THE IMPACT OF CLIMATIC FACTORS AND FOOD SECURITY ON DEMOGRAPHIC FERTILITY IN PUNJAB, PAKISTAN THROUGH GEOSPATIAL STRUCTURAL MODELLING (GSSM)

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ABSTRACT: Punjab is not only the most fertile province of Pakistan but also the most fertile demographically with 3.4 total fertility rate. The fertility rate is an important demographic phenomenon that has significant implications for sustainable development, particularly in agricultural regions such as Punjab, Pakistan. In recent years, scholars and policymakers have increasingly focused on the link between fertility rate and soil fertility. As soil fertility is an important determinant of agricultural productivity and food security. This research article has explored the relationship and impact of the main climatic factors like maximum and minimum temperature, precipitation and Gross Primary Productivity on total fertility rate of districts of Punjab, for the year 2021. Geospatial Structural modeling (GSSM) has been designed to estimate the influence of climatic factors directly on fertility and its indirect influence on fertility through gross primary productivity and child mortality rate on total fertility rate of districts of Punjab. All the said geospatial primary and secondary datasets are analyzed in ArcGIS environment and resultant map are generated. The results shows that there is the direct and significant impact of gross primary productivity and child mortality rate on the total fertility rate. While there is indirect impact of mean annual precipitation, mean annual maximum and minimum temperature on the total fertility rate. Hence, there is negative direct impact of said factors on total fertility rate of the districts of the Punjab.

Key words: Total fertility rate, Geospatial Structural modeling (GSSM), fertility trend, Food security, Punjab.

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INTRODUCTION

According to Global Climate Risk Index Report (2022) Pakistan is the eighth most vulnerable country to long-term and short-term climatic change risk. Natural disasters due to change in temperature and pattern of precipitation become the cause of change in population dynamics like fertility, mortality and on the pattern of migration in effected areas of the world (Bakhtsiyarava *et al.,* 2018; Grace *et al.,* 2015). In the country (Pakistan) which is ranking fifth in most populous country of the world, more than 20 million people were affected national wide by the floods in 2010 (Frankenberg, 2015). But the national wide floods of 2022 were disastrous in Pakistan due to in that year, only the month of July received more than 180 percent rainfall only in areas of Punjab. It was the wettest July in Pakistan after 1961 (PMD, 2022). It was unprecedented disaster for the crops of Pakistan, especially to the Punjab. Punjab is known as the food basket of the Pakistan and most populace province of the country with 110 million individuals. Adverse and frequent events of climatic disastrous creates food insecurity, which also becomes the changing in population dynamics (Parvin *et al.,* 2016). It is detected that there is positive and negative change in trend of precipitation around the world, which is increasing towards tropical (Alferd *et al.*, 2017).

It is said that mean temperature of the world has increased almost about 1.1 C^{0} after the industrialization. Due to rise in temperature and alternation in pattern of precipitation have a considerable impact on the composition and productivity of the soil. Since soils are related to climate system in a very complex way through nutrient and hydrologic cycles and said factors of climate are predicted to have a possible impact on soil fertility through the physical, chemical, and biological properties of soil (Mondal, 2021). Change in climatic factors affects the environment, including soil productivity but also the human behaviour and human fertility (Brevik 2012; Sellers and Gray, 2019). Barreca (2017) found that hot weather delays the birth rate because it raises health care cost. Many human geographers already have studied the impact of climatic elements on human health (Jiang and Hardee, 2011; Frey and Singer, 210; Kabir *et al.*, 2009).

Chen et al. (2021) is found that there is positive impact on crop productivity of maximum temperature and negative indirect impact on the demographic fertility. It has direct positive effect and indirect negative impact on the child mortality rate of Bangladesh's population between 1966 to 2015. According to Planning and Development Board of Punjab (2021) government of

Punjab is fronting serious challenges in terms of catering population of Punjab.

However, despite its agricultural productivity, Punjab is facing significant challenges related to soil fertility, which is an essential factor in determining the long-term productivity of agricultural lands. There is growing evidence that temperature change, human fertility transition, and soil fertility are interrelated (Generoso, 2015). Although, the relationship between fertility transition and soil fertility is complex and multifaceted and can be influenced by various other social, economic, and environmental factors. Therefore, this study aims to find out the linkage and impact of climatic factors to the soil productivity on the demographic fertility of the districts of the Punjab.

