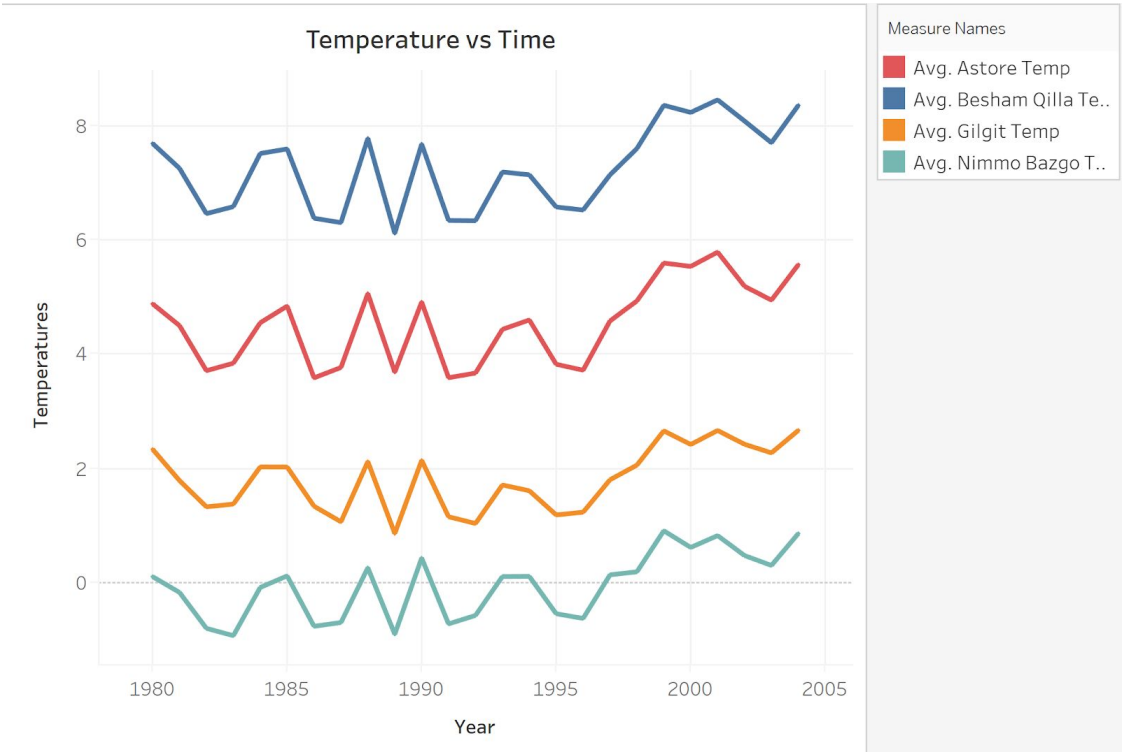

Fig 5: Annual trends in Temperature in 4 cities

The monthly and seasonal data gives the following conclusions:

- The monthly temperature shows a rough bell-curve with July and January to be the hottest and coldest months respectively.
- The highest average temperature in July is observed to around 15 celsius while the minimum average temperature is observed to go below -10 celsius.
- The seasonal temperature trends are as expected with winter and autumn temperature going all the way below zero, while the opposite is observed for summer and spring.
- The seasonal graph shows changes in the mean temperature with respect to seasons. These seasons have been classified on the basis of months as follows:
    - Winter: December, January, February
    - Spring: March, April, May
    - Summer: June, July, August, September
    - Autumn: October, November, December
- Fig 5. Shows a general increase in temperatures amongst all the 4 cities. It can be seen that there is a significant rise in temperatures from 1996 onwards.

Now that we have investigated the trends in temperature, we can now see the trends in river flow and compare its trends with that of temperature.

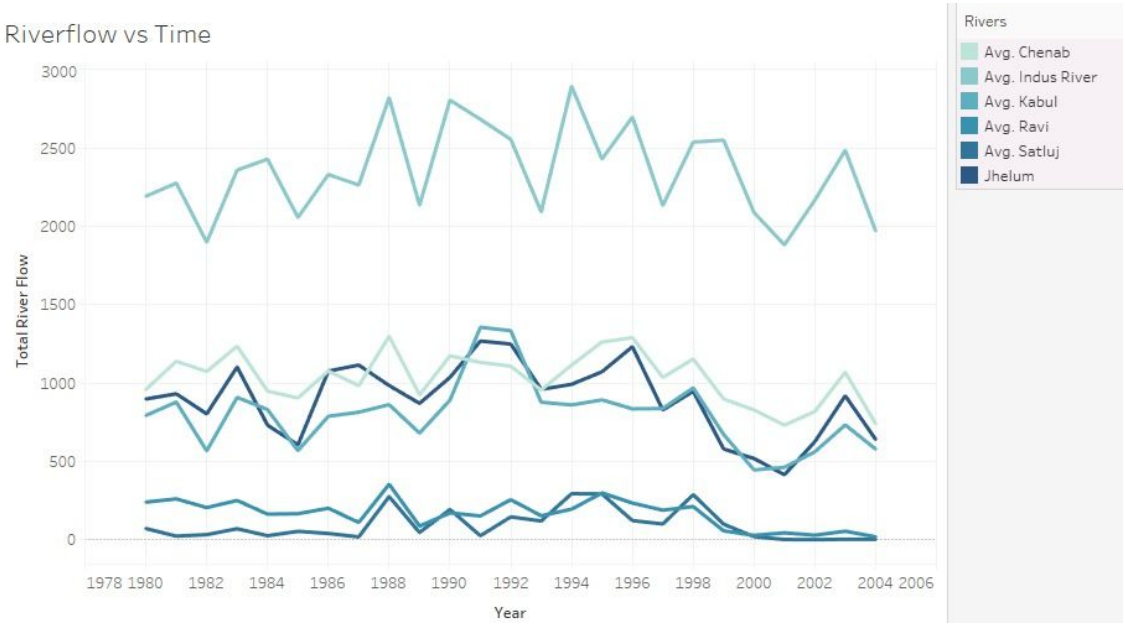

Fig.6: Trends in river flow with time.

