How to Cite This Article: Ullah, N., Azhar, S., Rehman, T., Tahir, P., & Amjad, M. (2025). Spatial Distribution of Polio Cases in Pakistan: A GIS-Based Approach for Identifying High-Risk Areas. *Journal of Social Sciences Review*, *5*(2), 31-47. https://doi.org/10.62843/jssr.v5i2.535

Volume 5, **Issue** 2 (Spring 2025)
Pages: 31-47
ISSN (Online): 2789-4428
DOI: 10.62843/jssr.v5i2.535
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JOURNAL OF SOCIAL SCIENCES REVIEW (JSSR)

Spatial Distribution of Polio Cases in Pakistan: A GIS-Based Approach for Identifying High-Risk Areas

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Abstract: *Poliomyelitis (Polio) is a disabling disorder caused by a virus that damages the human brain. People without signs of polio and people ill with poliovirus can silently spread the virus. This study evaluates the geospatial distribution of polio cases, team distribution strategies, and identifies high-risk areas in Pakistan. The polio data was acquired from the National Emergency Operation Center (EOC) from 2017 to 2021. The collected data was analyzed in Excel sheets and then converted into a geodatabase file for geospatial processing. ArcGIS 18.8.2 was employed for the processing and interpolation to find out the spatial patterns of polio cases and guiding trends of the disease. Moran's I analysis was used to assess the trend between polio cases and the geographical location. All the provinces and districts were divided into three classes: high, medium, and low, based on polio-verified cases. Results show that in most rural areas of Balochistan, Khyber Pakhtunkhwa, and Sindh, there was a continuous occurrence of polio cases. In 2019, there were many cases in Khyber Pakhtunkhwa, whereas in other provinces smaller number of polio-affected children. The 2020 results give a high number of polio cases in Lakki Marwat, Khyber Pakhtunkhwa, but in 2021, there was only one case reported throughout Pakistan that was in Killa Abdullah, Balochistan. Furthermore, the clustering design of polio cases is found in the southwest region of Khyber Pakhtunkhwa and the Northwest of Balochistan. This study will facilitate the planning and management of polio vaccination campaigns that aims to reach all children across Pakistan.*

Keywords: Geospatial Analysis, Polio Vaccination, Temporal Analysis, GIS, Balochistan, Pakistan

Introduction

In the 19th century, the initial outbreaks of poliomyelitis disease in Europe were documented, and epidemics in the United States were first reported in 1843 (Losey et al., 2019). However, Polio was declared a pandemic in the world in the 20th century, especially in the 1940s and 1950s. At the start of the 20th century, the poliovirus was among the most feared diseases in the world, as hundreds of people and thousands of children were still affected in many countries every year. Poliovirus affects the spinal cord of the human body, which can cause lifetime paralysis. It is transferred by one person to another and is spread widely through the fecal-oral route, or, barely, by a common medium such as polluted water and food (Waisbord et al., 2010). Afterward, the poliovirus enters the intestine, from where it can attack the nervous system and disturb the spinal cord.

In 1970, a survey published that polio also became widespread in developing countries. As the situation worsened in the early 20th century because of the polio pandemic, polio got the attention of medical researchers and scientists worldwide (Mahmud et al., 2020). In May 1988, the World Health Organization

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(WHO) was in partnership with the Global Polio Eradication Initiative (GPEI), UNICEF, Rotary International, and the US Centers for Disease Control and Prevention and started eradicating polio. As a result, the polio cases decreased by 99% globally, and the three regions, America, Western Pacific, and Europe, were certified as polio-free regions by the World Health Organization (Dong et al., 2020). The GPEI has succeeded in shrinking polio cases from countries till now, it is 125 globally to only two countries, Pakistan and Afghanistan (Ahmad et al., 2015). The global initiative to eradicate poliovirus has seen significant successes but continues to face challenges, particularly in Pakistan. In 1974, Pakistan started the polio immunization campaign, and the efforts for eradication officially started in 1994. But poliovirus transmission is not controlled and is still categorized as an endemic and a major health issue (Ahmad et al., 2015; Vyas et al., 2008). As of March 2021, there has been only one documented polio case in Pakistan, 84 cases in 2020, and 147 cases in 2019. In Pakistan, the Polio Eradication Initiative is failing due to many reasons such as illiteracy, the war against terrorism, poor healthcare systems, security issues to frontline health workers, reduction in vaccinator number, misconceptions regarding the OPV efficacy and Polio Vaccine among local communities, and awful perception of parents (Oteri et al., 2021).

A geographic information system (GIS) is proficient in integrating, displaying, modeling, analyzing, querying, and mapping geospatial datasets. Geo-health applications can play an important role by determining the spatial and temporal variations and risk elements of disease (Mahmud et al., 2020). GIS can help health officials deal with the geographical transmission and outbreak of disease by analyzing the exact spatial and temporal appearances of diseases from GIS maps (Chabot-Couture et al., 2015). Previously, these practices have also been adopted to find out the clustering pattern of sleeping sickness, break-bone fever, HIV, COVID-19, and human granulocytic ehrlichiosis (HGE) (Zulu, Kalipeni, & Johannes, 2014; Franch-Pardo et al., 2020). GIS plays a crucial role in observing and controlling epidemic diseases and can improve the provision of health care services to the affected area. Applications of geospatial technologies can also help the immunization campaign against a specific disease by determining the current coverage of the target population and unvaccinated population, mapping immunization resources and key features, identifying barriers in the immunization campaign, and monitoring immunization programs (Kamadjeu, 2009). It requires an effort for the polio eradication fight to unite with other protecting health services that provide widespread centers for public care and educate governance and systems of accountability. Literature documents reported on polio eradication activities and any polio-related running programs, policies, political events in partnerships with religious advocacy events to achieve the milestones or external events that obstructed polio eradication efforts (Tanskanen et al., 2012; Ataullahjan et al., 2021).

The persistence of poliovirus transmission in Pakistan, particularly within the Balochistan region, is characterized by various challenges that impede effective eradication efforts. This paper performs spatial analysis on poliomyelitis cases using statistical methods such as Interpolation, Autocorrelation, Cluster, and outlier analysis of Moran's- I, and temporal analysis to study cases, team distribution pattern, and population concerning time using the past five years data (2017-2021) collected from National Emergency Operation Center. This study identified the risk zones of Pakistan by approaching the ground truth data and some statistical variables like the number of cases and the team divided in an area and population (Sánchez-Martín et al., 2019). The use of remote sensing data for geo-health has expanded over time and covers locations that are not easily accessible or even recorded. It is as diverse as research conducted for emergency preparedness, outbreak response, humanitarian crisis, and disaster management (Sánchez-Martín et al., 2019; Dogru et al., 2017). Regrettably, health professionals still have problems reading relevant satellite data based on quality, time, and cost, especially in Pakistan. The method followed in this paper is based on ground truth data and realities to understand the ongoing situation of epidemic location and monitor the working process and give methods to prove the potential of geospatial technologies to help health professionals (Ahmad et al., 2015). The appearance of the COVID-19 coronavirus disease 2019 stood as a threat to polio extinction efforts. In April 2020, polio immunization plans all over Pakistan were paused to mitigate the spread of COVID-19. This policy has increased the vulnerability of already endangered children to polio. Understanding the barriers to service delivery and the working factors that affect the effective working of the polio driver are essential to its success (Ataullahjan et al., 2021).