Study Area: Punjab is the most populace province of Pakistan. It known as the food basket of Pakistan. Therefore, one could say that Punjab is not only the most fertile province of Pakistan but also fertile demographically with 3.4 total fertility rate with growth rate of 2.13%. Population density of 536 people per square kilometres. Punjab is selected as study area for the present research paper.

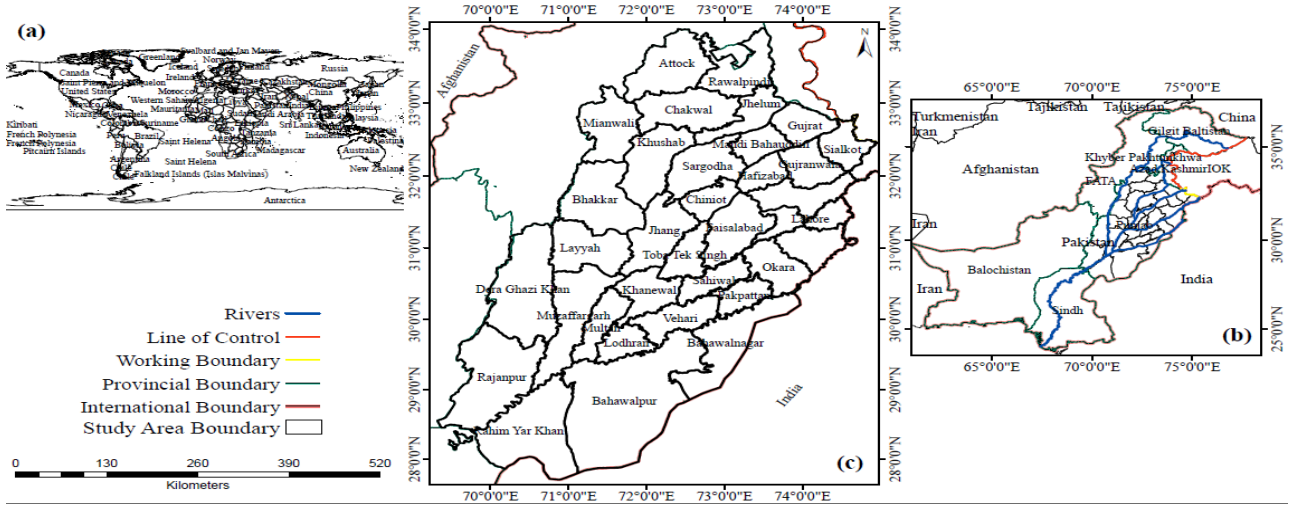

Fig. 1 Map Showing Study Area (a) Map of the World (b) Map of The Pakistan (c) Map of the Punjab, the study area.

MATERIAL AND MEATHODS

This study incorporates two main climatic factors temperature (max. & min.) and precipitation, with the Gross Primary Productivity (GPP) by the raster dataset of Punjab and demographic data of total fertility rate (TFR) of districts of Punjab for the year 2021 with child mortality rate (CMR). Climatic data were obtained from Pakistan Metrological Department (PMD, 2021) for the year 2021. The data for TFR and CMR was obtained from the Pakistan Bureau of Statistics (PBS) (https :// www. pbs.gov.pk/dag-punjab) and the United Population Divisions (https://population.un.org/wpp/; MICS Punjab, 2021). The Gross Primary Production (GPP) was downloaded from the MODIS website for the month of the July (https://modis.gsfc.nasa.gov/data/ data prod /mod17. php).

The Primary Production products are designed to provide an accurate regular measure of the growth of terrestrial vegetation. The product is a cumulative composite of GPP values based on the radiation use efficiency concept that may be used as inputs to data models for calculating terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. Gross primary productivity (GPP) is the rate at which primary producers save and collect biomass for energy conservation (Ashton *et al.*, 2012). Soil productivity in terms of fertility could be estimated through is depended on the GPP values of an area. The dependent variable is TFR while the independent variables are temperature, precipitation, GPP geospatial dataset, and child mortality rate. Because agricultural productivity is the result of GPP.