As hypothesized above, due to a 0.2 increase in mean temperature before 1992, there was an observed lower temperature from 1992-1994 due to melting of glaciers. This hypothesis gets more strength here as we see a sudden rise in the river flow of the Indus river in 1994. However, this is not observed in the rest of the rivers which might be the consequence of their geographical location. The River Indus has its origins in the North where most glaciers are found. While Kabul is towards the West and Chenab, Ravi, Satluj and Jhelum are all towards the east of the Upper Indus Plain. However, the confirmation of this hypothesis is still subject to more research and analysis.

Secondly, it was noticed that after 1996, the mean temperatures faced an increase. Here in *Fig. 6,* we can see that the mean river flows have faced lower numbers than anywhere before and this trend has stayed consistent through all the rivers. This indicates that due to higher temperatures, river flow has been negatively affected. This might be because of higher water evaporation rates due to higher temperatures. To further investigate this relation, we have done linear regression and separately plotted the river flow with temperature.

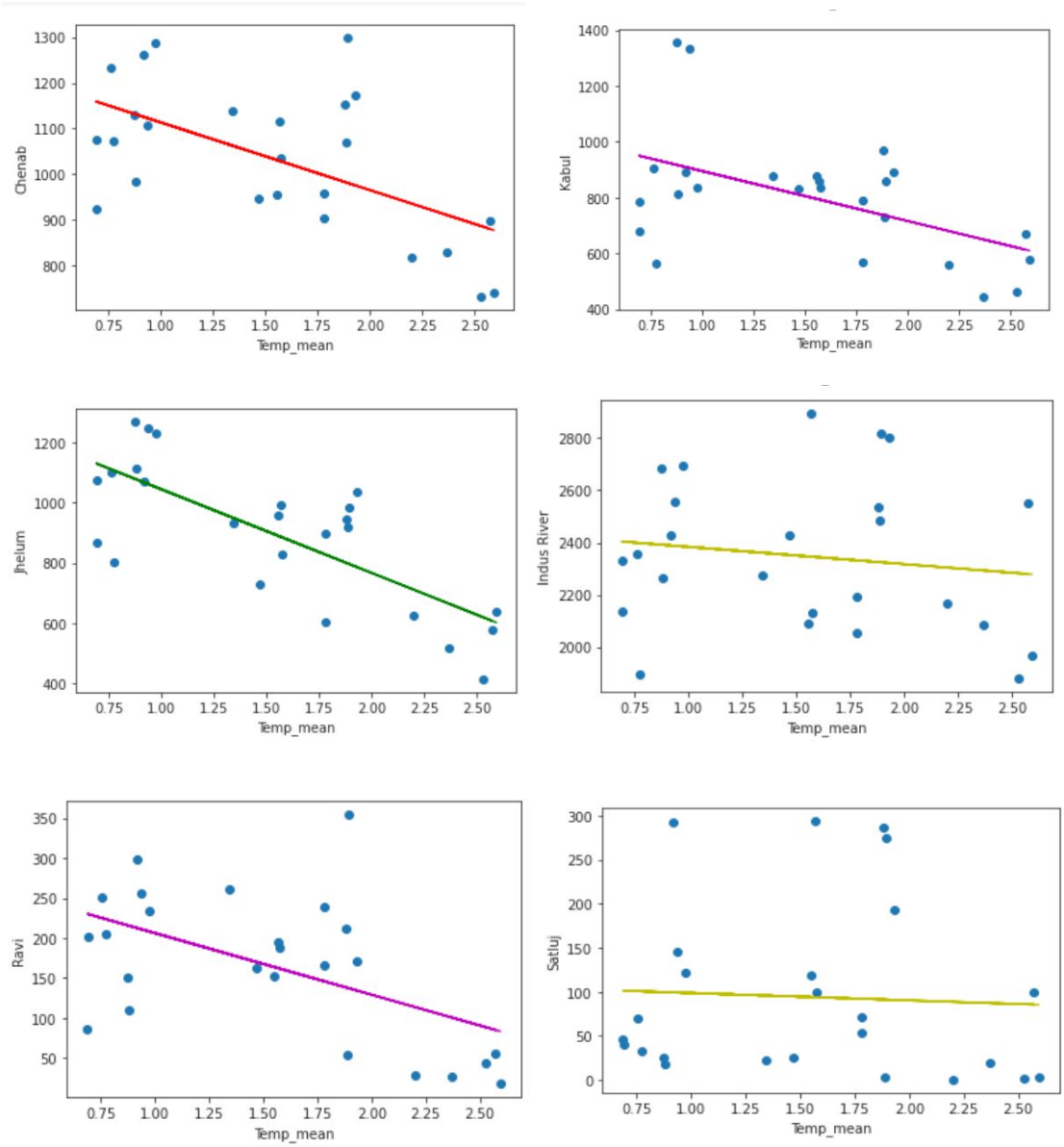

Fig. 7: Relationship between average temperature and river flow with time for river Chenab, Kabul, Jhelum, Indus, Rabi and Satluj respectively.

Hence, the linear regression further proved that there has been a negative correlation between temperature and river flow with time. This analysis of yearly trends in temperature and river flow provided a bigger picture. For a more in-depth and diverse analysis, we have also compared the seasonal variations and monthly trends in river flow and we will now compare it with temperature.