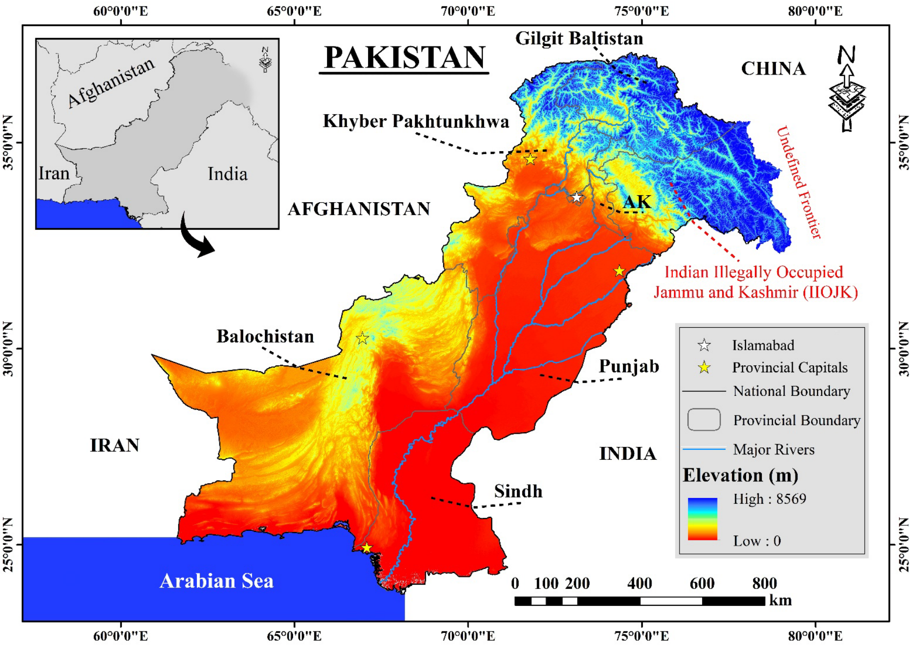
Materials and Methods

Study Area

After the partition of British India, on August 14, 1947, Pakistan emerged as an independent country. Pakistan is a South Asian state that lies between 23.35° to 37.05° N latitudes and 60.50° to 77.50°E longitudes (Embassy of Pakistan, Sweden, 2025), and is surrounded by India to the east, Iran to the west, Afghanistan to the north-west, China to the north, and the Arabian Sea to the south (Ntsama et al., 2021). Pakistan spans an area of over 881,913 km^2, consists of rich plains, mountains, and deserts. Administratively, Pakistan is subdivided into four provinces: Punjab, Khyber Pakhtunkhwa, Sindh, and Balochistan; a capital territory (Islamabad); and two autonomous territories: Azad Jammu and Kashmir (AJK) and Gilgit Baltistan (GB). According to the 7^{th} Population and Housing Census, the total population of Pakistan is 241.49 million (PBS, 2023), the fifth most populous country in the world. Pakistan has a diverse topography that includes high mountain ranges, vast plateaus, fertile plains, and deserts. The tall peaks of the Hindu Kush and Karakoram ranges, which include K2, the second-highest mountain in the world, may be seen in the northern areas of the country. The country is traversed by the Indus River, which sustains livelihoods and agriculture (Consulate General of Pakistan, 2025). Major ethnic groups, including Punjabis, Pashtuns, Sindhis, Baloch, Muhajirs, and others, make up the majority of the country's population. Urdu is the official language of the country, while English is frequently used as the official language. Many natural resources, such as minerals, energy sources, and fertile land, are abundant in Pakistan. Coal, natural gas, copper, gold, and other minerals are all abundant in the country. About 42% of Pakistan's workforce is employed in agriculture, which is the backbone of the country's economy and accounts for about 23% of GDP. Additionally, livestock is essential for both exports and home consumption. Better monitoring methods, contemporary feed practices, and enhanced disease control might all contribute to the sector's potential for future expansion (Mahmood, 2024). Pakistan has a diverse geography and climate that supports over 29 different kinds of fruits. Mangoes, citrus fruits (such as oranges and kinnow), bananas, apples, dates, guavas, pomegranates, and grapes are among the main fruits. The country is one of the world's leading producers of dates and mangoes (Wattoo & Ahmad, 2024). About 28% of the nation's fruits, such as guavas, dates, bananas, mangoes, and sapodillas, are produced in Sindh. About 10% of fruits come from Balochistan, also known as the "Fruit Basket of Pakistan," where the most common fruits are apples, apricots, cherries, almonds, and pistachios (Abdul Rauf, 2024). The Balochistan province's main economic activities include livestock, agriculture, fisheries, and the extraction of minerals like coal, chromite, copper, and so on are the province's primary economic sectors (Ullah et al., 2025).

Figure 1

Map of Study Area (Pakistan) and its Provincial Boundaries



Balochistan's geographical landscape presents unique challenges for polio eradication. Balochistan is most backward region in Pakistan in terms of social development (Panezai, 2017). Balochistan faces severe problems in ensuring the availability of healthcare facilities at the district level (Ullah et al., 2025). Even in Quetta, which is capital city of Balochistan, health facilities are inadequate (Mengal et al., 2025). The province comprises significant populations living in remote areas, which exacerbates vaccination challenges.

For this study, the occurrence of poliovirus in every district of Pakistan was used, whereas the districts in Balochistan were analyzed in detail, encompassing different factors such as culture, gender, literacy, and awareness of the polio vaccine. Balochistan, as the largest province of Pakistan, was considered a hotspot of polio in 2021.

Data Acquisition and Management

Geographical information systems for research and managing strategies depend on the accessibility of exact and suitable data (Bendavid et al., 2012). The scope and objectives of the study are to geospatially analyze data of Polio cases and team distribution strategies in Pakistan, which were acquired from the National Emergency Operation Center (EOC) from 2017 to 2021. The acquired data was converted into a geodatabase file to use in geospatial processing. Statistical data and geographic attributes, including location, district boundaries, and a base map of Pakistan, were attained from different sources. Table 1 shows the data used for the geospatial and statistical processing. The EOC program was initiated for the eradication of polio. The collected data was converted into Excel sheets and then attached to the featured data for the districts.

Table 1

Dataset and Sources

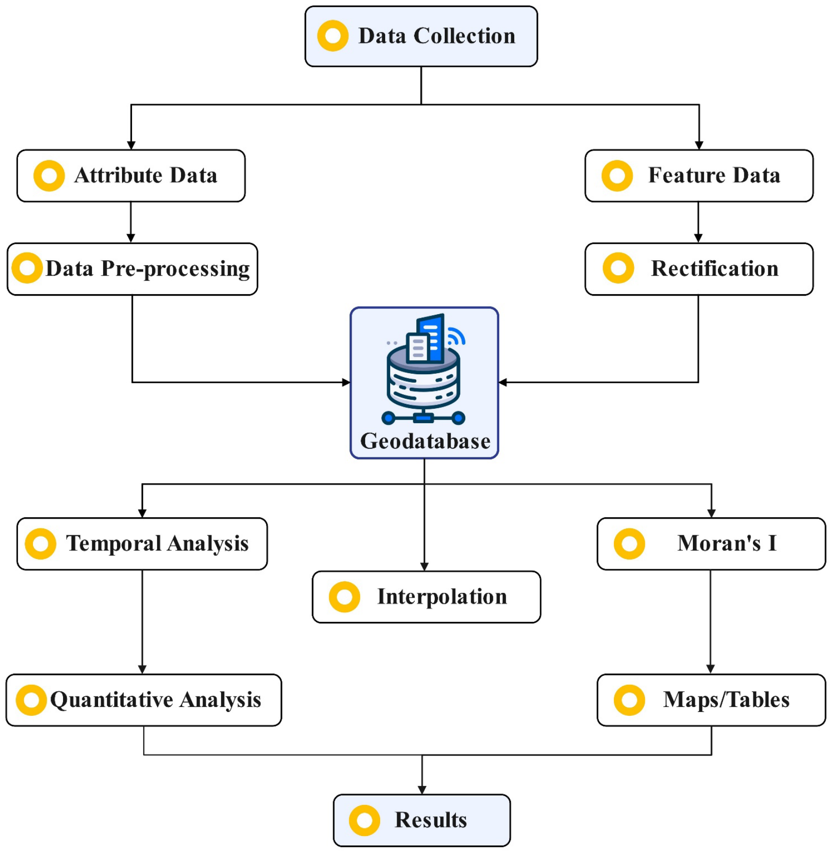
Data	Source	Link
Statistical data	Emergency Operations Center	http://www.epi.gov.pk/emergency- operations-center/
SRTM DEM	USGS	https://earthexplorer.usgs.gov/
Shapefiles (.shp)	SDSSL	https://ncgsa.org.pk/spatial-decision-support-system-lab-sdssl/

Framework

A geodatabase provides information such as spatial developments in the data and how attributes are distributed over the features in a spatial arrangement. The geostatistical analysis finds out spatial designs, clusters over the location based on polio cases, and guiding trends of the disease. In ArcGIS 10.8.2, geospatial processing and interpolation tools are used to compute geographic patterns. However, in this present study, spatial variation in polio cases was observed using maps. The interpolation technique is used for mapping the spatial scattering and identifying risk in provinces and districts. Moran’s I analysis is used to assess the trend between polio cases and the geographical location. Furthermore, the situation of polio vaccine coverage is discussed in Balochistan. The framework (Figure 2) of this study includes the process of spatial filtering applied to data for temporal analysis, interpolation, Moran’s I, and quantitative analysis for results in the form of maps, graphs, and tables.

To create the geodatabase of polio cases, team and vaccination coverage, and other variables have been used for the analysis using available provincial and district data. The spatial filtering procedure was applied to the geodatabase for the rectification of featured data and pre-processing of statistical data to decrease the errors in the data. Attribute data is prepared to be imported into the ArcGIS environment for further processing (Gammino et al., 2014). Districts of the study area are divided into four classes: high, medium, and low endemic districts based on attribute data. The temporal analysis was done first on province data of the years 2017 to 2021 and then on district data of the year 2019 to 2021.