Path analysis has been adopted as a statistical tool to examine the direct and indirect impact of climatic factors on soil fertility and then on child mortality and finally on demographic fertility of the Punjab. So, to get a result, suitable geospatial structural model (GSSM) is formulated. The GSSM path analysis model allows us to distinguish the direct impact of climate change on fertility and its indirect impact on fertility through soil fertility or food security. Path analysis is an extension of the regression model. It is a standard multiple regression technique using a standard form of dependent and predictable variables with zero mean and unit variance. Therefore, equation 1 has been formulated in ArcMap

10.5. and run into a GIS environment to get Geospatial results and the relationship and impact of exogenic and endogenic factors on demographic total fertility rate (TFR). It is a very useful method for exploring how fertility responds to climate shock in the short term and researchers could modified it according to their need. It means that causal order between the variables is specified by the researcher (Christy, 2005). The equation is formulated as:

GSSM = TFR + CMR + GPP+ MAPP + MATmin + MATmax Equation. 1

RESULTS AND DISCUSSION

Spatial analysis allows researcher to solve and explain complex location-oriented problems. It becomes easy to explore and understand geospatial analysed data from a geographic viewpoint, determine relationships, detect and quantify patterns, assess trends, and make predictions and decisions. In the geospatial maps of TFR for the year 2021 shows that highest fertility values in Rahim Yar Kan and Dera Ghazi Khan in southern and in south western Punjab respectively. On the other hand, Rajanpur shows low rate of total fertility due the direct impact of high CMR, although the actual fertility rate is 3.2 in this area. These districts are shown with reddish brown colour. While Lahore, Faisalabad, Jhelum, Gujrat and Khushab almost in white colour are showing very low rate of TFR in map (2a) and (2b).

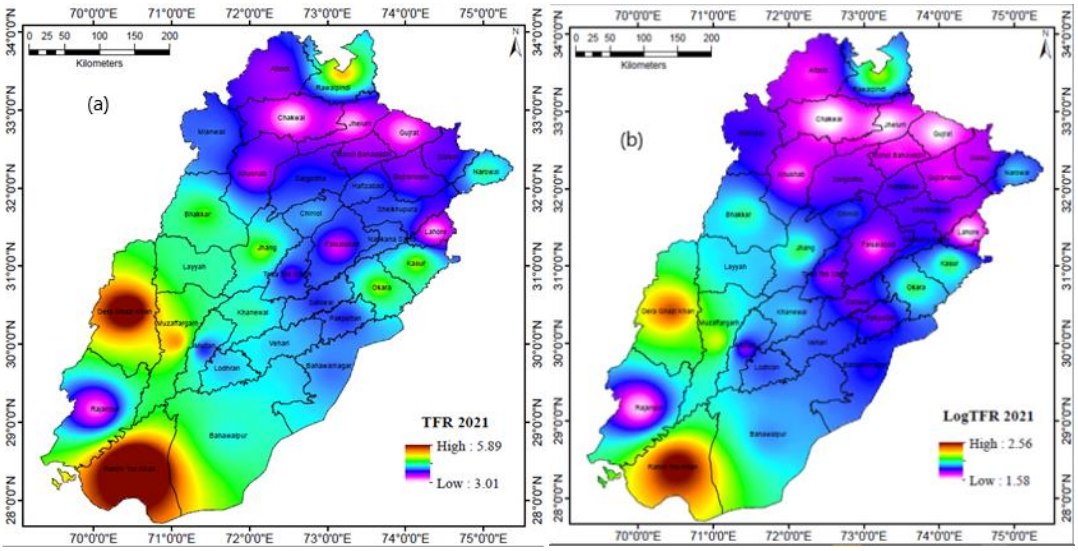

Fig. 2 Maps Showing (2a) Total fertility Rate (TRF) in Punjab districts and (2b) Log of TFR in districts of Punjab

Figures 3a and 3b are showing CMR and log of CMR, in the districts of Punjab. Geospatial visualization makes it easy to locate high values of CMR in north western part of Punjab with brown colour in Gujrat, Sialkot, Narowal, in due the impact direct impact of high CMR (25.7), although the actual Fertility rate is 3.2 in this area. These districts are shown with reddish brown colour. While Lahore, Faisalabad, Jhelum, Gujrat and Gujranwala and Nankana Sahib. The trend is decreasing to medium to low rate towards south of Punjab till Multan with Yellow and green colour and then again showing high trend of mortality in Rajanpur and Rahim Yar Khan. While the Chakawal, Jhelum and Layyah show low values of child mortality with white colours in maps. The high CMR shows that there is the impact of temperate in these districts as the mean annual minimum temperature and mean annual maximum are observed high in the Year 2021 Maps (4a, 4b, 5a, 5b).

