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Pattern analysis of substandard and inadequate distribution of educational resources in urban–rural areas of Abbottabad, Pakistan

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Abstract Despite an extensive system of public schools, Abbottabad, Pakistan has a chronically low literacy rate. A factor contributing to these low literacy rates might be a spatial mismatch between public schools and dense settlements in fast-growing urban and semi-urban areas of this municipal region. To test this proposition, the locations of 153 public schools were collected using hand-held GPS devices to create a geo-database, and a road network was created from the open street map and Google imagery. Nearest

neighbor, K-function, Spearman's Rho, and directional analyses were applied to this data to overcome limitations of sparse geo-spatial data. A point pattern analysis shows that more than 50% of secondary schools were clustered south of the city while most of the built-up area was in the north. Localizing Geo-spatial data, spatial restructuring, and reorganization of schools in the study area would support rational planning and enhance student access to school facilities.

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Introduction

Basic education is the right of every child and key to success towards progress in Pakistan. Easy access and upgraded school facilities can act as a catalyst to increase the number of students attending classes at all levels. Schools scattered across uneven geographical terrain, however, limits accessibility in isolated areas like Abbottabad, Pakistan. This problem can be framed in terms of non-spatial and spatial accessibility. Non-spatial accessibility focuses on non-geographic factors like income, religion, and ethnicity while distance and travel time are spatial accessibility variables (Awad-Gladewitz 2014). The problem in Abbottabad is not the number of school facilities, but rather the spatial distribution of schools that is limiting the services of schools to students.

A distribution pattern analysis of schools for education planning can incorporate the expected marked area as a key factor in the location-based decision-making. Analysis based on the concept of distribution and accessibility is therefore ideally suitable to be integrated with GIS (Al-Enazi et al. 2016; Li et al. 2014; Jong and Ritsema 1999). Geographical Information Systems (GIS) provide advanced analysis tools and complete data packages for analyzing service pattern distributions and demographic information. The goal is to analyze the mismatched distribution pattern of schools in Abbottabad with localizing geospatial technologies to suit the conditions in isolated areas like Abbottabad, Pakistan.

Acquiring and authenticating of data related to schools and overcoming the sparsity of spatial data is the main problem; putting the data into a structure for the area where no study has been conducted using spatial data is a challenge that must be tackled. A geographic, non-geographic and statistical data into a local geo-database will aid in finding a mismatch in distribution pattern. With the help of GPS locations of schools, pattern analysis, and optical imagery, school locations can be analyzed and distribution problems can be solved. Output results of the analysis are carried

out using GIS-based methodology based on spatial data spatial analysis.

Background

Pakistan is among the most densely populated countries in the world with population of 197 million in 2017, but ranks among the least developed in terms of human development as estimated by World Bank 2017. Pakistan has not shown improvement in the field of education and in terms of education spending, it is ranked 145th out of the 160 countries (Munir et al. 2015). The literacy rate in Pakistan is only 58%, which means that 42% of the population is unable to read and write. Budget allocation is another constraint as the government spent only 2.0% of GDP in the last decade on education directed toward personnel, leaving insufficient funding for curriculum development, teacher training, supervision of education, or physical infrastructure improvements (Qazi et al. 2014). Growth in these areas can lead towards a higher overall level of education, one that supports national development goals (Scott and Rajabifard 2017).

Pakistan is among the developing countries that face income inequality as well as low literacy rate, reaching a critical level during the 1980s and early 1990s (Shahbaz et al. 2012; Gylfason and Zoega 2003). In countries where the distribution of land, labour, capital and education is equal, it is more probable that the income will be equally distributed (Sumari et al. 2019; Carnoy et al. 2012; Lucas 1988). The majority of people settled in rural areas of Pakistan are poor, thus there are insufficient financial resources for rural communities to provide primary education to their children.

Despite elements related to non-physical accessibility, physical accessibility is also one of the fundamental components that is directly related to the schooling of children. If the schools are far from residential areas, people especially poor families might refuse to send their children. This suggests that the positioning and design of school buildings should match the distribution of the population. In other words, lower accessibility to schools is directly homologous to how the schools are located in the city. Therefore, understanding the spatial occurrence pattern of school points in the city is necessary to overcome location problems.

A point is a location of an event of interest; a point pattern analysis addresses the spatial arrangement of groups of points or events in a geographical space. From a statistical point of view, an observed spatial point pattern can be thought of as the outcome of a spatial stochastic process. The behaviour of a typical spatial distribution process may be categorized in terms of its first-order and second-order properties. Informally, the first-order properties describe the way in which the expected value (mean or average) of the process varies across space, however, second-order properties describe the covariance or correlation between values of the process at different regions in space. Some second-order statistics use the information on all inter-point distances and provide more information on the scale of the pattern (Ripley 1976, 1977, 1981; Diggle 1983; Bailey and Gatrell 1995).

To understand ‘pattern’ in observed spatial data, it is valuable to appreciate that this might rise either from region-wide first-order variation or from second-order variation, or from a combination of both. Formally, first-order properties are described in terms of the intensity, $\lambda(s)$, of the process, which is the mean number of events per unit area at the point ‘s’ (Diggle 1983). This is defined as the mathematical limit:

$$\lambda(s) = \lim_{ds \rightarrow 0} \left\{ \frac{E(Y(ds))}{ds} \right\} \quad (1)$$

where ‘ds’ is a small region around the point ‘s’, ‘E ()’ is the expectation operator and ‘ds’ is the area of this region. $Y(ds)$ refers to the number of events in this small region.

The second-order properties of a spatial point process involve the relationship between numbers of events in pairs of sub-regions within a study region. This is again formally defined in terms of a limit, the second-order intensity of the process:

$$\gamma(s_i, s_j) = \lim_{ds_i, ds_j \rightarrow 0} \left\{ \frac{E(Y(ds_i)Y(ds_j))}{ds_i ds_j} \right\} \quad (2)$$

with similar notation to that described above.