Figure 2
The Framework Used in this Study



Interpolation
The Inverse Distance Weighting (IDW) method was applied to find the occurrence rate of polio cases at the district level for all the provinces of Pakistan. The IDW method in GIS is applied for the mapping of spatial distribution and potential risk regions. Using this method, polio cases are interpolated and used to predict the polio spread pattern across Pakistan. Reliable data on the number for the inverse distance weighting interpolation practice is perfect because it keeps the whole statistical distribution of the polio case rate. The IDW processed values get lower as the distance increases from the location of cases (Grubesic & Murray, 2001).

Moran's I
Moran's I finds the connection between several cases and their positions simultaneously. The output of the experiment proposes a p-value by autocorrelation, which indicates positive or negative links among cases and locations. If results show zero value, it means no relation exists between them. Moran's, I executed in ArcMap 10.8.2 for the number of polio cases in Pakistan to spatially recognize the infection. Moran's I values are between -1 to +1. Using Moran's I, z-score, and p-value can also be measured. The positive Z score value shows that neighboring features also have identical data, and the negative Z score gives no relation, so these features show outliers (Anselin, Syabri, & Kho, 2010; Zhang et al., 2008).

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

For this research, Moran's I test is useful to find out the spatial link in polio cases and evaluate the spatial pattern of disease, district-wise wise whether it is clustered or dispersed.

Results
Polio Vaccination Coverage in Pakistan
Polio vaccination coverage in Pakistan remains a major concern, as Pakistan is one of only two worldwide where the poliovirus still persists. Efforts to eradicate polio in Pakistan have experienced mixed success,

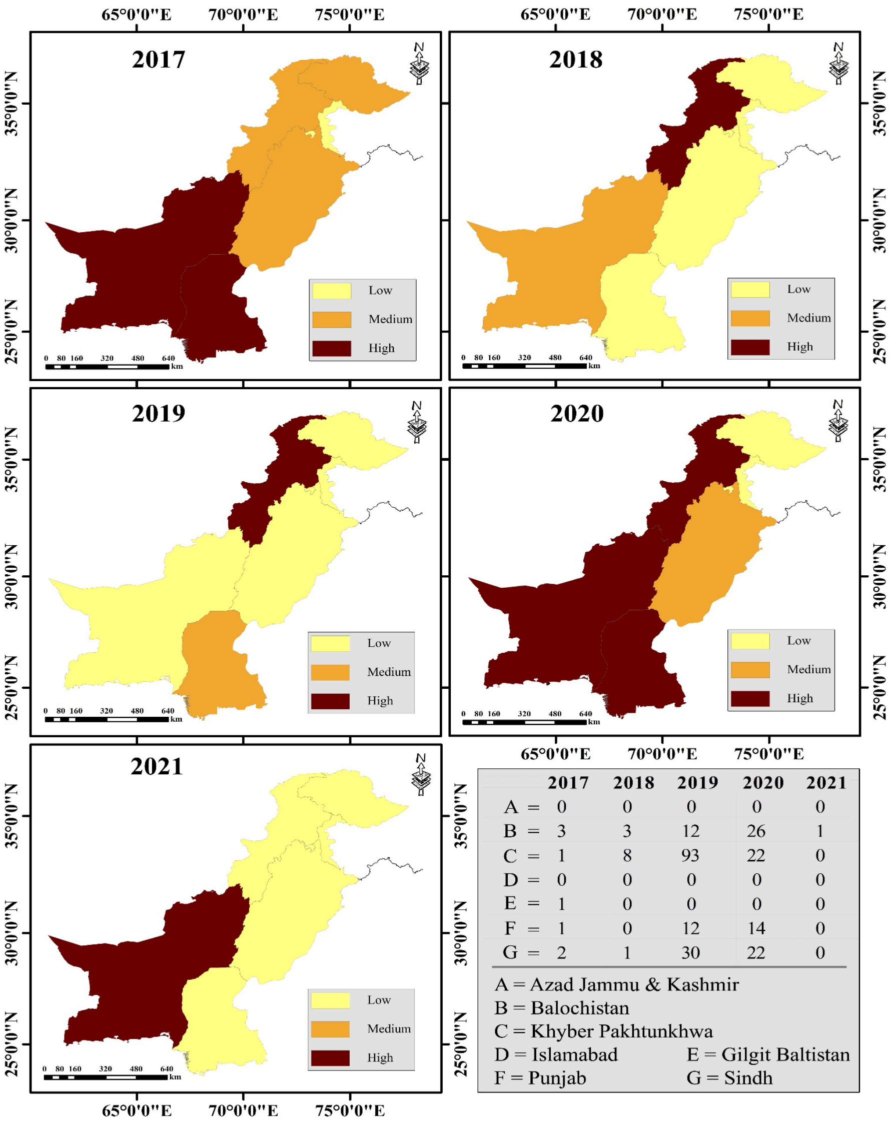
mainly due to operational challenges, vaccine indecision enhanced by misinformation, and security issues that have overwhelmed vaccination campaigns in the country (Mbaeyi et al., 2024). Pakistan saw sharp decline in polio cases notably in 2015 due to national efforts (Morales et al., 2016). However, considerable challenges persist, and an increase has been reported in polio cases recently. Vaccine coverage disparities remain noticeable, especially between urban and rural areas. These differences are further complicated by the emergence of community resistance to vaccination in different areas of the country (Syed et al., 2025).

Province-wise Temporal Analysis of Polio Cases

The spatial and temporal analysis of polio across Pakistan from 2017 to 2021 reveals significant variation in intensity and distribution over time. The study of polio for the years (2017 to 2021) recognized the spatiotemporal design and areas that are at risk provincially and district-wise using spatial processing of raw data with GIS tools. Temporal analysis of poliovirus using yearly data shows the hotspot regions of Pakistan in the past. Results show that in most rural areas of Balochistan, Khyber Pakhtunkhwa, specifically former FATA, and Sindh. These regions had a continuous occurrence of polio-infected children. In 2017, high hazard levels affected Balochistan, Sindh, and Punjab, with medium levels in Khyber Pakhtunkhwa and low in the north. By 2018, hazards shifted northward, with high levels in Khyber Pakhtunkhwa and medium levels in Balochistan and Sindh. The year 2020 marked the most critical period, with widespread high hazard levels engulfing almost all provinces, particularly Balochistan. In the year 2021, there was only one case found that was in Killa Abdullah, Balochistan as shown in Figure 3.

Figure 3

Provincial Temporal Analysis of Polio Cases in Pakistan, with Three Classes: High, Medium, and Low



	2017	2018	2019	2020	2021
A =	0	0	0	0	0
B =	3	3	12	26	1
C =	1	8	93	22	0
D =	0	0	0	0	0
E =	1	0	0	0	0
F =	1	0	12	14	0
G =	2	1	30	22	0

District-wise Temporal Analysis of Polio Cases

District-wise temporal analysis was carried out for all the districts of Pakistan. This analysis was processed by using several cases per year. In 2019, there were many cases in Khyber Pakhtunkhwa, whereas in other provinces smaller number of polio-affected children (Figure 4). The 2020 results also give a high number of polio cases in the Laki Marwat district of Khyber Pakhtunkhwa (Figure 5). But there is a sudden change in the year 2021, where in the whole of Pakistan, there is only one case that is in Killa Abdulla district of Balochistan (Figure 6). Based on this analysis, the visual interpretation of the featured and statistical data shows that this may be because COVID-19-infected patients are not covered properly.