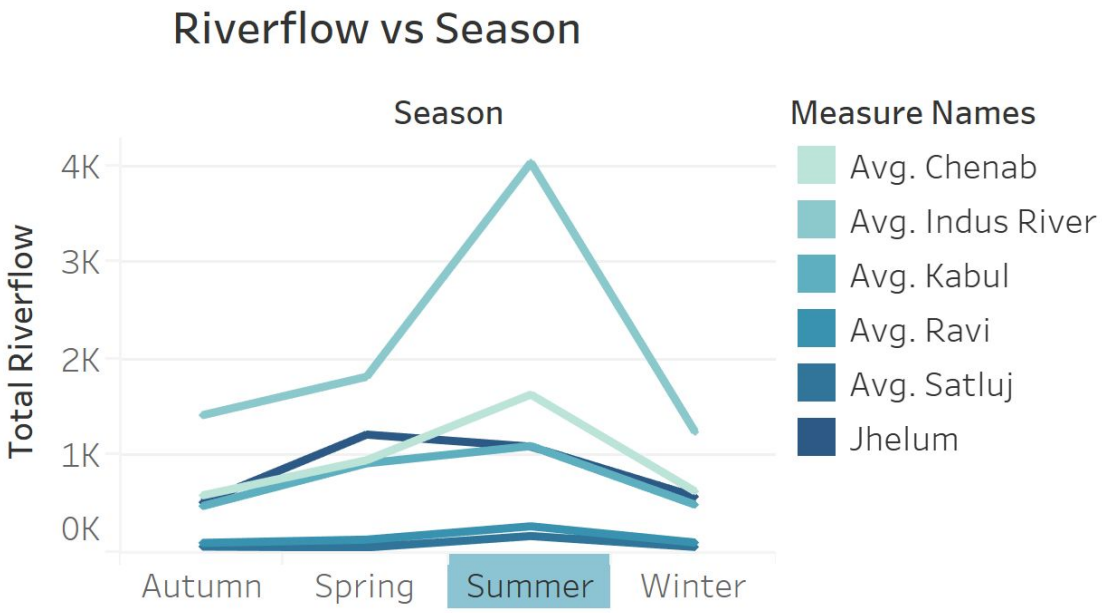

Fig. 8: Relationship between riverflow and season

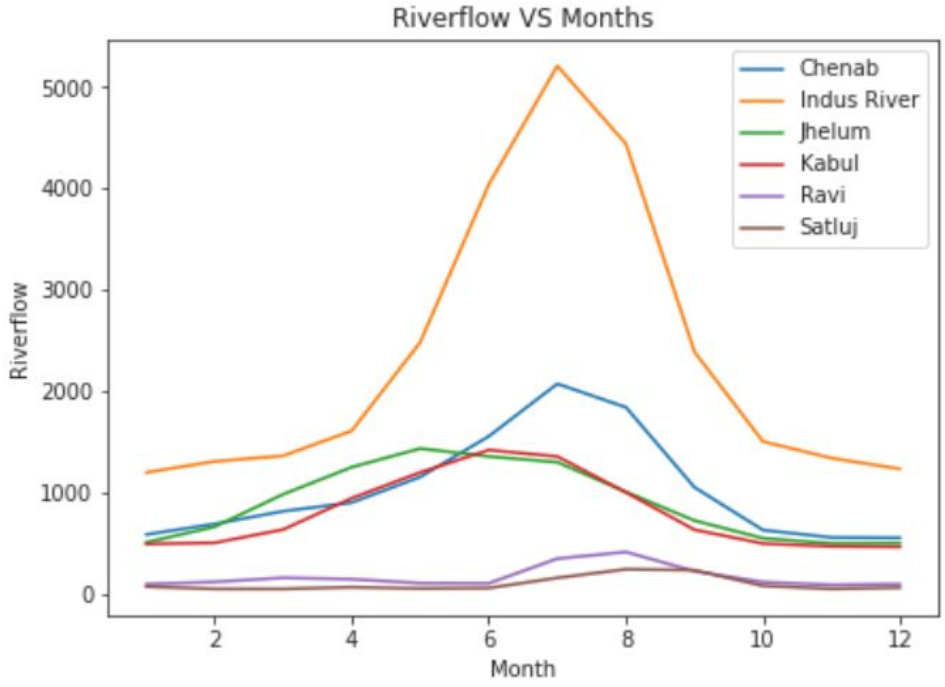

Fig. 9 : Variations in temperature with month.

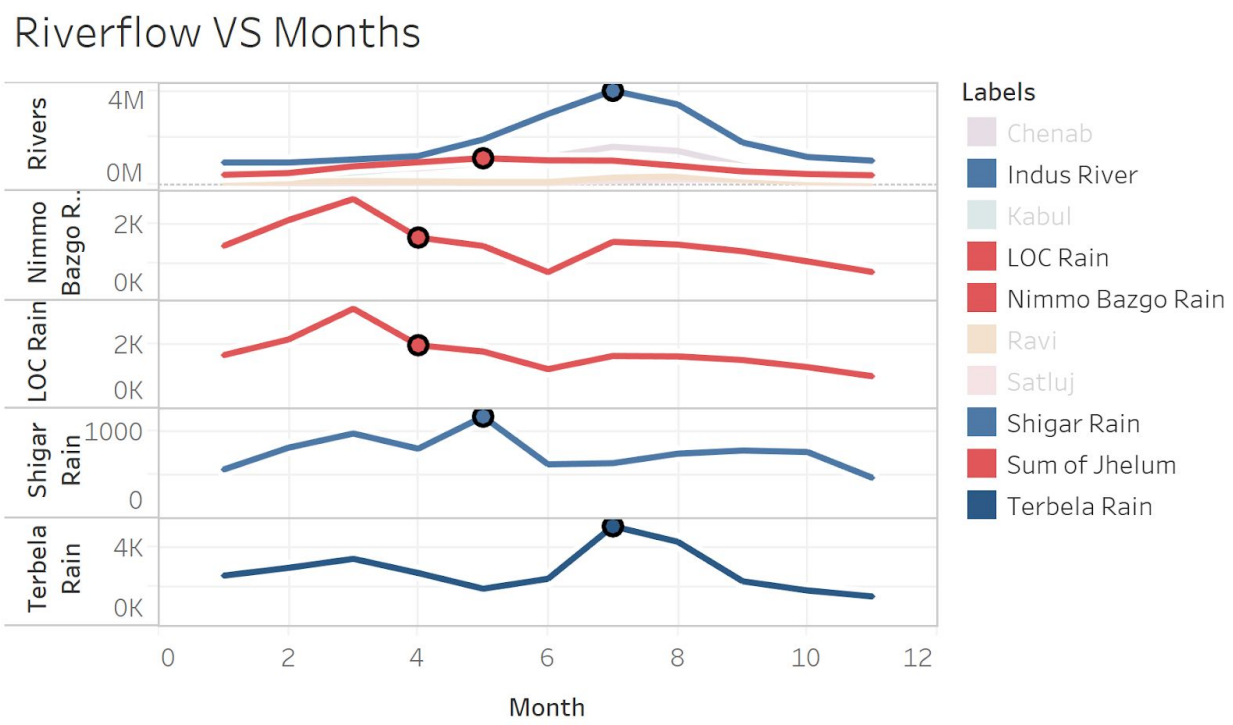

Fig. 10 : Variations in river flow of Indus River and Jhelum River compared to Rain in its surrounding areas