We say that a point process is stationary if the intensity is constant over a study region, so that; ‘ $s = X$ ’ and, in addition, ‘ $y(s_i, s_j) = y(s_i - s_j) = y(d)$ ’. The latter implies that the second-order intensity depends only on the vector difference, d (direction and

distance), between ‘ s_i ’ and ‘ s_j ’ and not on their absolute locations.

Analysis goal is to explore primary connection between public school points in order to explain and evaluate the phenomenon of mismatched pattern of schools. In this research, points are schools that are spread in different areas of the Abbottabad. Geographical information System (GIS) technologies are used to understand the geographical distribution of schools and to rectify the distribution pattern problems (Al-Enazi et al. 2016; Møller and Waagepetersen 2003). Understanding the significance of having a planned spatial distribution of schools does not only aid in construction of new school facilities but also in converting some of the existing buildings into school classrooms and other facilities (Sumari et al. 2017; Musakwa 2017).

Methodology

A methodology developed for identifying spatial variation in school facilities in terms of spatial distributional mismatch of schools. To map the spatial distribution of school facilities, locations of school facilities were collected by hand-held GPS devices and geocoded in software platform. The spatial configuration of road network in the study area was mapped in terms of the spatial layout to represent road structure using both open street maps and Google imagery.

A point pattern analysis aids in formalizing a hypothesis that how well points distributed in space and relation among them. There are many point pattern analysis methods to evaluate the pattern or arrangement of points. Based on different analysis points categorized into random, uniform, clustered and dispersed. In this study, we are considering spatially clustered and dispersed school facilities. In order to assess the mismatch in distribution Nearest Neighbor, Standard Deviation Ellipse, Spearman’s Rho and Ripley’s K techniques were performed.

The idea of standard deviation ellipse (SDE) is to show the dispersion of points around the mean center. This can be used to analyze the ambiguity between the school points, directional growth, and estimating the spatial uncertainty between coordinate frames representing the relative locations (Smith and Cheeseman 1986; Wong 1998). Nearest neighbour analysis

examines the distances between each point and the closest point to it, and then compares these to the expected values for a random sample of points from a complete spatial randomness (CSR) pattern (Boots and Getis 1988). Ripley's K-function is typically used to compare a given point distribution with a random distribution; i.e., the point distribution under investigation is tested against the null hypothesis that the points are distributed randomly and independently (Kiskowski et al. 2009).

Study area

The study area for this research is Abbottabad City, Khyber Pakhtunkhwa (KPK) shown in Fig. 1. Abbottabad is one of the fastest developing cities in KPK, with an area of 18,013 km² at the altitude of 4120 feet (1260 m) with almost 1.3 million people. Most of the population lives in north-western areas of the city because the eastern areas are occupied by the military bases and academies. The city is well known for its beautiful weather and popular scenic spots attracting thousands of tourists every year. The city is surrounded at all four sides by the Sarban hills which allow for pleasant weather in summer but gets very

cold during winter. We selected this study area because there is no research has been done in this domain and there is no definitive dataset of Abbottabad school pattern analysis available. Therefore, we created a local geo-database to meet the requirements for the school pattern analysis.

Data collection and pre-processing

The school facilities data were collected from two main sources: (a) Abbottabad District Education Office (DEO) and (b) Independent Monitoring unit (IMU). Both of these datasets were merged together to find the duplicate values. These duplicate values were then deleted to get the unique value for each school facility. After that, these values were geocoded and joined to the already geocoded point level school locations. A total of 165 school locations were found in the data set and reduced to 153 after eliminating duplicate values. Figure 2 demonstrates the school facilities data collection and preparation.

Knowing the residential area of the city in order to understand the distribution of the population can be very useful. This is not the key focus of our research, but population in the city can help in analyzing the