Figure 4

District-Wise Temporal Analysis to Show the Number of Polio Cases in 2019

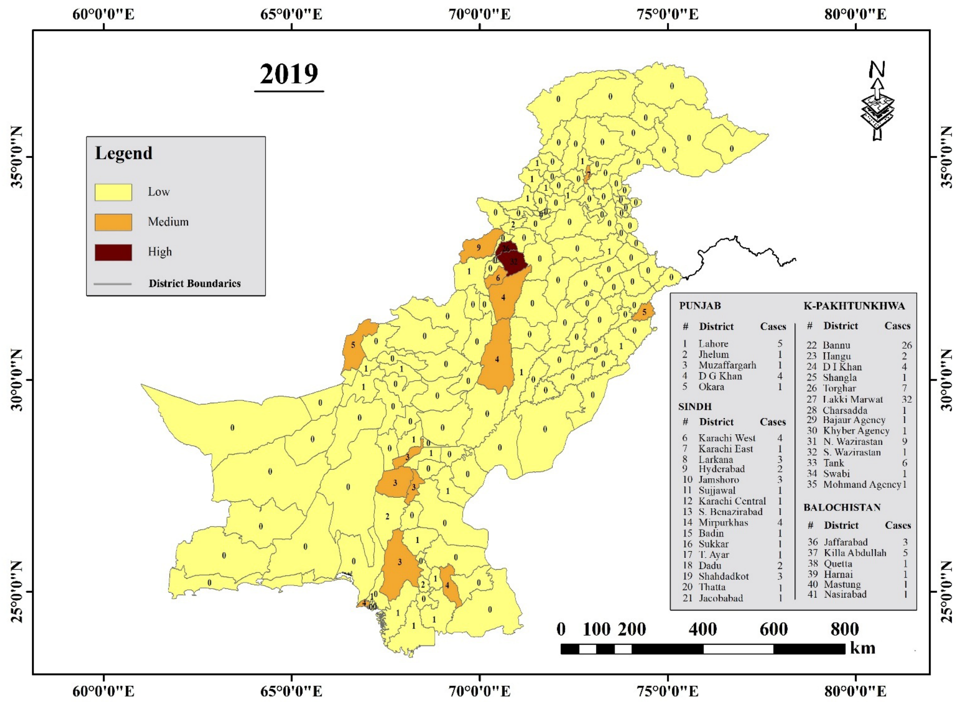


Figure 5

District-Wise Temporal Analysis to Show the Number of Polio Cases in 2020

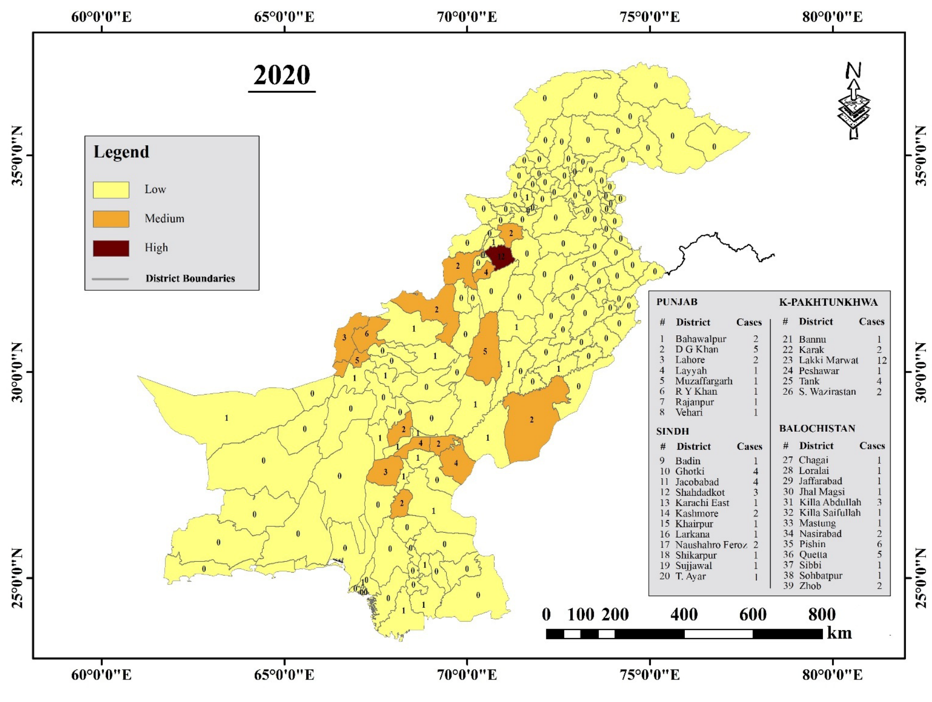
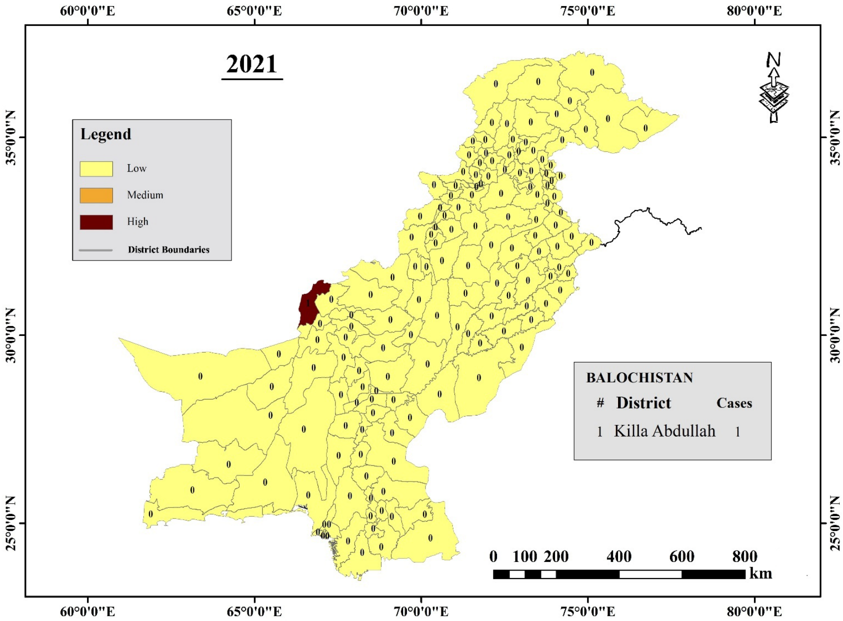


Figure 6

District-Wise Temporal Analysis to Show the Number of Polio Cases in 2021



Inverse Distance Weighting (IDW) Analysis of Polio Cases

The spatial technique applied in this study to reduce the errors in data; the Inverse Distance Weighting (IDW) method was used to find and show the districts that are under polio stress. Through literature review, the present research process shows that the IDW technique of interpolation is proven superior to Kriging for predicting the spatial arrangement of polio cases and vaccine coverage. Observing the results of processing the IDW has advantages over the Kriging method of interpolation. The IDW analysis of polio cases reveals distinct spatial patterns of disease intensity across Pakistan. The IDW method in the study classifies the rate of polio disease in the regions of Balochistan and Khyber Pakhtunkhwa, where pronounced hotspots were observed (Figures 7 and 8). The year 2019 saw hotspots in Khyber Pakhtunkhwa and other increase cases in Punjab. By 2020, the spatial distribution of polio cases showed small, localized clusters with moderate intensity appeared in parts of Balochistan, Sindh, and southern Khyber Pakhtunkhwa.

Figure 7

The IDW Analysis for the Year 2019 to Predict the Number of Cases in the Hotspot Regions, the Process Shows a High Number of Cases in Khyber Pakhtunkhwa

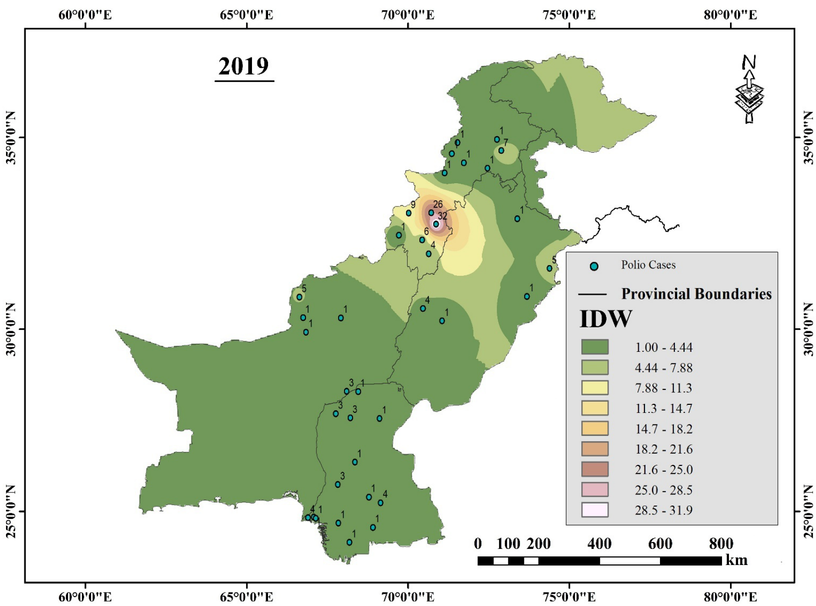
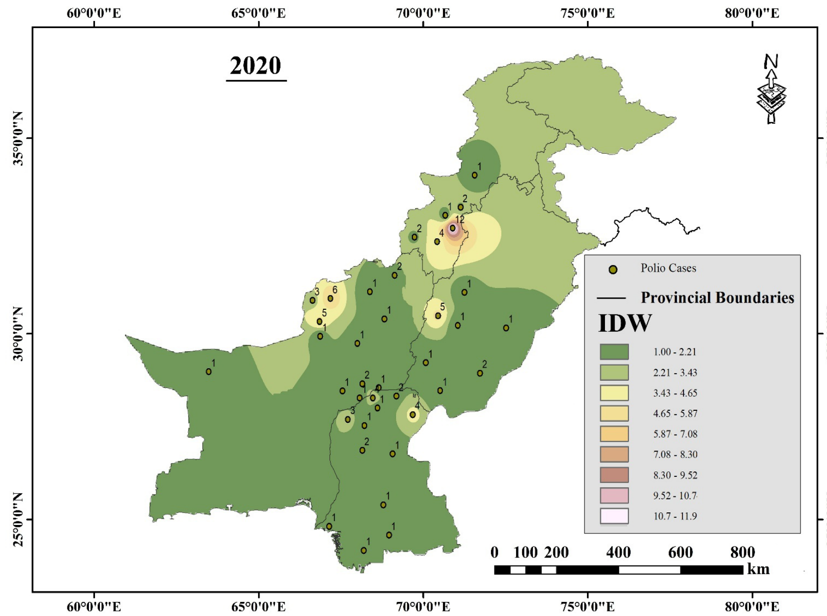