As shown in Figure 9, there is a significant increase in river flow in Summers which might be the consequence of melting of glaciers up North. There is a significant increase in river flow with respect to change in weather to a more hotter weather. The temperature then falls significantly as winter starts. Similar relationships can be observed in Autumn and Spring. The river flow in Autumn is lower and gradually increases as Spring approaches.

So does that negate our observation above that mean temperature is inversely related with river flow? The answer is No. Because here we are observing trends for just 4 seasons in a year where the weather change is part of the cycle and cannot be compared to global climate change. We observed the former conclusion after analyzing almost 2.5 decades of data which cannot be compared with usual changes in temperature due to weather.

Let's also analyze the trends with respect to month.

- There is an overall increase in river flow from June to July. July was the month where highest average temperatures were observed (*Fig.3)* and we can see that the flow in the Indus river peaked in the same month which might also be due to melting of glaciers.
- Jhelum shows an unusual behavior and has peak river flow in March, As shown in Fig 10, when plotted Jhelum and Indus and compared it with rains in the surrounding areas of these rivers, it can be deduced that as rain in areas around Jhelum decreases, the river flow also decreases whereas as river flow in indus increases, it can be observed that the rain in surrounding areas also increases.
- River Kabul and Jhelum face a downfall in river flow between June to August while Ravi and Sutlej face greater river flows at the same time. This might be a consequence of their geographical location because Ravi and Sutlej lie towards the East while Kabul is to the West most corner and Jhelum is towards the centre of the Indus plain.

This concludes the first part of our question: to investigate the current trend in river flow in the upper indus plain with respect to the change in temperature. We will now do similar analysis with Rain and analyze its effects on the river flow with time.

We take the similar approach and analyze the rain data and first look at yearly trends in rain in the upper Indus plain.

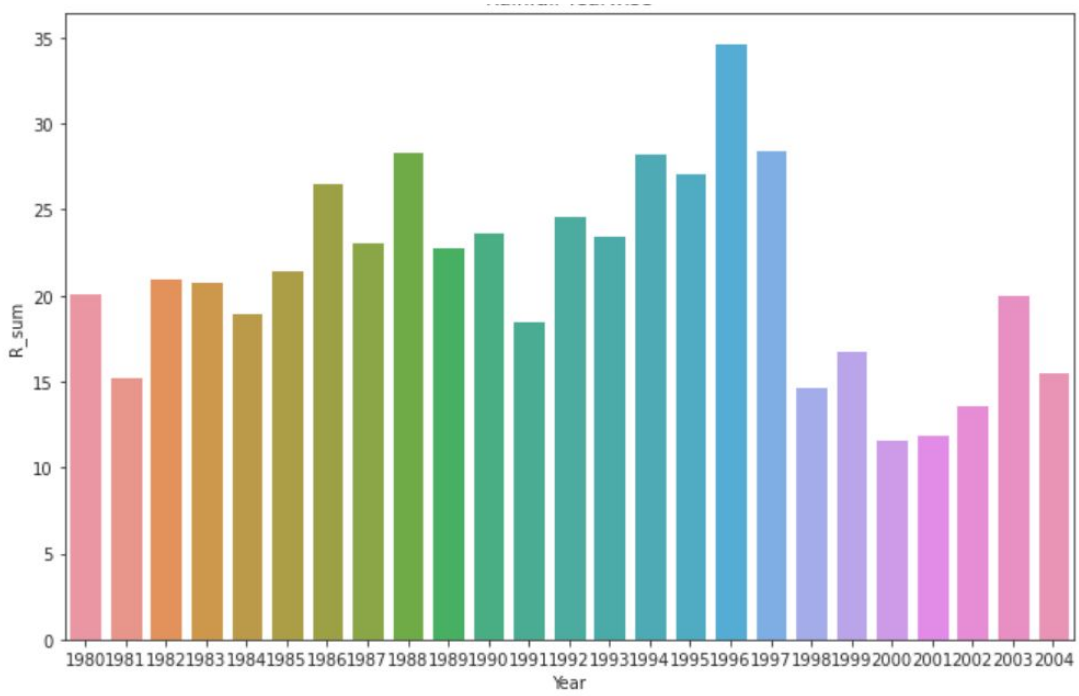

Fig. 11: Trends in Rain with time.

The bar plot shows that there was an extreme increase in rainfall in 1996 and then a sudden fall in the number after that as compared to the number before. As discussed above, temperature change drastically occurred in the same year ie. 1996, and the trends changed after that. This also relates to the changes in river flow where the river flow reduced after peaking in 1996, similar case happened with rains too. This shows that there is a direct relationship between rains and river flow. To further investigate that, we did a similar linear regression between river flows of all the rivers in the Upper Indus Plain and the rains.