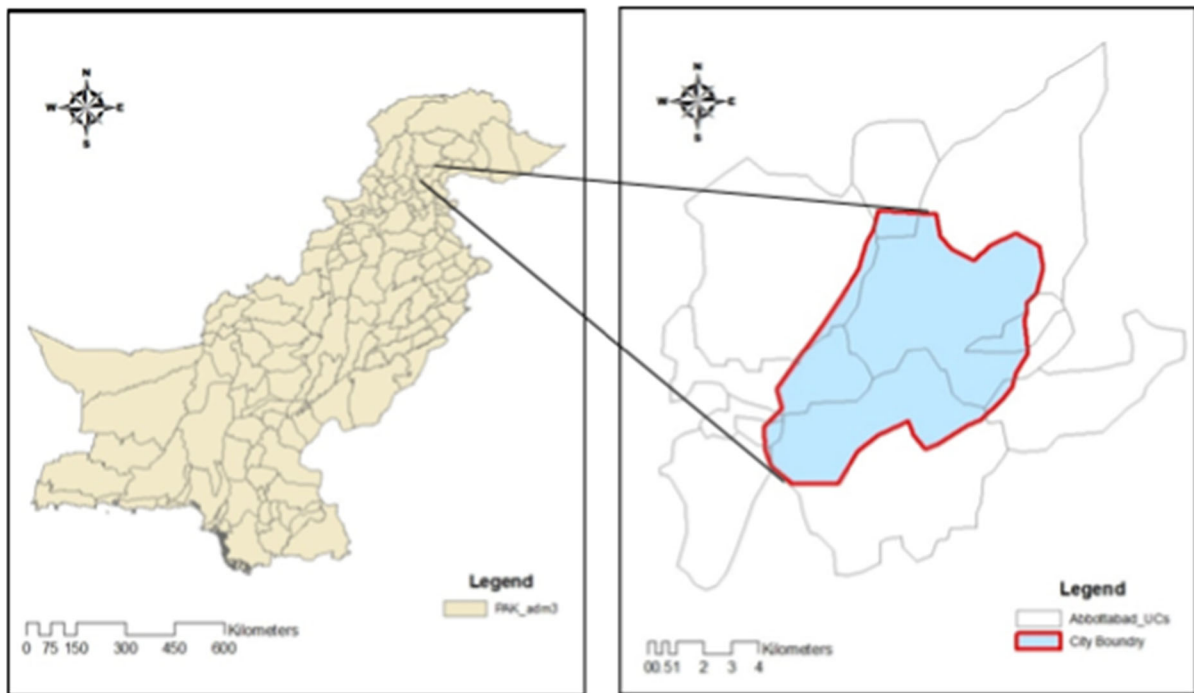


Fig. 1 The location of the study area

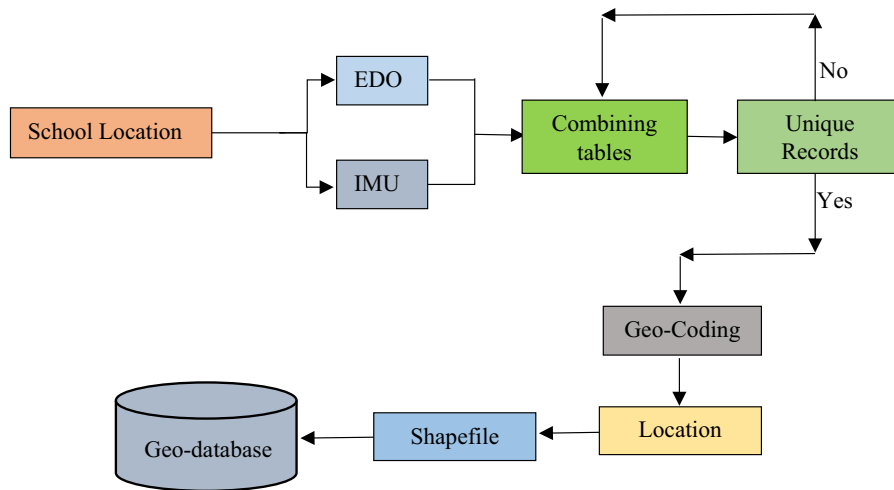


Fig. 2 School facility data collection and geo-database preparation process

relationship between schools and various residential areas of the city. If a school facility is near the residential area, it will be easy for students to access that school, hence the accessibility will be high. However, the data limitations created problems for achieving the desired results.

Because there is no parcel data for city municipality, it was not feasible to identify or differentiate the industrial, commercial, and residential buildings. Therefore, all the buildings are considered as residential area because, as from 4 years of field experience, we observed that commercial, industrial and house buildings are located close to each other. The process of classification and extraction of a residential area described in a process diagram shown in Fig. 3.

Results and analysis

Most of the areas in Abbottabad city contain hills, mountains, and inclined plains. Geographical visualization aids in the recognition of the pattern of schools in those areas. In Fig. 4 ‘a’ shows primary, ‘b’ shows middle, and ‘c’ shows high schools. Figures depict the distribution of school separately in order to understand the allocation of schools relative to the type, visualized as points in relation to roads.

Figure 4, suggests a disorder in the distribution of schools. The distribution of primary schools is relatively uniform as compared to secondary schools but many primary schools are outside the boundary of the city. Schools that are situated outside the boundary of the city are in the high, hilly areas, and difficult for primary school students to reach, especially in cold