Maps in figures (4a, 4b, 5a, 5b) are showing the range minimum and maximum annual temperature in the districts of the Punjab. It is clear by observing these maps that high minimum means annual temperature (MATmin.) are in north eastern districts area adjacent to Azad Kashmir and in the South eastern of Punjab.

The mean maximum annual temperature (MATmax.) are observed in southern the Punjab as most of the part of the Punjab is desert like Bahawalpur, Rahim Yar khan, Rajanpur and Dera Gazi Khan. These districts are shown in red colour. The reason that there is desert and receives less precipitation (5a, 5b). On the other hand, north and north eastern part of the Punjab show low range of maximum mean annual temperature. A narrow strip of low range of max. mean annual temperature is shown in western part of Rajanpur and Dera Gazi Khan districts. The trend is increasing from north to south.

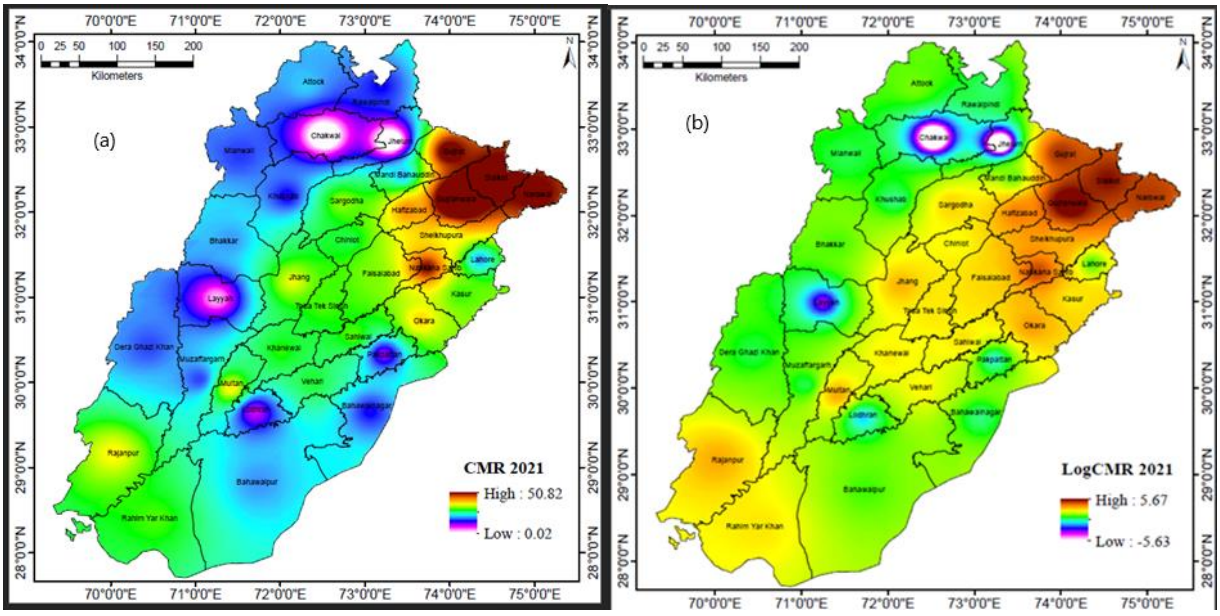

Fig. 3 Maps Showing (3a) Child Mortality Rate (CMR) in Punjab districts and (3b) Log of CMR in districts of Punjab