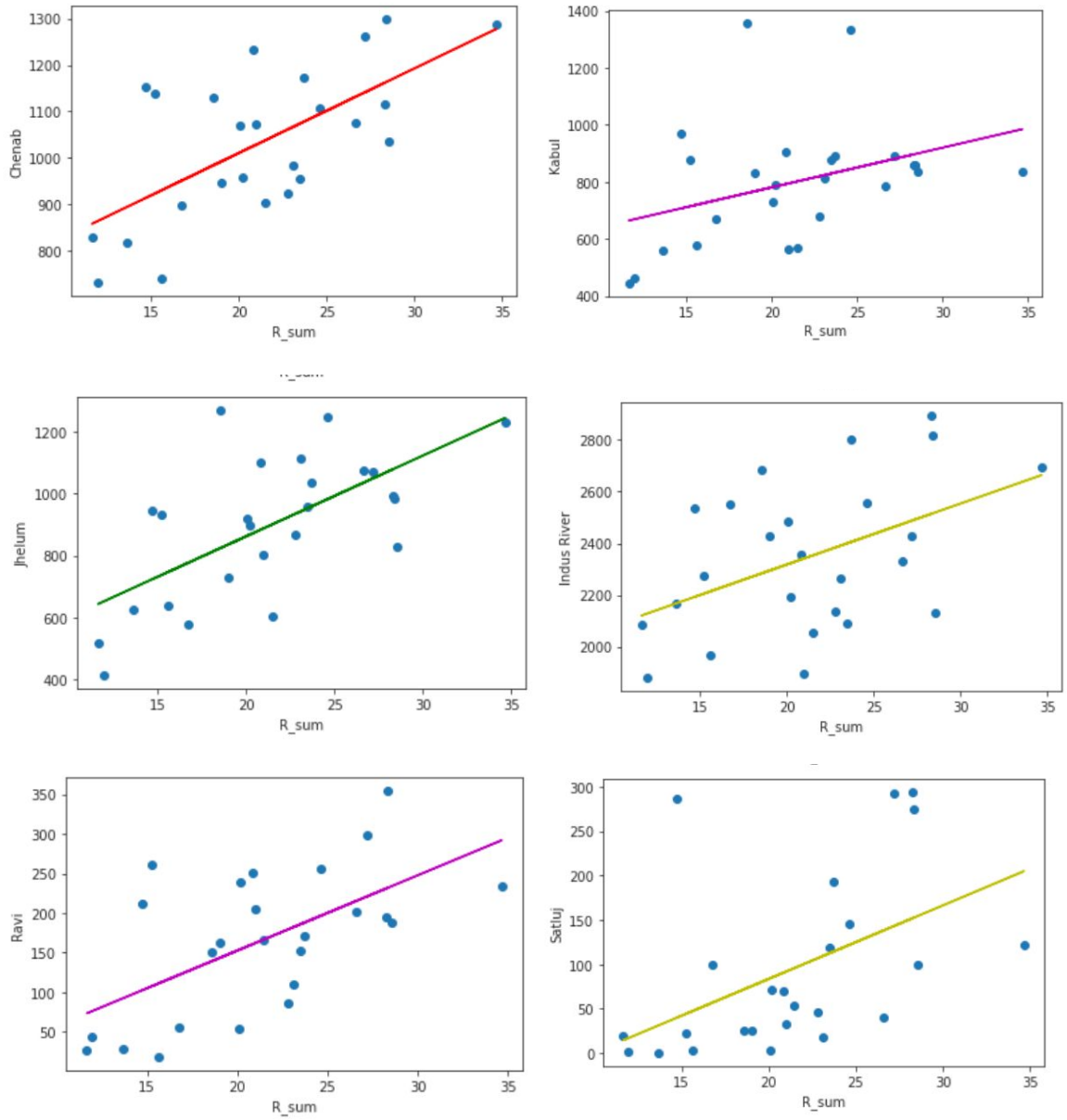

Fig. 12: Direct Relationship between rainfall and river flow with time for river Chenab, Kabul, Jhelum, Indus, Rabi and Satluj respectively.

Hence, proved that there is a direct correlation between rain and river flow hence when the rainfall decreased, the river flow decreased too.

For an in-depth analysis, we also plotted the rain flow with respect to months and seasons as well.