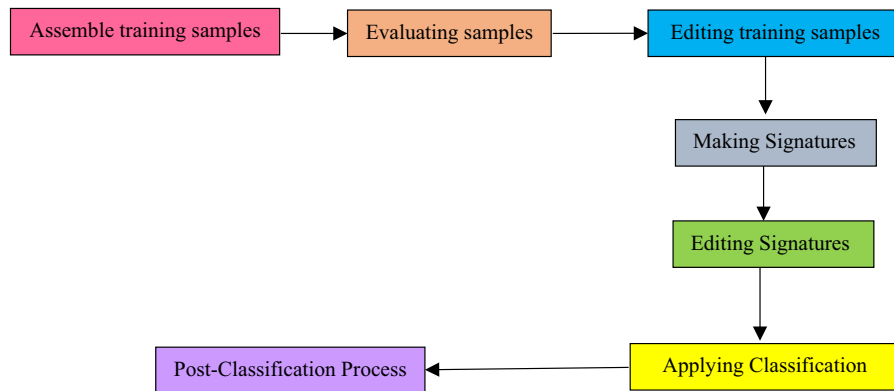


Fig. 3 Supervised classification process

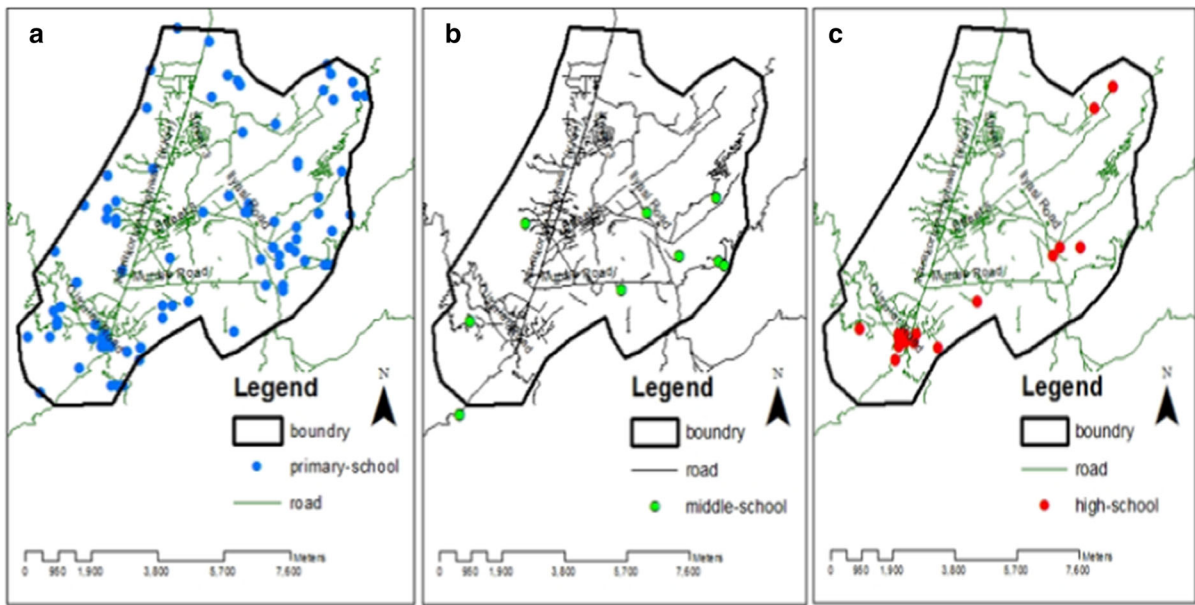


Fig. 4 Distribution of primary, middle and high schools

winter season. Figure 5, shows a kernel density map of schools in the Abbottabad, which explores how schools are concentrated.

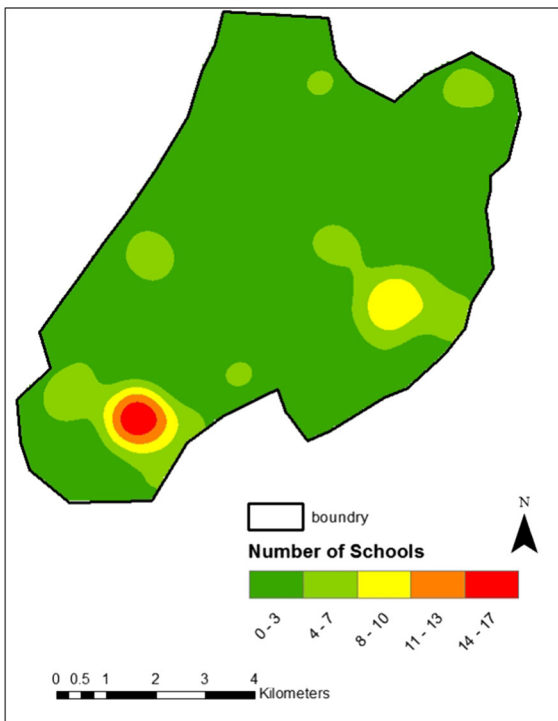


Fig. 5 School density map

In Fig. 5, Dark red color shows the high concentration of schools in a particular area while light-red color shows low density; suggesting that the concentration of schools is higher in southern and eastern parts and lower in the northern and western parts of the study area.

Directional distribution of schools

The mismatch of school facilities reflected in the direction of school distributions cross the study area. Directional ellipses show how far schools are spread and in what direction. A standard distance of school points, are calculated in both x and y directions that define an ellipse in direction of distribution. To define the axis of the ellipse, the mean points for x and y coordinates for primary and secondary schools were calculated using Eqs. (3) and (4):

$$Directional\ Ellipse(x) = \sqrt{\frac{\sum_{i=1}^n (x_i - X')}{n}} \quad (3)$$

$$Directional\ Ellipse(y) = \sqrt{\frac{\sum_{i=1}^n (y_i - Y')}{n}} \quad (4)$$

Figure 6 shows the direction of high school ellipse has a narrower shape, with a tighter, clustered distribution extending from southwest to northeast. The middle school's shape ellipse is wider and runs

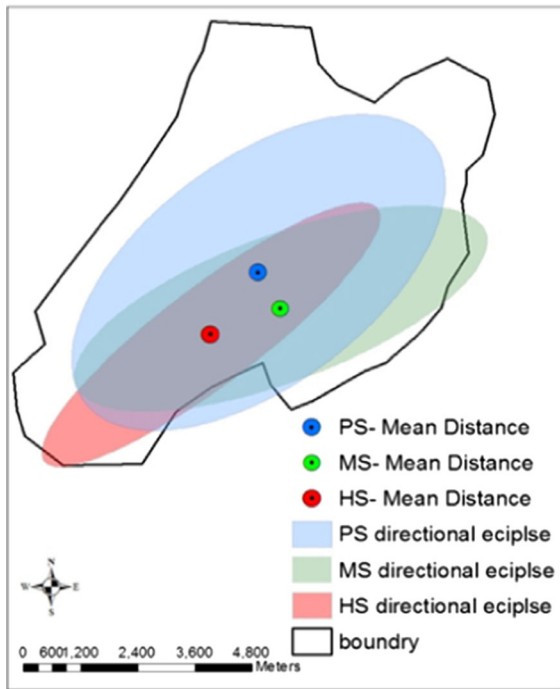


Fig. 6 Directional distribution of schools

more sharply from west to east. The directional ellipse for primary schools is close to shape of a circle, representing a more evenly distributed pattern.

Student–school association ratio in each buffer

A method of Spearman’s Rho (R) used to determine a correlation of the number of students with respect to their school-level within each 500-m buffer. This approach used to find correlation among irregular distributed ordinal variables. We applied two variables in this are; the number of students in all schools in each buffer cell, and the distance band of each buffer. Calculation was performed results using Eq. 3 for the value of Covariance, the values of standard deviation “St.Dev X” and “St.Dev Y” defines whether the correlation is significant.

$$R = \frac{\text{Covariance}}{(\text{St.Dev X} \times \text{St.Dev Y})} \tag{5}$$

Figure 7a, shows histogram and the values of R and P. The association between primary schools is statistically significant, (R = − 0.8022, p = 0.00097; N = 127).

Figure 7b, shows middle school correlation with students at distance of 500 m from are however not statistically significant, (with R = − 0.34387, for N = 127).

Figure 7c shows a relatively similar association of high schools with number of students at a distance of 500 m, that is also not statistically significant, (with R = − 0.34387, for N = 127). A statistical analysis of the correlation between distance bands and students is not enough to evaluate school mismatch. The distance between types of schools adds to this analysis, as no population data are available. The locations and counts of students at those schools is an indirect indicator of the target population of school-age children. That information applied in future to develop a standard distance between schools. Problems of the irregular distribution of schools can be resolved to some extent if a distance standard is set.