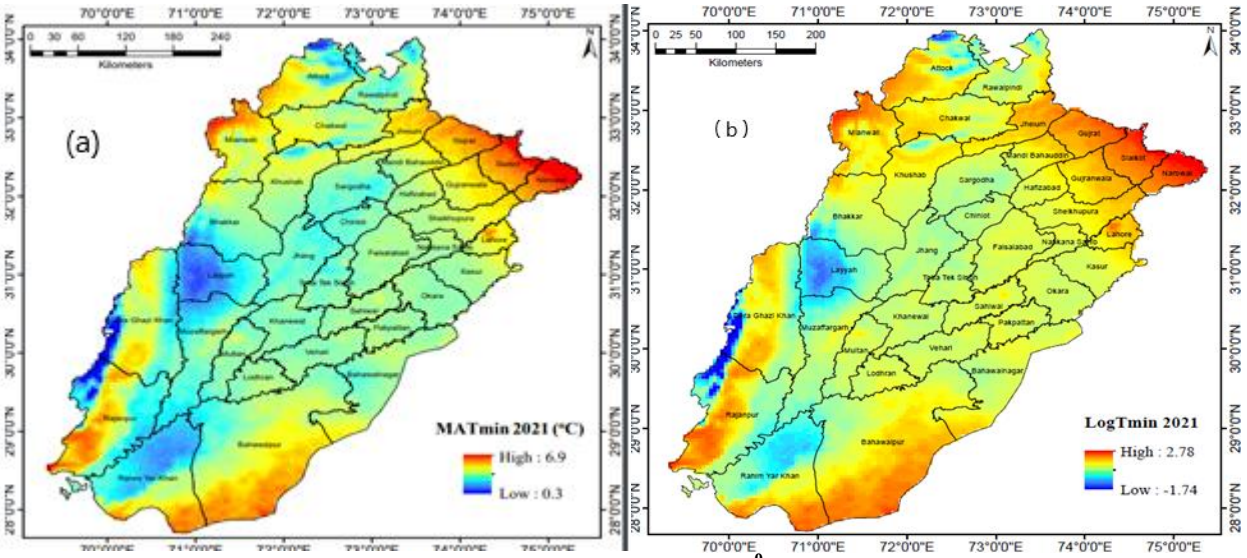

Fig. 4 Maps Showing (4a) Mean annual minimum Temperature (C^0) in the districts of Punjab and (4b) Log of Mean annual minimum Temperature in the districts of Punjab.

Maps in figure 6 (a and b) are showing mean annual precipitation (MAPP)in the districts of Punjab. Darker shade of blue shows high range of MAPP in districts while lighter shade of blue shows low range of MAPP in districts. The trend is decreasing from north to south word while north eastern part is showing dominancy.

Maps in figure 7 (a and b) are showing mean annual gross primary production (GPP) of the soil in the districts of the Punjab. The red shows low range of GPP of soils in districts while green colour shows high range of GPP in districts. The trend is decreasing from north to south word with only few patches of low productivity of soil. Yellow colour shows medium productivity of soil.

Direct and Indirect Impact of Selected Variables on TFR: The districts of Punjab's fertility trend are shown in graph (fig. 8). The trend of TFR in the 36 districts of the Punjab shows that the highest fertility rate is in Rajanpur and Rahim Yar Khan. In these districts their negative correlation between GPP while there is positive impact of mean minimum temperature on fertility rate. While cities in northern eastern and central Punjab like Lahore, Faisalabad, Gujrat etc, it is low. The rate of all the districts is still above the replacement level in the year

2021.The pace of decline is associated with big cities and industrialization while the districts with low rates are more prone to natural disasters like flood and associated with desert area and low soil productivity.

The standardized path coefficients from the path analysis are shown in table. 1 and in fig. 9. As we know that soil productivity ensures food security in an area. So, in present case, precipitation and temperature have a significant positive effect on GPP and indirectly to the production of the crops. Therefore, it has a direct positive effect on TFR and it has an indirect effect on TFR through a negative impact on the CMR. While the beta values shows that CMR has direct positive impact on TFR of a district in Punjab province.

On the other hand, mean annual minimum and maximum temperature and mean annual, and mean annual precipitation have direct positive effect on GPP and shows negative direct effect on TFR. But mean annual precipitation and mean minimum temperature have positive effect on CMR. Hence, influence the TFR of a district indirectly.

The total effect of GPP is positive on TFR and it have all have total positive impact on the CMR. While mean annual max. and min. temperature total impact is negative with FTR and the table1 shows positive total impact on TFR of mean annual precipitation. The total impact of CMR on TFR is also positive.