Figure 8

The IDW Analysis for the Year 2020 Shows a High Number of Cases in Khyber Pakhtunkhwa and Balochistan



Cluster Analysis of Polio Cases

The spatial analysis and the statistical tool in the current study identify the supply patterns of polio disease in polio-affected areas of Pakistan. ArcGIS plays an important part in finding the spatial autocorrelation of the geographic location and polio disease concerning time. Autocorrelation in polio disease patterns highlighted that polio has peaked in a few districts of Pakistan. The study area analysis shows the clustering design of polio cases in the southwest region of Khyber Pakhtunkhwa and the Northwest of Balochistan. The potential reasons are that the people of these areas have lower economic indicators, illiteracy, cultural and customary values, and previous experiences, which increase the polio disease rate in the region. The maps highlight the ongoing struggle with polio eradication in Pakistan, with persistent high-risk areas in the northwest and the emergence of new challenge zones, particularly in Balochistan (Figures 9 and 10).

Figure 9

Moran's I Cluster and Outlines Analysis to Classify the District according to the Number of Cases into HH, HL, and LL. This Process Shows a High Number of Cases in Khyber Pakhtunkhwa in 2019

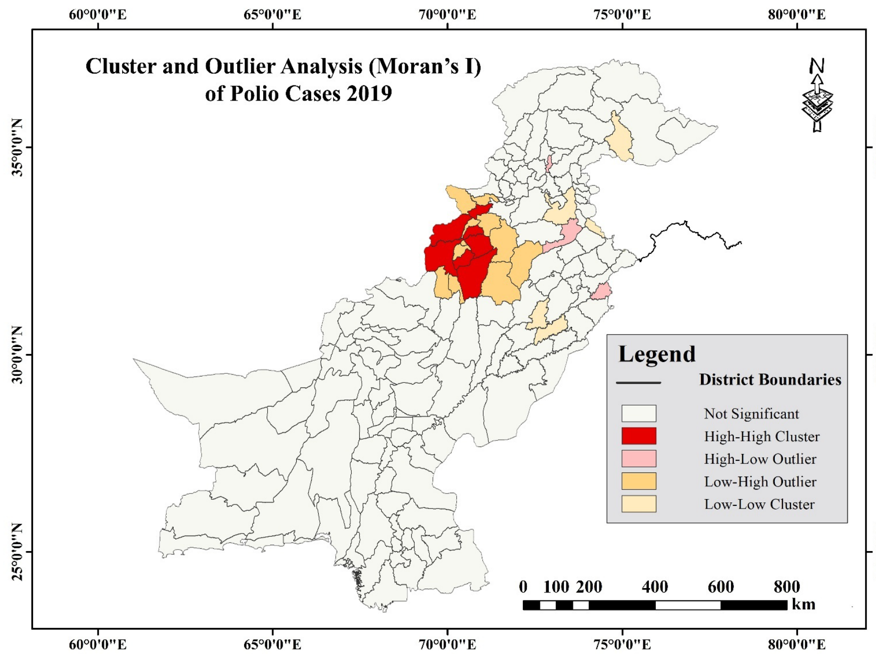
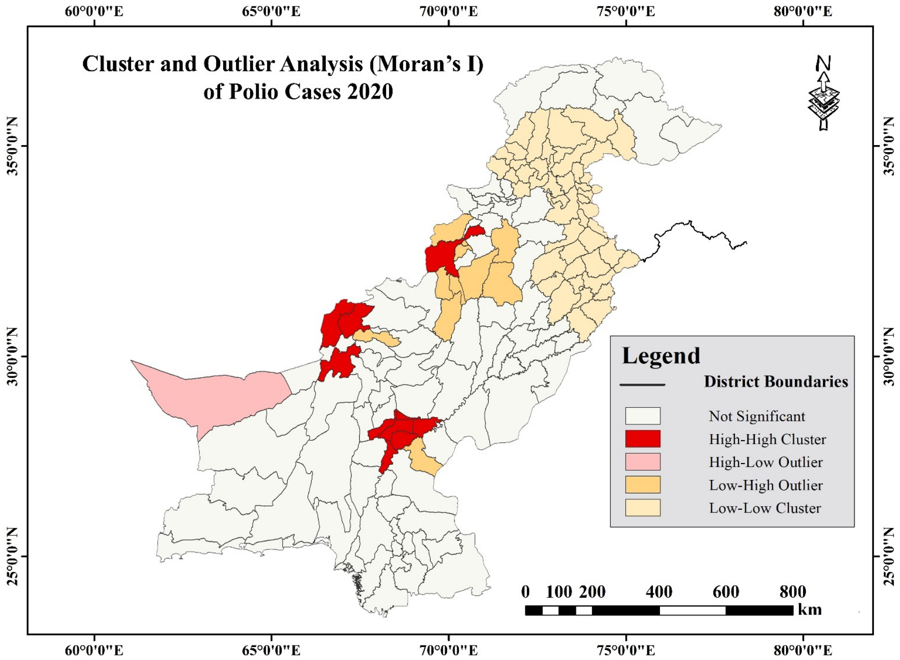


Figure 10

Moran's I to Show HH, HL, LH, and LL Clusters in the Different Regions of Pakistan



I index, Z-score, and the p-value are positive for the years 2019, 2020, and 2021 (Table 2). So, this gives a good relationship between many cases and locations.

Table 2

Moran's I Analysis of Three Years

Moran's I	2019	2020	2021
Moran's, I index	0.129603	0.114125	0.001473
z-score	5.211728	4.179180	1.075050
p-value	0.000689	0.000029	0.282352

Polio Cases in Balochistan

Data collected from the national EOC office shows that in 2021, there was only one case of polio, which was in the Killa Abdullah district. The findings of this study show that multiple factors are affecting the eradication of the poliovirus, specifically in North-West Balochistan. The factors affecting the eradication of the poliovirus are custom and culture, location, literacy, and refusal of the population.

Polio Campaign in Balochistan

After mapping years 2017 to 2021, province and district-wise wise some results and trends to highlight the year 2021, with the only district with polio cases. Temporal analysis shows that there is only one case of polio in the Killa Abdullah district. Variable analysis linked to this fact shows there are very few chances of this happening because it is a sudden change in the year 2021. Without using any specified technology or method, this drastic change is impossible.

The classification analysis is based on temporal and statistical results to examine the sudden drop in cases. (Figure 11) shows the total targeted children map for the campaign of June 2021, while Figure 12 shows the total number of covered children in the same campaign. Figure 13 depicts the relationship between targeted and covered children, showing that not all targets are achieved totally in different districts of Balochistan. The June 2021 polio campaign in Balochistan show a mixed result. The campaign clearly prioritized and deployed significant efforts in districts with large child populations, particularly in Quetta and surrounding districts, and eastern parts of the province. Despite high coverage, the districts with the largest target populations also reported the highest number of missed children from the polio campaign. This might be due to access issues or refusal from people for polio vaccine.