Nearest neighbor analysis

This method uses multiple techniques to identify the pattern of points. To establish whether these points are clustered or dispersed, a distance between each point and its closest neighbor is being calculated to averages these distances. This way an expected mean distance compared with observed mean distance. Now the index or ratio of nearest neighbor measure the similarity between observed values and expected values. If the value of ratio is less than 1 it is considered to be clustered and if the value is higher than it is considered to be dispersed. In order to observe if the observed points are randomly distributed a Z score test is computed at a confidence level of 95%; if value of Z is > 1.96 it indicates dispersed pattern and if it is < − 1.96 it indicates cluster pattern.

Table 1 shows a comparison among the results of point pattern analysis for primary, middle and high schools in the study area. As the ratio index of high schools is less than 1 that means it is clustered while the value of middle and primary is higher than 1. The middle school has the highest value of Z that shows, it is mostly dispersed while the value of primary school is 3.16 that indicates some of the areas have distribution closer to be clustered. Z-score value, also justifies this point pattern as the value of Z-score value, for high schools were < − 1.96, denoting a cluster while values of Z in primary and middle schools are > 1.96

Fig. 7 **a** Primary school correlation with students at 500 m from central highway. **b** Middle school correlation with students at 500 m from central highway. **c** High school correlation with students at 500 m from central highway

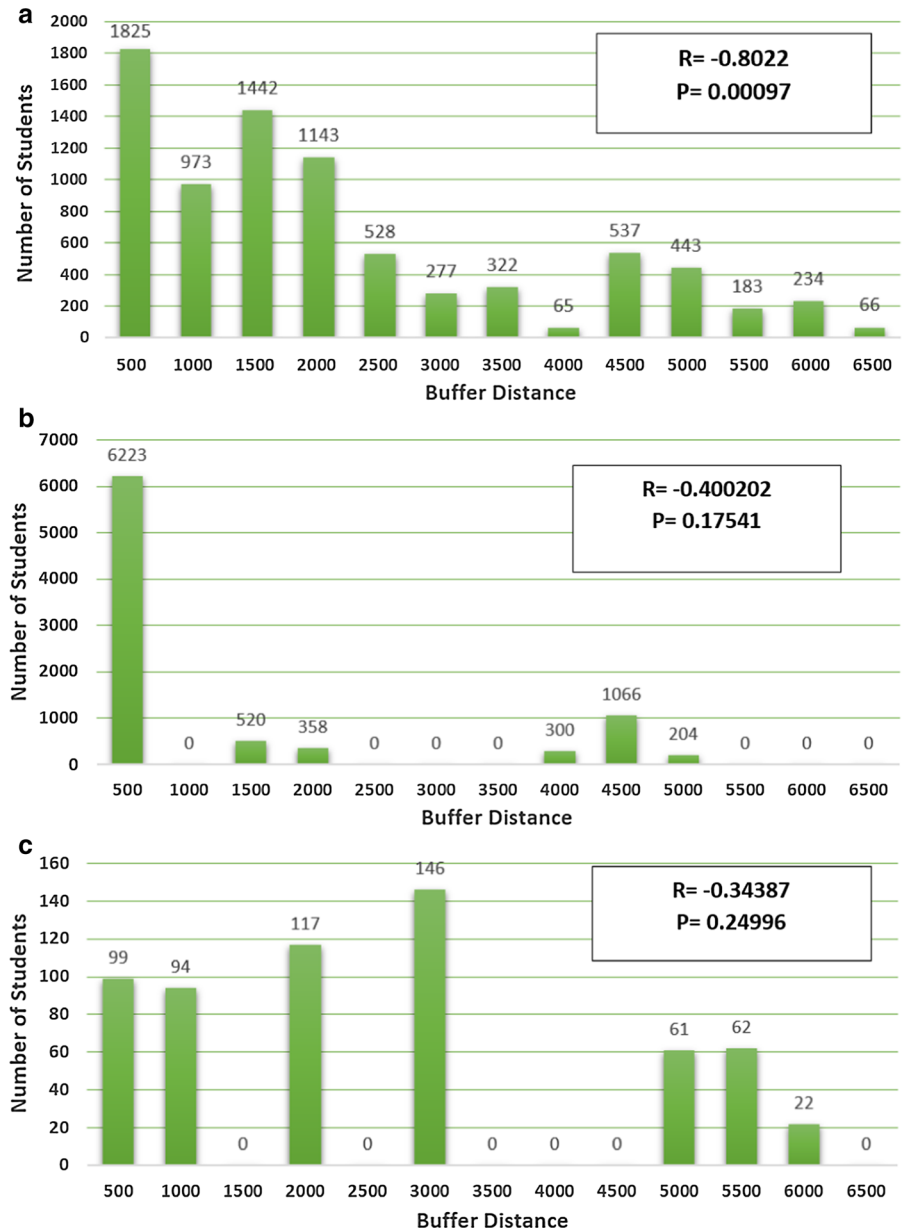


Table 1 Nearest neighbor analysis

Input feature class	High school	Middle school	Primary school
Study area (m)	5,900,600	5,900,600	5,900,600
Distance method	Euclidean	Euclidean	Euclidean
Z-score	- 3.91	17.44	46.57
p value	0.000091	0.0000	0.0000
Expected mean distance	931.52	404.85	107.77
Observed mean distance	469.46	1635.80	340.60
Nearest neighbor ratio	0.503	4.04	3.16

that indicates a dispersed pattern. In order to justify our results more extensively, used Ripley's K function.

K-function

This function measures the expected number of events within a distance of arbitrary points in a given radius. Graphs show expected and observed values of dispersion and clustering of schools with respect to the 500-m distance.