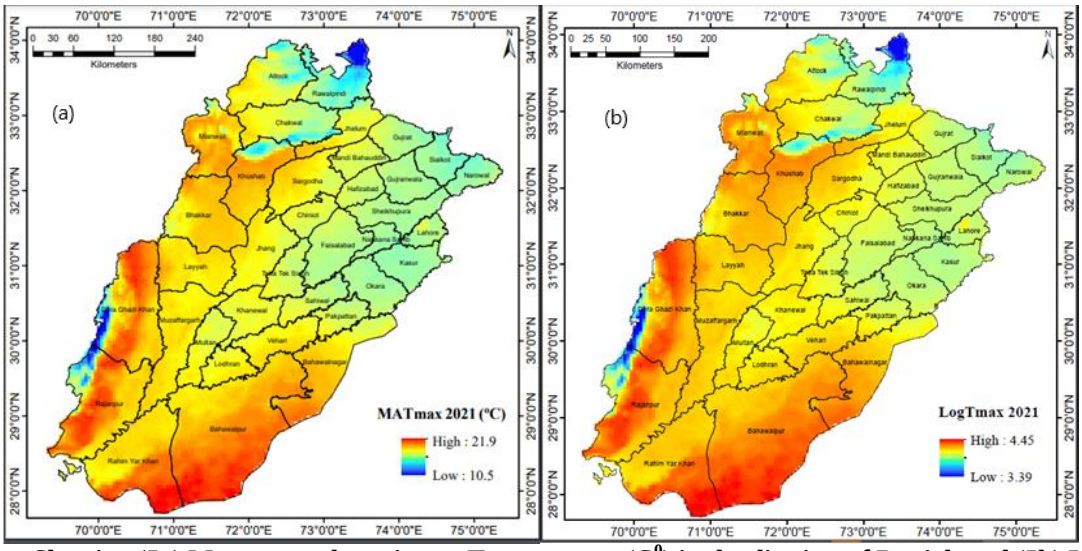

Fig. 5 Maps Showing (5a) Mean annual maximum Temperature (C^0) in the districts of Punjab and (5b) Log of Mean annual maximum Temperature in the districts of Punjab

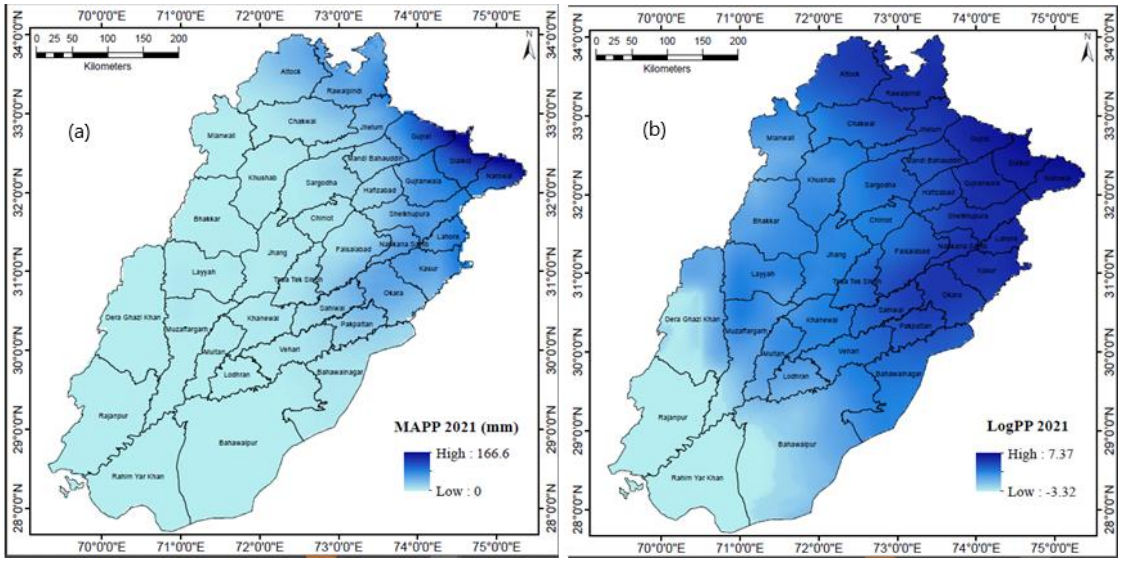

Fig. 6 Maps Showing (6a) Mean annual precipitation (mm) in the districts of Punjab and (6b) Log of Mean annual precipitation in the districts of Punjab