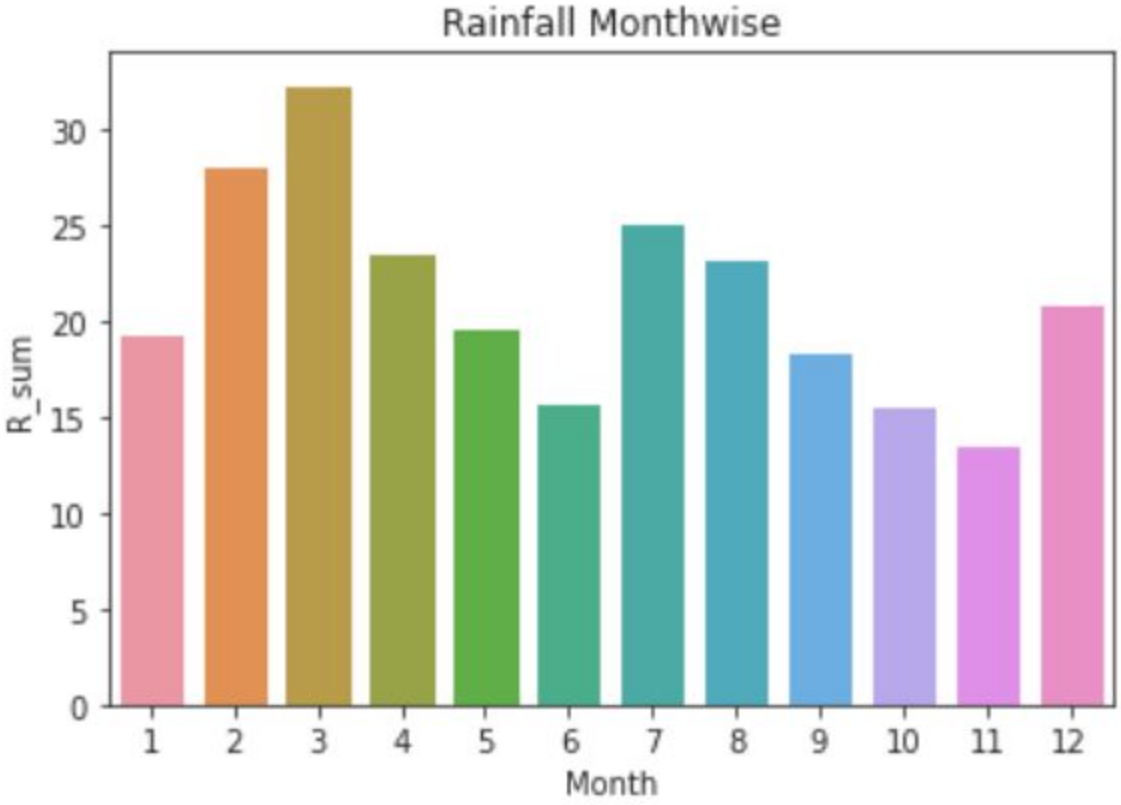

Fig. 12: Change in rain trends with respect to months

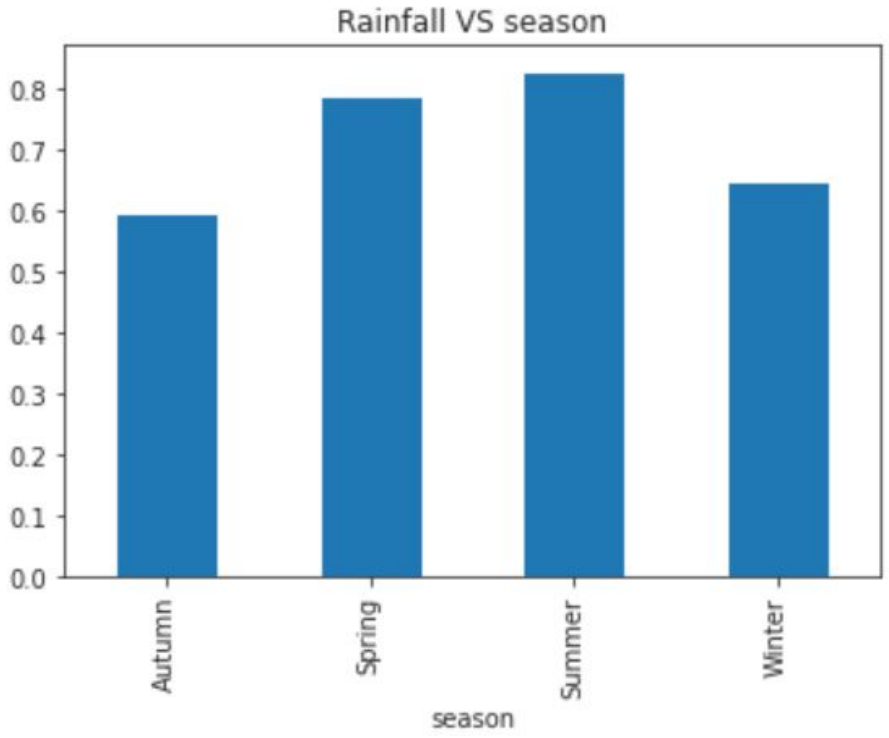

Fig. 13: Change in rain trends with respect to season

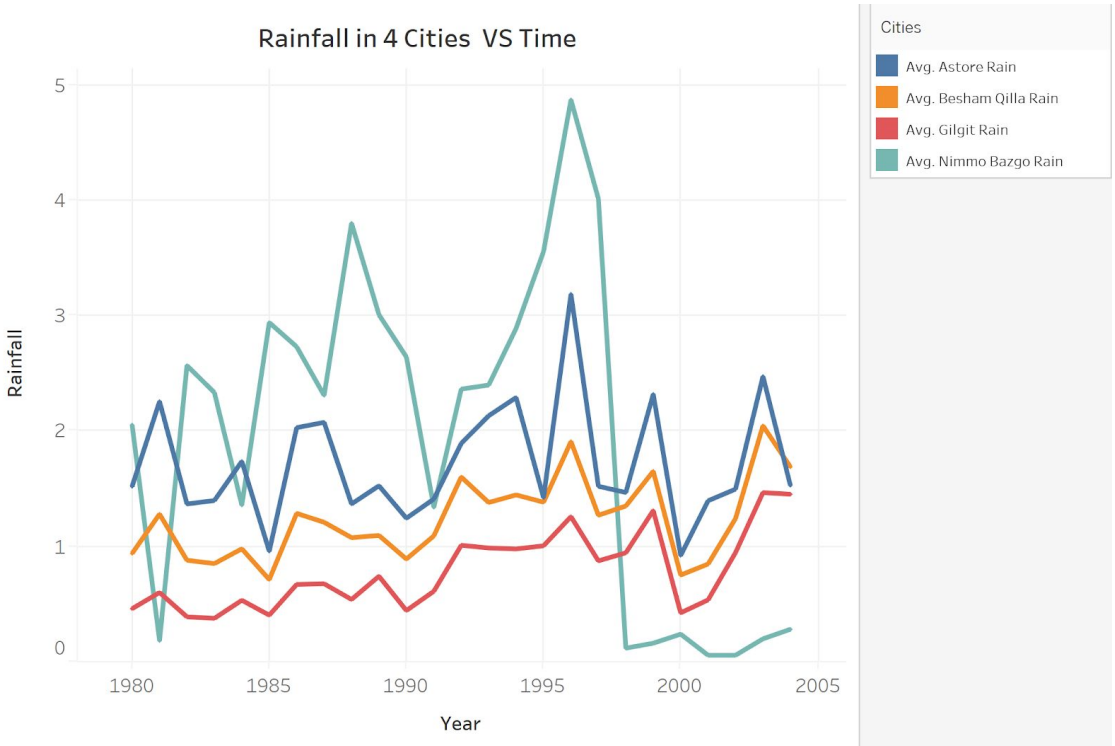

Fig. 14: Change in rain trends in all 4 cities

Following conclusions can be derived from monthly and seasonal trends:

- The highest rainfall is observed in February and March. This explains why the river flow in Jhelum in March unusually peaked. This also explains that Jhelum's river flow depends more on the rainfall than any other rivers.
- The rainfall increases again in July and gradually decreases, signalling monsoon rains.
- With respect to season, there can not be seen a relation on a surface level.
- While there is a general increasing trend amongst all the cities, Nimmo Bazgo shows an increase in rainfall until 1996, after which it decreases rapidly until 1999. In 1987, there difference in rainfall was maximum between Nimmo Bazgo and all the other cities.