Figure 8 shows expected and observed K-function values of clustering and dispersion of high, middle and primary schools respectively. In high school starts at the distance of 500-m buffer and cuts at about the distance of 3000 m where clustering happens and then goes to the negative dispersion. In middle school, values start with positive dispersion as the expected value of K-function and start to shape zigzag values where it cuts expected values and goes to negative dispersion. Similarly, in primary values start from positive and progresses to cluster and at distance of 2000 m it starts to be negative. All these shreds of evidence show a mismatch and uneven distribution with no pattern and standard distance.

With this uneven distribution in high slope areas, the probability to access school facilities becomes low. As the topography of the city has hills and inclined plain that usually refer to slope; calculating slope can help in perceiving the easiest path towards schools. Since most of the small roads connected to schools, calculating the slope of the area can help to find the best path to school for students.

Extraction of residential area

Residential area extraction in the city considered all the places with buildings. Since no municipality data is available, therefore, this is very challenging and hard to distinguish among different types of buildings. Therefore, if there are buildings the area has higher probability of people living there; thus, considered as the residential area. A supervised classification technique was applied to identify the buildings.

Figure 9 showing the supervised classification results of the study area. A red colour represents buildings and roads that are zoomed, shown in Fig. 8. Other two classes are vegetation and bare land. These two classes are not the essential points of interest in

this research. Small forests, croplands and other kinds of vegetation's are included in a single class of vegetation. On the other hand, most of the open spaces including, playgrounds, mountains and simple plains are included in a class of bare land. The purpose of extracting residential area was achieved to some extent, although the results are not of good accuracy. Many buildings merged due to a very small distance between them. An accuracy assessment test was carried out but putting Google earth imagery as a reference. The results of accuracy test shown in the Table 2.

Results of classification show a significant red colour in central and northwest parts of the city that means a huge part of the population lives in this area of the city. Nevertheless, according to the distribution of schools, the percentage of middle and high schools is very low in the north western and western areas where the density of buildings is high. A cluster of high schools, found in the southern area of the city where the number of buildings is quite less. This means a large number of students from northern and western parts of the city comes to southern part to access high schools.

On the other hand, in spatial distribution, many primary schools established in northeast parts of the city and according to classification results number of buildings is comparatively low. This analysis can aid decision makers to shift their focus towards high-populated areas in central, northeast and northwest parts when building a new school facility.

Discussion remarks and summary

In the Abbottabad District, 240,473 children were enrolled in public and private educational institutions as of 2015, but our research focused only on public (governmental) schools because of the student dropout and uneven locations in the city. The Elementary and Secondary Education Department (ESED) data show only 60% of the children are admitted in schools while 40% of the children in this district are not admitted in schools (District Education Plan, District Abbottabad, 2015–2020). Since 2015, the numbers of students are continuously increasing at school level and contains more students as compared to the middle and high levels. Statistics of the number of students at all levels

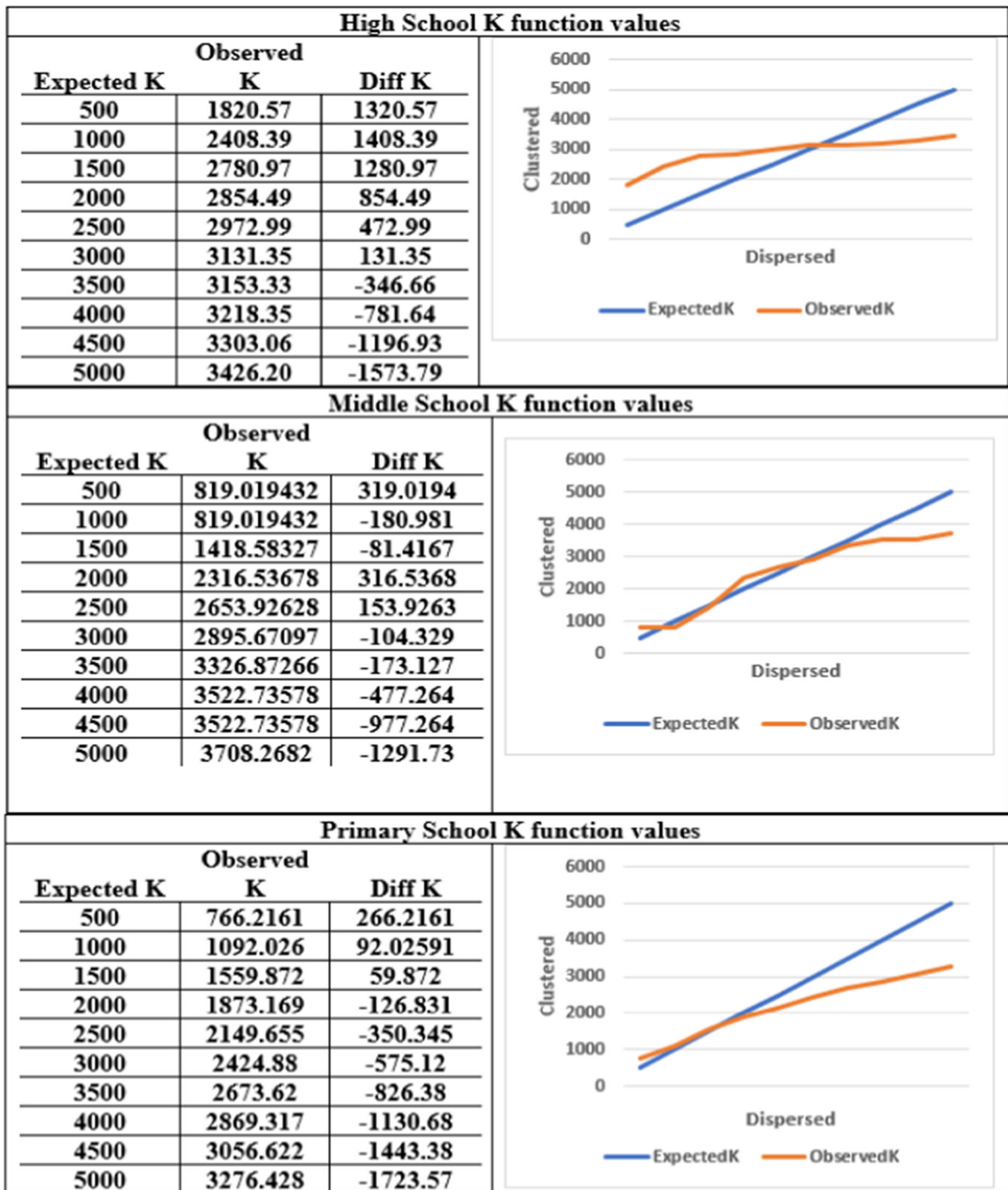


Fig. 8 K-function analysis

since 2015 to 2018 in Abbottabad District shown in the Table 3.