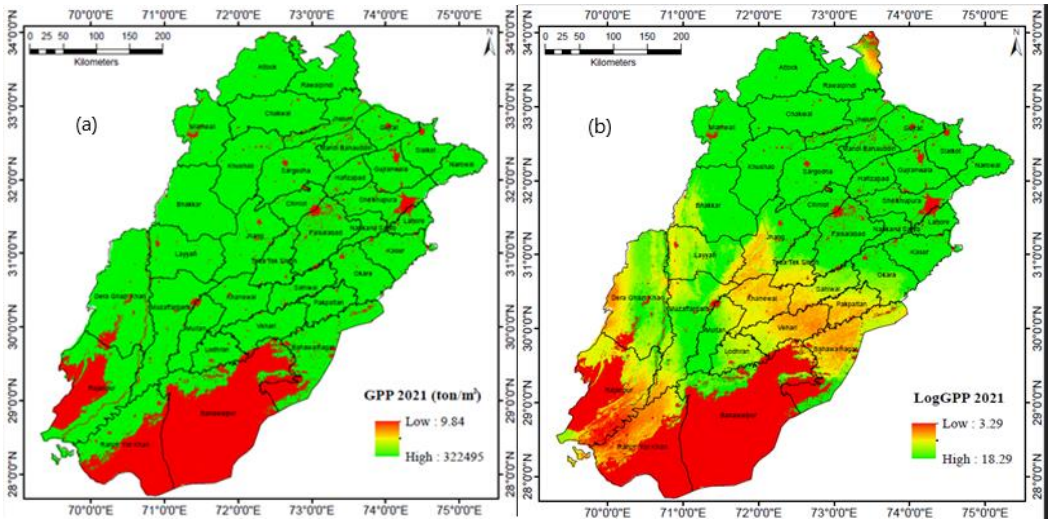

Fig. 7 Maps Showing (7a) Gross Primary Production (ton m^2) in the districts of Punjab and (7b) Log of Gross Primary Production in the districts of Punjab

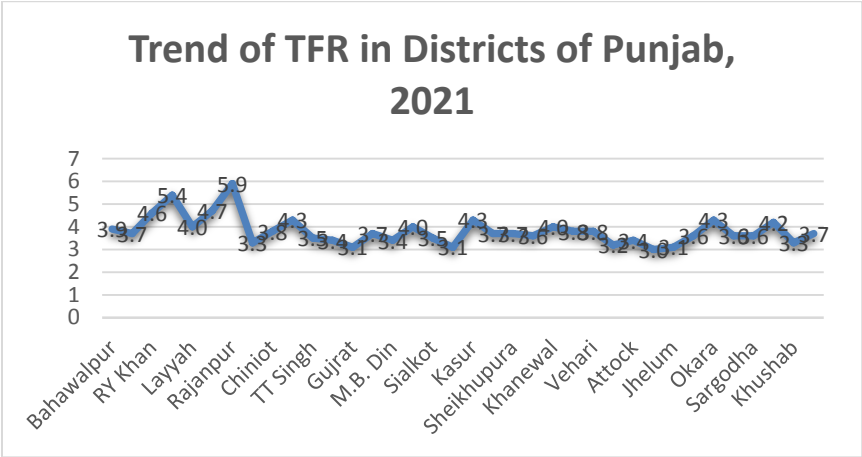

Fig.8 Graph showing trend of Total Fertility Rate (TFR) in districts of Punjab Source: Multiple Indicator Cluster Survey, 2021

The direct and indirect impacts of variables and their total effects of all the selected factors are shown in table 1 and GSSM and its classes are shown in resultant maps (9a and 9b) in figure 9.

Table 1: The Direct, indirect, and total effects of selected factors on TFR in the districts of Punjab in 2021.

Variables	Direct effect	Indirect effect	Total effect
Gross primary productivity	0.177	1.3	1.477
Mean annual maximum Temperature	-0.129	- 0.152	- 0.281
Mean annual minimum Temperature	- 0.378	0.214	- 0.164
Mean annual precipitation	- 0.477	1.04	0.563
Child mortality rate	0.25	/	0.25

RESULTANT MAPS OF GEOSPATIAL STRUCTURAL MODELING: The final results of Geospatial Structural Modeling are shown in figures 9 and 8. GSSM resultant map shows the direct and indirect impact of independent variables on the intermediate variable and finally on dependant variable TFR of districts of the Punjab with darker to lighter colours shows the final trend in districts and very clearly within the districts also. Moreover, the results of modeling are further sub-divided into five class to understand the results better. Five classes are very high, high, medium, low and very low. Districts with high TFR trends in

GSSM are Rawalpindi, Hafizabad, Narowal, Chiniot, Kasur, Okara, Nankana Sahib, Toba Tek Singh, Sahiwal and Pakpattan. While the TFR of the three districts Rahim Yar Khan, Rajanpur and Dera Gazi Khan are very low in GSSM. Multan and Khushab show medium pace in TFR. While Bahawalpur, Lodhran, Muzaffargarh, Bhakkar and Mianwali are with low TFR districts. Remaining districts including Lahore and Faisalabad have high class of TFR in Geospatial structural modeling map (9b).