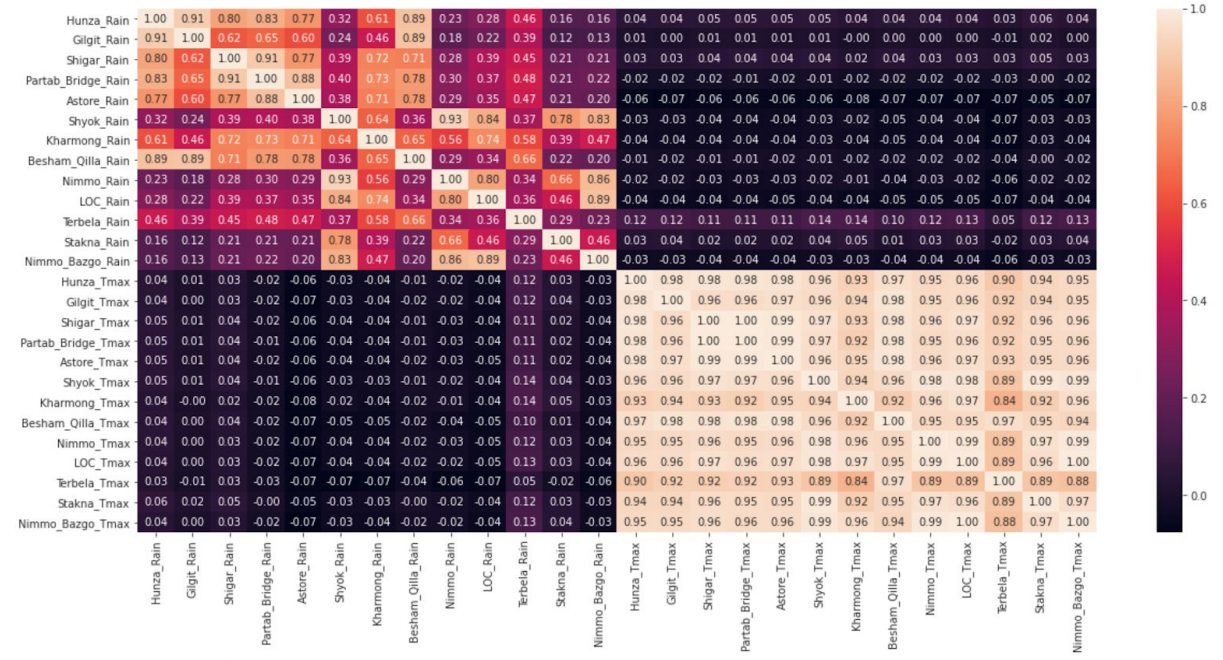

Fig 15 : Heatmap of Rain and Temperatures in all cities around Upper Indus catchment

The analysis of the heatmap in figure 15 will help understand the relationship of rain and temperature better. It can be observed that Rain vs Temperature in all cities are negatively correlated. This means that as temperature increases, Rain decreases and vice versa. However, it can also be noticed that the magnitude (-0.02) of the correlation is close to zero. This means there is not a linear trend between the two. Therefore, the increase in temperatures is because of the global warming that is changing the extreme temperatures and fluctuations in rainfall is affected by it, but not entirely. There are definitely other variables affecting rainfall which are beyond the scope of this study.

From the trends above, it can also be concluded that the main source of water in the Indus river catchments is not Glacier melt or Rainfall independently. Together, both have an impact on River flow.

Section 2: Predicting future trend in the river flow of the Indus River in Pakistan

After analyzing the current trends of riverflow and validating the effect of rainfall and temperature on the said variable. We trained a model to forecast the river flow for future. For this purpose we used two models:

1. **Seasonal Autoregressive Integrated Moving Average Exogenous (SARIMAX) model.**

SARIMAX is a seasonal equivalent of the ARIMAX model and it is used to predict the time series data which periodically repeats a pattern over time. The yearly trend for the river flow shows a definite pattern and we can use that pattern to create future predictions. Upon using SARIMAX, we came across the following pattern that repeats itself after every year.