The Table 3 shows continuous increment in number of students from 2015 to 2018 at all levels. Similarly, in 2017–2018, throughout the country,

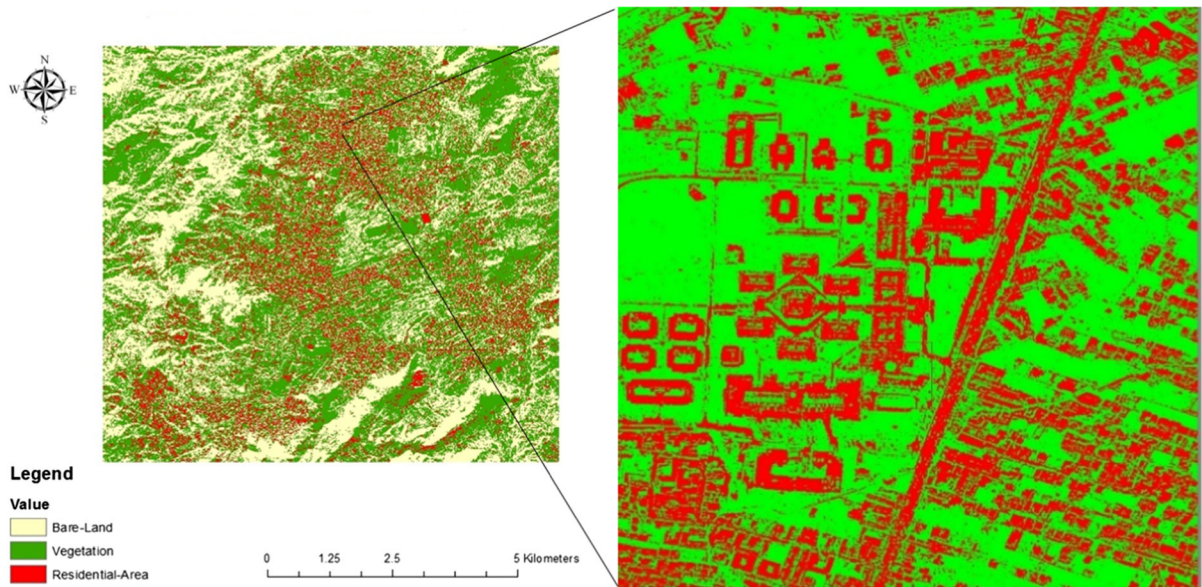


Fig. 9 Supervised classification of study area showing buildings and road in red color. (Color figure online)

Table 2 Accuracy assessment

<i>Accuracy assessment test of classification</i>	
Ground truth	
Commission	
Omission	
Producers accuracy	73.47
User's accuracy	69.32
Overall accuracy	70.85

Table 3 Yearly growth in student numbers in Abbottabad District. *Source:* Elementary and Secondary Education Department (ESED), Khyber Pakhtunkhwa, Pakistan

Year	2015	2016	2017	2018
Primary	120,711	134,939	143,303	152,165
Middle	13,011	14,545	15,546	16,401
High	32,731	36,589	38,857	41,260

overall enrolment in government schools was 4.381 million with 3.116 million students enrolled at primary level, 1.264 million students enrolled at middle and secondary level. However, if the numbers of enrolling students are increasing on one side, a continuous

dropout is happening on the other side. Dropout rate at admitted level is highest, while at the level of class 5 dropout rate is almost 0%. Moreover, the statistical data from educational department shows the dropout ratio of boys in primary is approximately 5% higher than the girls. Table 4 shows the dropout rates of both boys and girls at primary level.

Table 4 shows that the primary school level has the highest percentage of dropout rate. However, as the level goes up the percentage of dropout rate drops down. On basis of these statistics, multiple point pattern analysis carried out in order to justify that clustering of schools in a location and having of schools far from residential areas can be the cause of low accessibility and high dropout rate. Although there are multiple reasons for students to drop out of school, our research shows that low accessibility due clustering and mismatch of schools in the city might be a significant causal factor.

There is no definitive dataset of Abbottabad school pattern analysis available to validate the results, as this is the first research study that has been done in this domain in Abbottabad. Comparing the results with each other is a way to find out if they are more applicable or less applicable. A geographical distribution provided an overview of how schools are distributed in the study area that was also illustrated individually according to school's level. It shows

Table 4 Yearly boys and girls dropout rate at primary school level

Year	Kachi	Class 1	Class 2	Class 3	Class 4	Class 5	Total
2016–2017 (girls)	15,922	9995	9435	9021	8191	7134	59,698
2017–2018 (girls)	15,938	9664	9286	9074	8799	7616	60,377
2016–2017 (boys)	17,673	10,165	9591	9195	8534	7367	62,525
2017–2018 (boys)	17,082	9754	9263	8956	8837	8236	62,128
Girls dropout %	39.07	7.12	3.62	2.74	6.32	0.00	
Boys dropout %	44.14	9.0	6.55	3.95	4.07	0.00	

schools are randomly distributed that is evidently depicted by the pattern analysis results.