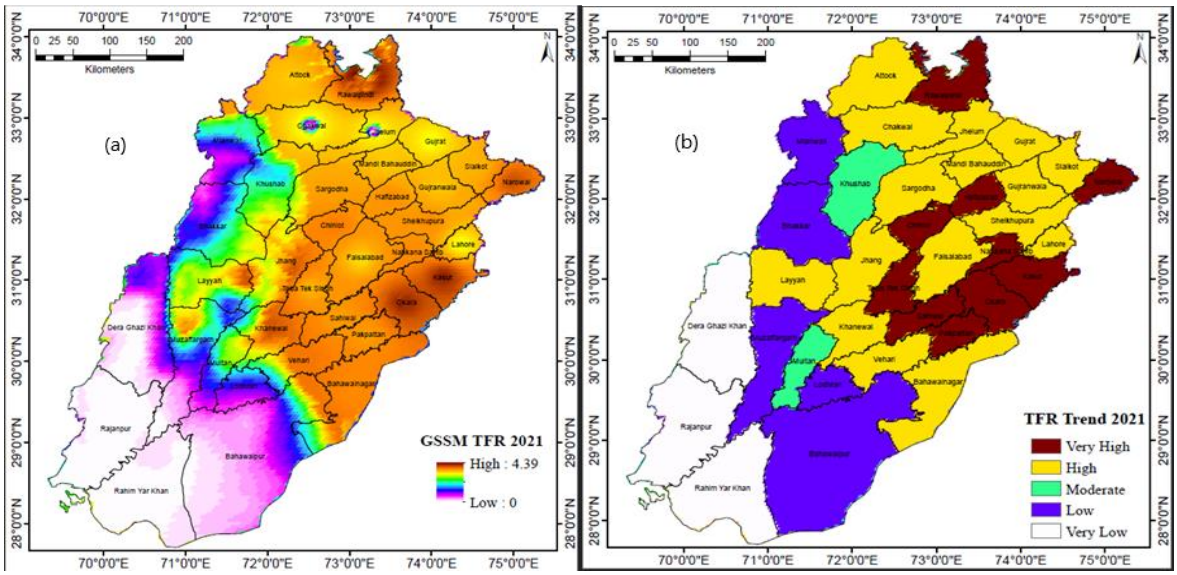

Fig.9 (9a) Map showing visual results of Geospatial modeling for TFR (9b) Map showing visual results of Geospatial modeling for TFR by dividing the districts of Punjab into five classes.

Conclusion: Total fertility rate is a very important factor for achieving the goal of sustainable development in a country, especially developing country like Pakistan. TFR of Punjab's districts are still high and the statistics are still above the replacement level (i.e., 2.1). The pace of decline is only associated with big cities and industrialization while the districts with low rates are more prone to natural disasters like flood and associated with desert area and low soil productivity.

To find out current fertility trend along with regional disparities Geospatial structural model is designed and path analysis has performed. For achieving the objective of present research work RS and GIS are used affectively to show direct and indirect impact of selected factors on TFR of the districts of Punjab. Maximum mean annual temperature and mean annual precipitation shows positive impact on GPP and GPP shows direct positive impact on fertility by ensuring food security. It is also concluded that the result shows there is positive impact of CMR on the TFR. Child mortality rate shows positively affected by mean annual minimum temperature and mean annual rainfall.

Although, there are number of other geographical and non-geographical factors which might affect the TFR of an area directly or indirectly like there are many agricultural inputs like fertilizers and use of agricultural technologies to enhance the gross primary productivity of the soil along with temperature and rainfall and social factors like education and social status by the participation of female in secondary and tertiary activities. But due the limitation of data acquisition only a few variables are included in the research work.

It is also concluded that the visual presentation of fertility data on the bases of selected geographical or climatic factors at the district level distinguished regional disparities easily by GSSM mapping. Thematic maps of GSSM with very high, medium, low, and very low TFR on the bases of results, are very helpful for policy maker to formulate future developmental plans for the province of Punjab and beneficial for empowering women of the study area.

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