Figure 11

The Map Displays the Total Number of Target Children in Balochistan

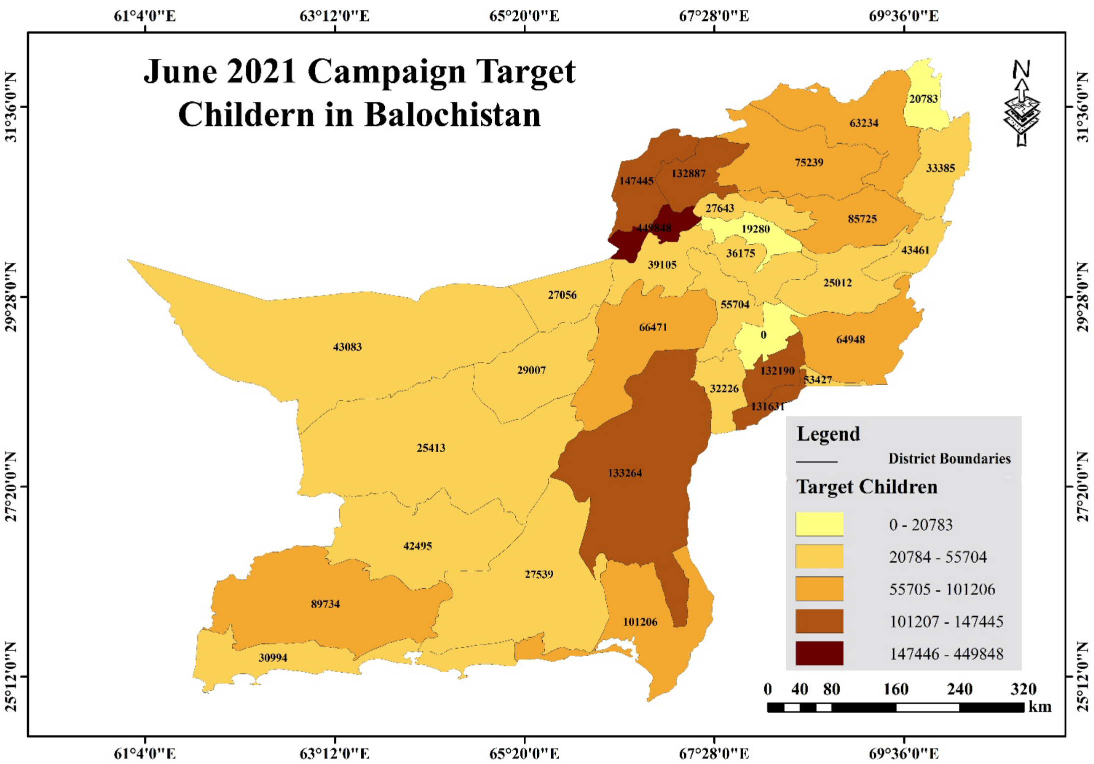


Figure 12

The Map Highlights the Total Number of Children Vaccinated during a Campaign of 2021 June

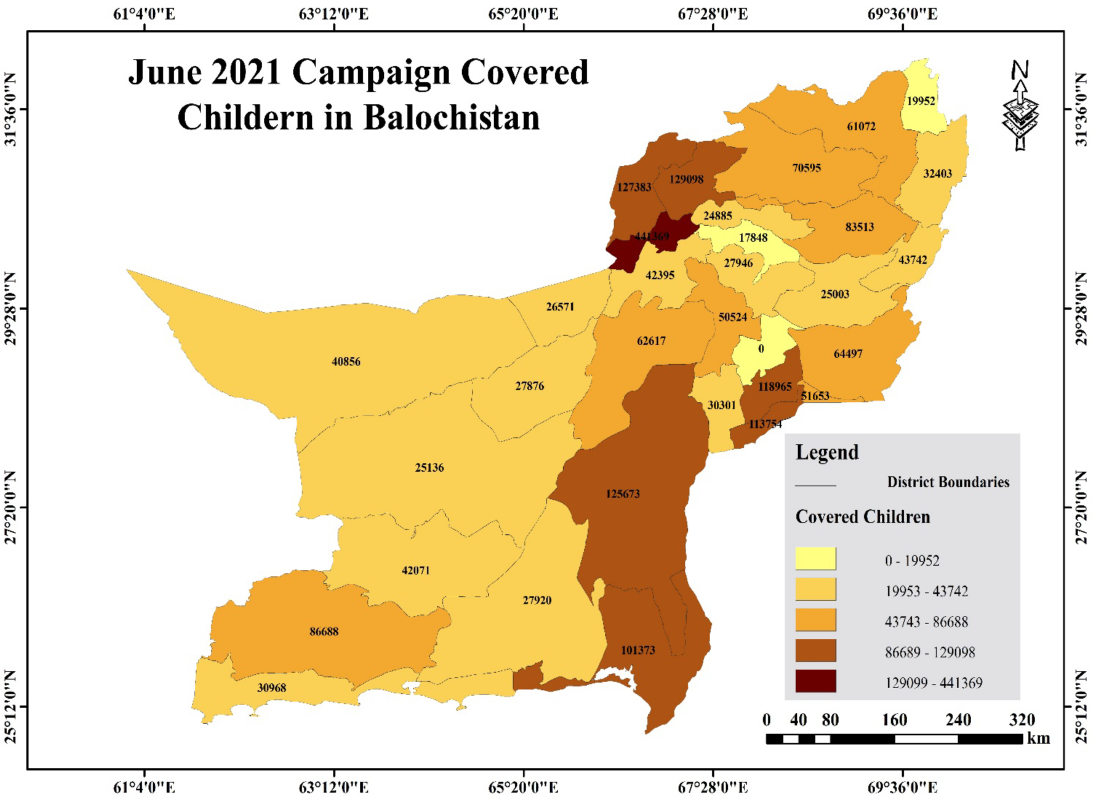
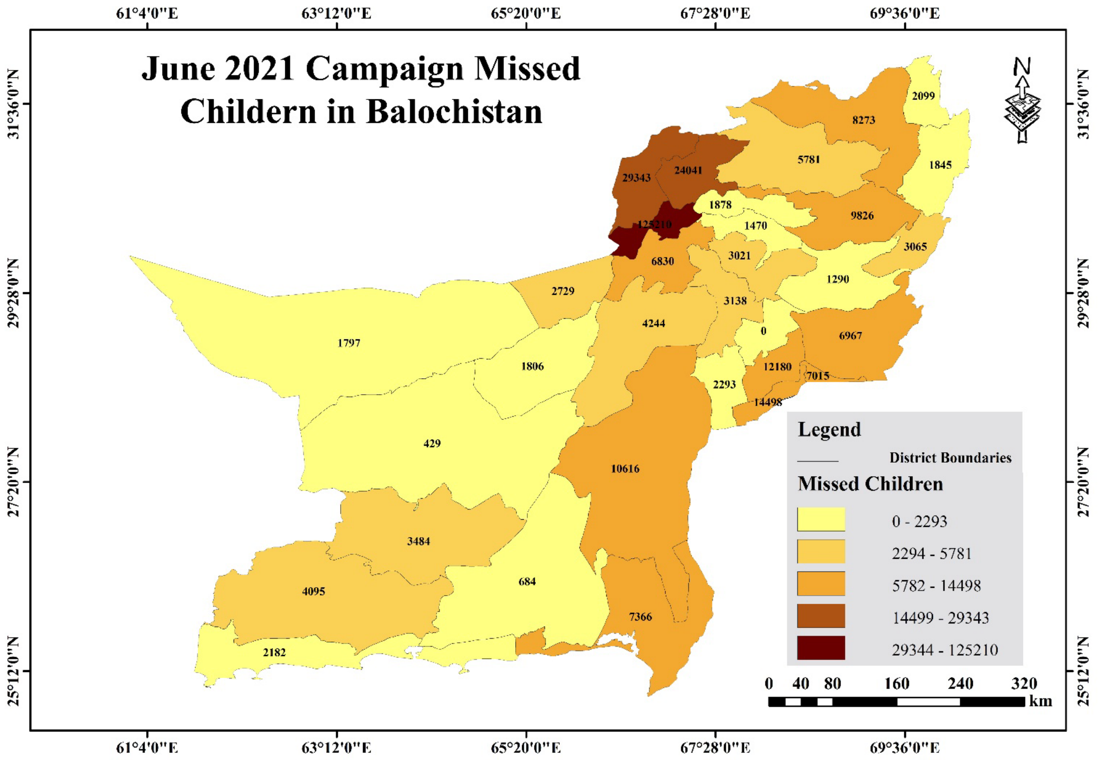


Figure 13

The Quantitative Analysis Process Shows the Number of Missed Children across Balochistan.



As it is mentioned that polio spreads from one to others, so it is a problematic situation in Balochistan. Many other factors predict the coming situation of polio, such as the movement of Afghan refugees, cultural restrictions, unavailable children, and refusal cases.

Discussion

The components interconnected with the polio vaccination problem in Pakistan, including the social and economic gaps along with community perception regarding vaccines, are quite complicated. Polio cases used to be considerably cut in Pakistan because of better governance, better infrastructural improvements to the government structure, and high investment in vaccination drives along with improvements in the vaccination structure within the mid-2010s. However, this progress seems to have hit a stand-still because of rising rural polio cases. (Morales et al., 2016; Verma et al., 2018). The misinformation surrounding vaccination drives coupled with security issues surrounding the access health personnel have to marginalized regions are significant factors contributing to the undoing of polio. (Hussain et al., 2016).

In 2020 Balochistan province seems to have reached an all-time high polio prevalence rate in Pakistan. Along with the issues of misinformation surrounding health infrastructure the socio-economic condition of the district contributes greatly (Shakeel et al., 2019). Having lower economic performance is a big reason to increased negative perception within the population towards details health structure. This weaker approach paired alongside traditional perception makes it a danger to any health initiative. (Aliya et al., 2020). In addition, case clustering of polio suggests important community-level determinants of vaccination coverage, such as strategic misconceptions and myths about vaccine safety and effectiveness (Habib et al., 2017). This is also witnessed through research uncovering that misconceptions about polio vaccinations common in many communities tend to build more resistance to vaccination drives (Aliya et al., 2020). In the 2021 vaccination campaigns, large numbers of children went unvaccinated, largely because of access constraints and socio-cultural refusals (Habib et al., 2023).