A point pattern analysis gave satisfactory results for the proposed hypothesis. Measures of centrality and spread, such as nearest neighbour and Ripley's K showed a mismatch in school distribution. However, although both these point pattern approaches provide detailed results, nearest neighbour analysis was most applicable to the available data. All these point pattern analysis results suggested a mismatch in distribution. In the end this study concluded that, because of uneven distributions of schools in this hilly area of Abbottabad, there is a need for reorganization and restructuring, in order to enhance the access to schools.

Conclusion

This study used different spatial approaches to analyze the problem of spatial mismatch in school placement in Abbottabad, finding that schools located in the study area are indeed mismatched. In addition, the research explored the differences of several models of spatial relationships as they pertain to school accessibility and pattern analysis. All these methods used analysis that can help decision-makers in improving decision making on various issues for not only spatial mismatching of school placement but also important services within the schools to both students and teachers. All of them have certain strengths and weaknesses, but the combination of these spatial analytical techniques, aids to get the accurate depiction of problems and creatively dealt with limitations of data by building a geospatial database that is best suitable for the developing cities like Abbottabad. This research serves as an exploratory step in order to enhance and improve school placement and data limitations in future in Abbottabad regarding education facilities.

References

- Al-Enazi, M., Mesbah, S., & Anwar, A. (2016). Schools distribution planning using GIS in Jeddah city. *International Journal of Computer Applications*, 0975–8887, 138(1), 33–36.
- Amemiya, E. C. (1964). Economic differentiation and social organization of standard metropolitan areas. *Journal of Regional Science*, 5(2), 57–61.
- Awad-Gladewitz, D. D. (2014). *Education sector development programme in Pakistan's Khyber Pakhtunkhwa province. Afghanistan/Pakistan: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)*. Retrieved from, <https://www.giz.de/expertise/downloads/giz2014-enfaltblatt-19-pakistan.pdf>.
- Bailey, T. C., & Gatrell, A. C. (1995). *Interactive spatial data analysis*. London: Longman Scientific & Technical.
- Bennett, R. J. (1979). *Spatial time series*. London: Pion.
- Boots, B. N., & Getis, A. (1988). *Point pattern analysis*. Beverly Hills: Sage University.
- Carnoy, M., Loyalka, P., & Androuschak, G. (2012). "Does expanding higher education equalize income distribution?" *The case of the BRIC countries* (pp. 1–44). Working Paper, Center for Education Policy Analysis.
- Diggle, P. J. (1983). *Statistical analysis of spatial point patterns*. Cambridge, MA: Academic Press.
- Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. *Geographical Analysis*, 24(23), 190–206.
- Gylfason, T., & Zoega, G. (2003). Education social equality and economic growth: A view of the landscape. *CESifo Economic Studies*, 49(4), 557–579.
- Jong, T., & Ritsema, J. R. (1999). Accessibility analysis and spatial competition effects in the context of GIS-supported service location planning. *Computers, Environment and Urban Systems*, 23(2), 75–89.
- Kiskowski, M. A., Hancock, J. F., & Kenworthy, A. K. (2009). On the use of Ripley's K-function and its derivatives to analyze domain size. *Biophysical Journal*, 97(4), 1095–1103.
- Li, D., Gong, J. A., & Yue, P. (2014). Geoinformatics education in China. *Geospatial Information Science*, 17(4), 208–218.
- Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3–42.
- Møller, J., & Waagepetersen, R. P. (2003). An introduction to simulation-based inference for spatial point processes. In J. Møller (Ed.), *Spatial statistics and computational methods* (Vol. 173)., Lecture Notes in Statistics New York, NY: Springer.

- Munir, F., Mehmood, N., & Zeb, A. (2015). Impact of redistribution on income inequality and economic growth in Pakistan. *Issues*, 3(2), 33–42.
- Musakwa, W. (2017). Perspectives on geospatial information technology usage in municipalities and geographic information systems (GIS) education amongst urban planners in Southern Africa. *Geospatial Information Science*, 20(2), 201–208.
- Qazi, W., Raza, S. A., & Jawaid, S. T. (2014). Higher education and growth performance of Pakistan: Evidence from multivariate framework. *Quality & Quantity*, 48(3), 1651–1665.
- Ripley, B. D. (1976). The second-order analysis of stationary point processes. *Journal of Applied Probability*, 13(2), 255–266.
- Ripley, B. D. (1977). Modeling spatial patterns. *Journal of the Royal Statistical Society, Series B*, 39(2), 172–212.
- Ripley, B. D. (1979). Tests of 'randomness' for spatial point patterns. *Journal of the Royal Statistical Society, Series B*, 41(3), 368–374.
- Ripley, B. D. (1981). *Spatial statistics*. Hoboken: Wiley.
- Scott, G., & Rajabifard, A. (2017). Sustainable development and geospatial information: A strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-Spatial Information Science*, 20(2), 59–76.
- Shahbaz, M., Islam, F., & Aamir, N. (2012). Is devaluation contractionary? Empirical evidence for Pakistan. *Economic Change and Restructuring*, 45(4), 299–316.
- Smith, R. C., & Cheeseman, P. (1986). On the representation and estimation of spatial uncertainty. *The International Journal of Robotics Research*, 5(4), 56–68. <https://doi.org/10.1177/027836498600500404>.
- Sumari, N. S., Shao, Z., & Kira, E. (2017). Challenges and opportunities for the advancement of GIS education in Tanzania. *Journal of Education and Practice*, 8(28), 67–75.
- Sumari, N. S., Shao, Z., Van Genderen, L. J., Musakwa, M., Ujoh, F., Washaya, P., et al. (2019). Status of geoinformatics education and training in Sub-Saharan Africa: Initiatives taken and challenges. *Journal of Geography in Higher Education*. <https://doi.org/10.1080/03098265.2019.1599831>.
- Wiegand, T., & Moloney, K. A. (2004). Rings, circles, and null-models for point pattern analysis in ecology. *Oikos*, 104(2), 209–229. <https://doi.org/10.1111/j.0030-1299.2004.12497.x>.
- Wong, D. W. (1998). Measuring multiethnic spatial segregation. *Urban Geography*, 19(1), 77–87.

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