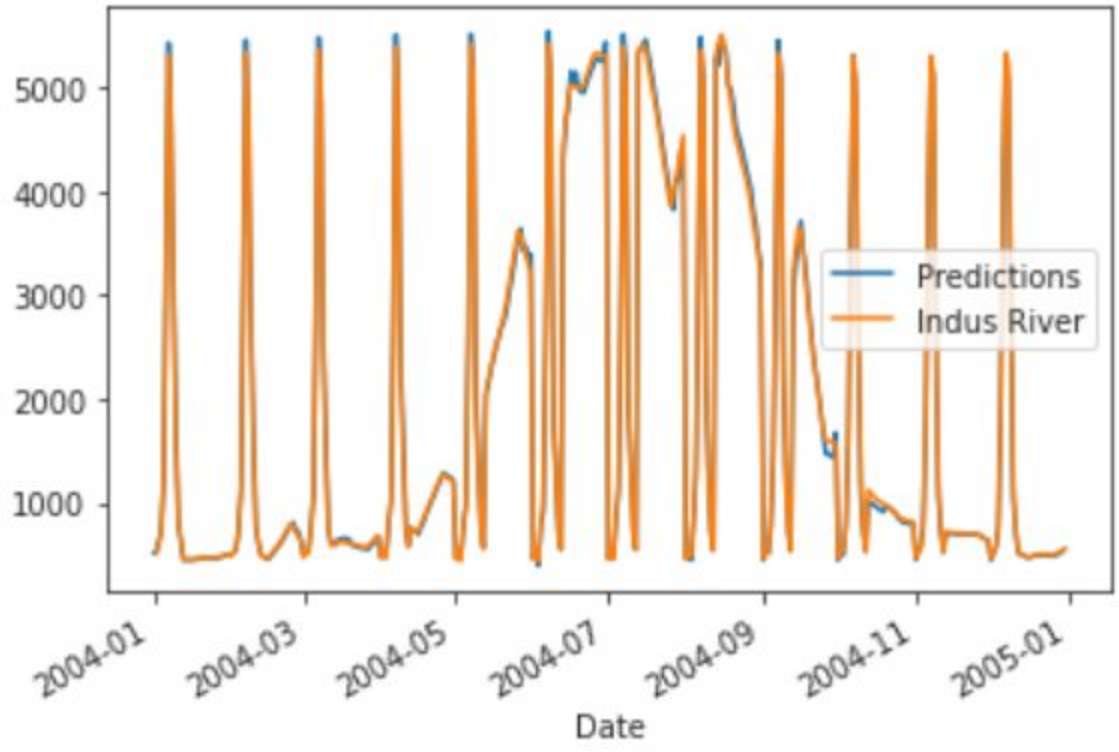

Fig. 13: Yearly pattern shown by Indus River test data v/s the predicted data

This pattern shows that over the course of the year, the river shows very steep peaks every month. However these peaks start persisting for a while starting from May all the way to October. With the highest persistent peak to be in August when the river reaches its maximum flow.

2. **Multiple Regression:**

We also used the results from the linear regression done in the previous sections to learn a multi regression model and predict the values of river flow accordingly. The linear regression separately told the effects of temperature and rain on river flow. Now we used those relations to predict the river flow considering rain and temperature to be primary variables. This model has the following histogram for error terms

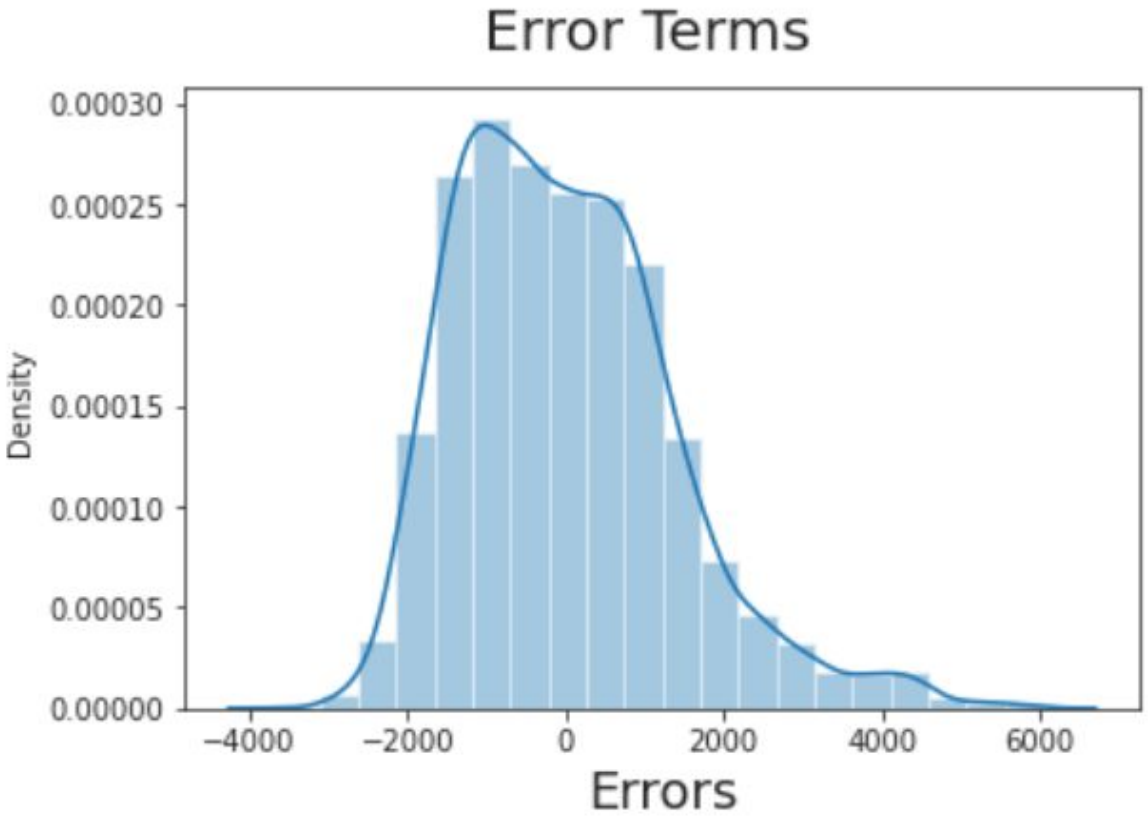

Fig. 14: Error terms for the multiple regression

For a perfect model the histogram should be normalized however, we see that even though its normalized but it is a bit skewed towards the left.

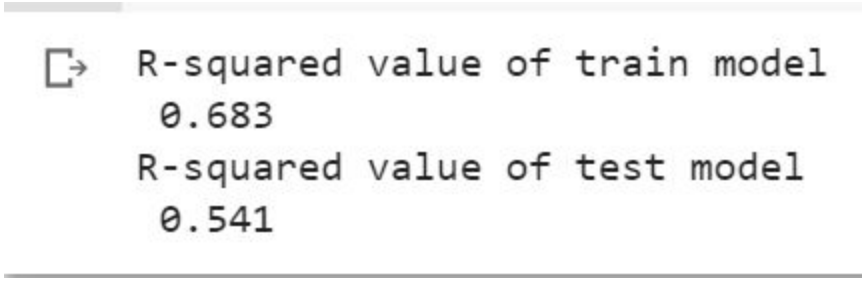

Fig. 15: R-squared values

These are the R-squared values we received for train and test dataset respectively with a small difference.

REFERENCES

1. https://www.dawn.com/news/1190394
2. PILDAT (2003) Issues of water resources in Pakistan-briefing paper for parliamentarians by PILDAT. Pakistan institute of legislative development and transparency.