The different temporal analyses from 2017-2021 illustrate that although vaccination strategies must be adaptable to local contexts, a combined approach that incorporates community engagement and education is necessary. New approaches, such as using technology for communication and educational outreach, could be highly effective in reaching hesitant groups, with a focus on ensuring that health workers are able to effectively address the most common concerns and barriers among communities (Am & Murtaza, 2016). These efforts are to be supplemented by security improvements in risk-prone zones since violence and conflict have in the past hindered immunization efforts (Hussain et al., 2016). Lastly, a strong system addressing the complex challenges complicating vaccine access in Pakistan must exist, prioritizing not only short-term vaccination requirements but also long-term community acceptance and trust of public health interventions.

The geographic information system is useful for epidemiological studies, and its role is significant due to its ability to integrate data sources and make difficult data understandable. This study focuses on finding the polio distribution pattern in Pakistan, both provincially and district-wise, mapping the related variables such as gender, region, culture, and polio vaccination coverage to reach all settlements. According to previous studies, a GIS-guided statistical approach in planning polio reporting is not utilized fully, and people are often left in danger of disease (Afifi & Darwish, 2018). Geospatial resulting estimates of populations bring into line with polio case data and allow more precise predictions of population and cases. If these operations are performed correctly, and data on geographic locations, number of cases, and population, collected properly. Then, the potential to raise vaccination coverage, eliminate polio, and improve productivity (Chabot-Couture et al., 2015). As one of the polio-affected countries, Pakistan depends upon Afghanistan for eradication, and vice versa. This goal can be achieved by improving the association for the common problem of polio eradication, and coordination with Afghanistan can help to achieve advanced vaccination strategies. COVID-19 has a direct impact on polio vaccination rates (Ataullahjan et al., 2021). The distraction of polio campaigns to control COVID-19 through social distancing and, more importantly, supply problems may have severe long-term influences on the polio program's progress. Governance, accountability, and unpredictable leadership have delayed the success of the polio program and the effectiveness of the campaigns. The article contains a review of the barriers and organizers linked with the delivery of polio eradication in Pakistan.

Policy Implications

Integrating geospatial data and previous methods can provide high-risk polio regions, which supports a future scientist in inspecting the spatiotemporal designs of polio disease, factors, and reasons. This research helps health officials to use innovative techniques to recognize the pattern of polio outbreaks by applying spatial statistical techniques instead of depending only on old manual methods. The decision-makers and vaccination campaign personnel can then use these analyses on Geographical Information Systems (GIS) maps to manage all settlement locations in the targeted districts. This research will also facilitate the management of polio vaccination campaigns planning that aims to reach all children across Pakistan and seek to transform poliovirus data into information necessary for strategic planning.

Future Work

The GIS method, which grows the volume of the labor force through technology solutions, offers extra profits to the polio program. Health workers use geospatial tools to estimate total area, populations, and hotspot regions for vaccination strategies through visual interpretation. GIS in vaccination helps to do real-time monitoring of polio cases and the team as well to find service delivery gaps. Furthermore, future studies should consider evaluating the team area coverage pattern, tracing nomadic movement through data collected by polio workers, and introducing a VTS vaccination tracking system to eliminate Polio from Pakistan (Pradhan et al., 2012).

Conclusion

Polio is a pandemic disease, and Pakistan faces challenges against polio eradication. the ongoing struggle against polio in Pakistan highlights both the significant achievements and the formidable challenges that characterize the journey toward full eradication of the disease. The data analyzed from 2017 to 2021 clearly show a fluctuating trend in polio cases, exacerbated by various socio-political and health system deficiencies, mainly with Balochistan and Khyber Pakhtunkhwa emerging as persistent hotspot of transmission. The findings of the present study indicate that polio cases were consistently occurring in the majority of rural regions in Sindh, Khyber Pakhtunkhwa, and Balochistan. While there were fewer polio-affected children in other provinces in 2019, Khyber Pakhtunkhwa saw a large number of infections. According to the 2020 data, Lakki Marwat, Khyber Pakhtunkhwa, had a high number of polio cases; however, in 2021, just one case in Killa Abdullah, Balochistan, was reported in the country. Although substantial progress was noted in the reduction of polio cases, particularly in 2015 due to dedicated vaccination drives, this progress has proved unsustainable, with recent years witnessing resurgent outbreaks largely driven by operational challenges, vaccine hesitancy, and misinformation among communities.

GIS-based planning is a way to improve vaccination coverage and identify risk areas. Spatial and temporal analyses highlighted the role of Geographic Information System (GIS) methodologies in identifying polio hotspots, enabling more targeted interventions. The inconsistency in vaccine coverage, particularly between urban and rural populations, remains a critical barrier in the fight against polio. Moreover, socioeconomic factors such as poverty, illiteracy, and community mistrust critically hinder vaccination efforts. The emergence of misinformation regarding vaccine safety and efficacy, heavily proliferated by social media, adds another layer of complexity to the challenges faced by health workers in reaching the unvaccinated. The unprecedented impact of the COVID-19 pandemic has further complicated these efforts, contributing to significant drops in overall polio vaccination rates due to the redirection of health resources and the exacerbation of existing hesitancy. This has highlighted the necessity for adaptive strategies that incorporate community engagement and education, enabling health authorities to effectively counter misinformation and increase public trust in vaccination services.

Author Contributions: Niamat Ullah, and Shanila Azhar. led the idea, design, and supervision of the data analysis and editing. Penha Tahir, Tehmoor Rehman, and Muhammad Amjad: methodology, visualization, writing review, and editing. All the authors have contributed to the paper and approved the submitted version of the manuscript.
Conflicts of Interest: The authors declare no conflict of interest.
Availability of data and materials: Data and materials for the present study will be available upon request from the corresponding author (niamatullahza@gmail.com).
Acknowledgments: The authors are grateful to the Spatial Decision Support Systems (SDSS) Lab (NCGSA) for providing guidance and expert support for the present study.
Funding: No funding

References

Afifi, A. A., & Darwish, K. M. (2018). Detection and impact of land encroachment in El-Beheira governorate, Egypt. Modeling Earth Systems and Environment, 4(2), 517–526. https://doi.org/10.1007/s40808-018-0462-9

Ahmad, U., Ahmad, S. R., & Luqman, M. (2015). A study of polio disease in Pakistan using GIS approach. *International Journal of Scientific & Technology Research*, 4(6), 315–322.

Aliya, B., Karim, M., Mahnoor, R., Hina, G., Ashraf, S., Humayun, U., ... & Bakar, M. (2020). Reasons for parental hesitancy towards oral polio vaccine (OPV): a cross sectional study in Khyber agency, Pakistan. *Journal of Rehman Medical Institute, 6*(3), 03-07. https://doi.org/10.52442/jrmi.v6i3.182

Anselin, L., Syabri, I., & Kho, Y. (2010). GeoDa: An Introduction to Spatial Data Analysis. In *Handbook of Applied Spatial Analysis* (pp. 73–89). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-03647-7_5

Am, K. & Murtaza, A. (2016). Effect of mobile phone text messages reminders on uptake of routine immunization among children in Pakistan-study protocol for a randomized clinical trial. *Journal of Vaccines & Vaccination,* 7(4). https://doi.org/10.4172/2157-7560.1000333

Ataullahjan, A., Ahsan, H., Soofi, S., Habib, M. A., & Bhutta, Z. A. (2021). Eradicating polio in Pakistan: A systematic review of programs and policies. *Expert Review of Vaccines, 20*(6), 1–18. https://doi.org/10.1080/14760584.2021.1915139

Bendavid, E., Holmes, C. B., Bhattacharya, J., & Miller, G. (2012). HIV development assistance and adult mortality in Africa. *JAMA, 307*(19), 2060–2067. https://doi.org/10.1001/jama.2012.2001

Chabot-Couture, G., Seaman, V. Y., Wenger, J., Moonen, B., & Magill, A. (2015). Advancing digital methods in the fight against communicable diseases. *International Health*, 7(2), 79–81. https://doi.org/10.1093/inthealth/ihv008

Consulate General of Pakistan, Los Angeles. (2025). *About Pakistan.* https://pakconsulatela.org/about-pakistan/

Dogru, A. O., David, R. M., Ulugtekin, N., Goksel, C., Seker, D. Z., & Sözen, S. (2017). GIS based spatial pattern analysis: Children with Hepatitis A in Turkey. *Environmental Research*, 156, 349–357. https://doi.org/10.1016/j.envres.2017.04.001

Dong, T. Q., Rhoda, D. A., & Mercer, L. D. (2020). Impact of state weights on national vaccination coverage estimates from household surveys in Nigeria. *Vaccine, 38*(32), 5060–5070. https://doi.org/10.1016/j.vaccine.2020.05.026

Embassy of Pakistan, Sweden. (2025). About Pakistan. https://pakistanembassy.se/about-pakistan/

Franch-Pardo, I., Napoletano, B. M., Rosete-Verges, F., & Billa, L. (2020). Spatial analysis and GIS in the study of COVID-19: A review. *Science of The Total Environment*, 739, 140033. https://doi.org/10.1016/j.scitotenv.2020.140033

Gammino, V. M., Nuhu, A., Chenoweth, P., Manneh, F., Young, R. R., Sugerman, D. E., Gerber, S., Abanida, E., & Gasasira, A. (2014). Using geographic information systems to track polio vaccination team performance: Pilot project report. *The Journal of Infectious Diseases, 210*(Suppl 1), S98–S101. https://doi.org/10.1093/infdis/jit285

Habib, A., Tabassum, F., Hussain, I., Khan, T., Syed, N., Shaheen, F., ... & Bhutta, Z. (2023). Exploring knowledge and perceptions of polio disease and its immunization in polio high-risk areas of Pakistan. *Vaccines, 11*(7), 1206. https://doi.org/10.3390/vaccines11071206

Habib, A., Soofi, S., Ali, N., Hussain, I., Tabassum, F., Suhag, Z., ... & Bhutta, Z. (2017). Knowledge and perceptions of polio and polio immunization in polio high-risk areas of Pakistan. *Journal of Public Health Policy, 38*(1), 16-36. https://doi.org/10.1057/s41271-016-0056-6

Hussain, S. F., Patel, P., & Sullivan, R. (2016). Eradicating polio in Pakistan: An analysis of the challenges and solutions to this security and health issue. *Globalization and Health, 12*, 63. https://doi.org/10.1186/s12992-016-0195-3

Kamadjeu, R. (2009). Tracking the polio virus down the Congo River: A case study on the use of Google Earth™ in public health planning and mapping. *International Journal of Health Geographics*, *8*(1), 4. https://doi.org/10.1186/1476-072X-8-4

Losey, L., Ogden, E., Bisrat, F., Solomon, R., Newberry, D., Coates, E., Ward, D., Hilmi, L., LeBan, K., Burrowes, V., & Perry, H. B. (2019). The CORE Group Polio Project: An overview of its history and its contributions to the global polio eradication initiative. *The American Journal of Tropical Medicine and Hygiene*, *101*(4 Suppl), 4–14. https://doi.org/10.4269/ajtmh.18-0916

Mahmud, M. Z., Seaman, V., Mahmud, M. Z., & Touray, K. M. (2020). Using polio GIS maps to increase coverage during mass immunization campaigns in northern Nigeria. In *Research Square*. https://doi.org/10.21203/rs.2.21515/v2

Mbaeyi, C., Ul Haq, A., Safdar, R. M., Khan, Z., Corkum, M., Henderson, E., Wadood, Z. M., Alam, M. M., & Franka, R. (2024). Progress Toward Poliomyelitis Eradication - Pakistan, January 2023-June 2024. MMWR. *Morbidity and mortality weekly report*, *73*(36), 788–792. https://doi.org/10.15585/mmwr.mm7336a2

Mengal, S., Ullah, N., Rehman, T., & Ullah, S. (2025). Comparison between the Problems of Urbanization in Quetta City and Hub City: An Urban Geographical Perspective. *ACADEMIA International Journal for Social Sciences*, *4*(1), 375-391. https://doi.org/10.63056/ACAD.004.01.0079

Morales, M., Tangermann, R., & Wassilak, S. (2016). Progress toward polio eradication — worldwide, 2015–2016. *MMWR Morbidity and Mortality Weekly Report*, *65*(18), 470-473. https://doi.org/10.15585/mmwr.mm6518a4

Ntsama, B., Bwaka, A., Katsande, R., Obiang, R. M., Oyaole, D. R., Mkanda, P., & Okeibunor, J. (2021). Polio data quality improvement in the African region. *Journal of Immunological Sciences*, *Special Issue*(2), 126–133. https://doi.org/10.29245/2578-3009/2021/S2.1105

Oteri, A. J., Adamu, U., Dieng, B., Bawa, S., Terna, N., Nsubuga, P., & Shuaib, F. (2021). Nigeria experience on the use of polio assets for the 2017/18 measles vaccination campaign follow-up. *Vaccine*, *39*(Suppl 3), C3–C11. https://doi.org/10.1016/j.vaccine.2021.04.040

Panezai, S. (2017). Access to and Utilization of Primary Health Care Services in Balochistan: A Gender Specific Study. *Doctor of Philosophy, Asian Institute of Technology*.

Pakistan Bureau of Statistics (BPS). (2023). *7th Population and Housing Census - Detailed Results*. Pakistan Bureau of Statistics. https://www.pbs.gov.pk/digital-census/detailed-results

Pradhan, N., Ryman, T. K., Varkey, S., Ranjan, A., Gupta, S. K., Krishna, G., Swetanki, R. P., & Young, R. (2012). Expanding and improving urban outreach immunization in Patna, India. *Tropical Medicine & International Health*, *17*(3), 292–299. https://doi.org/10.1111/j.1365-3156.2011.02916.x

Shakeel, S., Brown, M., Sethi, S., & Mackey, T. (2019). Achieving the end game: employing "vaccine diplomacy" to eradicate polio in Pakistan. *BMC Public Health*, *19*, 79. https://doi.org/10.1186/s12889-019-6393-1

Syed, A. R. S., Raza, S. S. M., Zakir, S. J., Chishti, M. A. S., Ahmad, S., Khan, H. D., Khaliq, A., Muzammil, M. A., & Oduoye, M. O. (2025). Mission of polio eradication in Pakistan- a review on challenges and future recommendations. *New Microbes and New Infections*, *64*, 101571. https://doi.org/10.1016/j.nmni.2025.101571

Tanskanen, A., Nillos, L. T., Lehtinen, A., Nohynek, H., Sanvictores, D. H. M., Simões, E. A., Tallo, V. L., & Lucero, M. G. (2012). Geographic information system and tools of spatial analysis in a pneumococcal vaccine trial. *BMC Research Notes*, *5*(1), 51. https://doi.org/10.1186/1756-0500-5-51

Ullah, S., Ullah, N., Tariq, A., Panezai, S., Tahir, P., & Khan, B. (2025). Spatial assessment of the availability of healthcare facilities at the district level in Balochistan using GIS: Identifying gaps and way forward. *Spatial Information Research*, *33*(2), 8. https://doi.org/10.1007/s41324-025-00602-7

Verma, A. A., Jimenez, M. P., Tangermann, R. H., Subramanian, S. V., & Razak, F. (2018). Insecurity, polio vaccination rates, and polio incidence in northwest Pakistan. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(7), 1593–1598. https://doi.org/10.1073/pnas.1711923115

Vyas, A., Upadhyay, A., & Kalsariya, S. (2008). Polio eradication drive: Issues and challenges – Visualization through GIS. In Geoinformation Technology for Better Health . *International Conference on Geoinformation Technology for Better Health.*, 1–6.

Waisbord, S., Shimp, L., Ogden, E. W., & Morry, C. (2010). Communication for polio eradication: Improving the quality of communication programming through real-time monitoring and evaluation. *Journal of Health Communication*, *15*(sup1), 9–24. https://doi.org/10.1080/10810731003695375

Zhang, C., Luo, L., Xu, W., & Ledwith, V. (2008). Use of local Moran's I and GIS to identify pollution hotspots of Pb in urban soils of Galway, Ireland. *Science of the Total Environment, 398*(1–3), 212–221. https://doi.org/10.1016/j.scitotenv.2008.03.011

Zulu, L. C., Kalipeni, E., & Johannes, E. (2014). Analyzing spatial clustering and the spatiotemporal nature and trends of HIV/AIDS prevalence using GIS: The case of Malawi, 1994–2010. *BMC Infectious Diseases, 14*(1), 285. https://doi.org/10.1186/1471-2334-14-285

Grubesic, T. H., & Murray, A. T. (2001, December). Detecting hot spots using cluster analysis and GIS. In *Proceedings from the fifth annual international crime mapping research conference* (Vol. 26).

Wattoo, K. S., & Ahmad, W. (2024, April 22). *ANALYSIS: Fruits production on a downward spiral.* Dawn. https://www.dawn.com/news/1828703

Rauf, A. (2024, June 3). *The significance of fruit economy for Pakistan: A critical appraisal*. Republic Policy. https://republicpolicy.com/the-significance-of-fruit-economy-for-pakistan-a-critical-appraisal/

Rauf, A. (2024, June 3). *The significance of fruit economy for Pakistan: A critical appraisal.* Republic Policy. https://republicpolicy.com/the-significance-of-fruit-economy-for-pakistan-a-critical-appraisal/

Mahmood, A. (2024, June 12). *Economic Survey 2023-24: Agriculture's 'best performance' in two decades helps drive economic growth.* Dawn. https://www.dawn.com/news/1839339