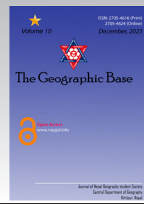
The Geographic Base

Journal Homepage: https://www.ngssnepal.org/journal



Spatial Analysis of Settlement Pattern based on Topography of Pokhara Metropolitan City

Khagendra Raj Poudel[1]*, Tek Raj Paneru[2]

[1]Lecturer, Department of Geography, Prithvi Narayan Campus, Pokhara, Nepal
[2]Lecturer of Geography, Dadeldhura Multiple Campus, Dadeldhura, Nepal

***Corresponding author:** khagendra.poudel@prnc.tu.edu.np

Article info

Keywords:
Settlement pattern, topography, slope, altitude, nearest neighbour index, Pokhara

Received: 7th Sept. 2023

Accepted: 15th Oct. 2023

DOI: https://doi.org/10.3126/tgb.v10i01.71806

Abstract

This study attempts to analyze the spatial distribution of settlement patterns of Pokhara Metropolitan City. The objective of the study is to assess the effect of altitude and slope on settlement pattern. The settlement areas of Pokhara Metropolitan City are categorized into three classes of altitude and five classes of slope degree. The study has used the spatial technique based on the Nearest Neighbor Index and ArcGIS and MS Excel application software. Point based settlement data were collected from the Department of Survey, Nepal and topographical data was collected from ASTER DEM satellite platform. The result shows that the settlement pattern in the Pokhara valley is that settlements are densely concentrated in the flat terrain, especially in 1-10 wards, and support infrastructure development with commercial activities. Conversely, as the elevation increases towards the surrounding hills, the settlement pattern become tendency towards more dispersed. The pattern based on altitude, below 1200 meters reveals dispersed settlement pattern, whereas above revels random. Similarly, the pattern of slope degree indicates dispersed to more disperse according to increase of slope degree.

Introduction

Settlement is very important in human survival. It's location is determined through generations by natural, cultural, and social causes (Xi et al., 2018). The pattern of settlement is influenced by a number of factors. Indeed, many researchers have studied the formation and evolution of settlement patterns. The topography played an important role in the distribution of settlements (Portnov et al., 2007; Shrestha, 2019). Research on prehistoric hominid sites shows that these settlements were located on a gentle slope or alluvial terrace near rivers. Topography influences the natural conditions, including soil erosion, hydrothermal condition, and nutrient level. It also influences land use (Zhou et al., 2013).

The topography of Pokhara is versatile and complex, ranging from flatlands to hills and mountains. In addition to geographical positioning, the topography within Pokhara is influenced by other factors such as floods, sinkholes, and river bank cutting. As such, the topographic features are very important in determining the settlement distribution pattern (Fort et al., 2018; Poudel & Hamal, 2021). Other factors contributing to the layout and types of settlements include geological conditions, soil conditions, elevation, and slope inclination.

Geography, a spatial science, involves the consideration of phenomena with respect to the inequality in the distribution of physical and human features about the surface of Earth and resources. This inequality in distribution to the functioning of human societies; hence, the interest spatial patterns is central to geographical research. Spatial pattern refers to the arrangement and disposition of objects in the landscape, which could be analyzed through spatial analysis techniques that seek to determine the pattern of points, lines, areas, and surfaces on a map (Goodchild, 1980). The roots of spatial analysis are quantitative methods and related to the philosophy of positivism (Sapkota, 2017). Spatial point pattern analysis is a particular kind of spatial analysis that appeared in the late 1950s and early 1960s as an important class of geographic inquiry. The methods were borrowed from plant ecology and were applied by geographers to at a first range of contexts including settlement distributions (Gatrell et al., 1996) and the spatial arrangement of stores within urban areas (Fotheringham & Rogerson, 1993). These various methods are broadly decided into two categories: a) distance-based techniques, which utilize spacing of points to describe pattern, such as mean distance to nearest neighbor, and b) area-based techniques, which consider the frequency distribution of points within defined subregions or quadrats (Haggett, 1994). Point pattern analysis (PPA) analyzes a spatial point distribution. Different methodologies and measures are used within PPA for the study and interpretation of the characteristics of point patterns, including density-based and distance-based methods (Boots et al., 2020). Characteristics of point patterns are usually classified into first-order and second-order properties. First-order properties concern the characteristics of individual locations and their spatial variations, whereas second-order properties study interactions between points. For instance, the density-based approaches, such as Kernel density, generally deal with first-order properties, while the distance-based approaches make a measurement of second-order properties, considering distances of pairs of points (Zhang et al., 2014).

In recent years, spatial point processes, and point pattern analysis regained interest. This interest has been mostly spurred by developments in GIS and, generally, by the increased availability of geo-referenced databases, offering data that are often suitable for spatial point pattern analysis (Borruso, 2008). Maps are essential in portraying spatial information about the Earth to help individuals comprehend the distribution of physical and cultural features. However, it is not possible to show all the features on a map; therefore, using symbols to represent and communicate information regarding real-world objects (Zhang et al., 2014). Such symbols can be differentiated according to three classes: point, line, and area or polygon. Point symbols represent zero-order features such as settlements, schools, or buildings; they show an exact location on a map. Line symbols show linear features of rivers, roads, and canals. Area symbols are used while mapping the representation such as an urban built-up area, agricultural area, lakes, or forests (Linkha, 2020).

In this paper, the investigation of the interaction between altitude and slope is unique and will provide insight into urban planning over complex topographies an aspect that was not covered in previous studies.

Methods and Materials

The Study Area

Pokhara metropolitan city lies in the Pokhara valley. It extends between 28^0 04' 26" N to 28^0 20' 18" N latitudes and 83^0 47' 30" to 84^0 09'12" E longitudes and the lowest elevation is from 480 m. to 2705 m. with the total area covers 464.24 Sq.km (Figure 1). Pokhara metropolitan city was started populating since 1950 after the eradication of endemic of malaria.

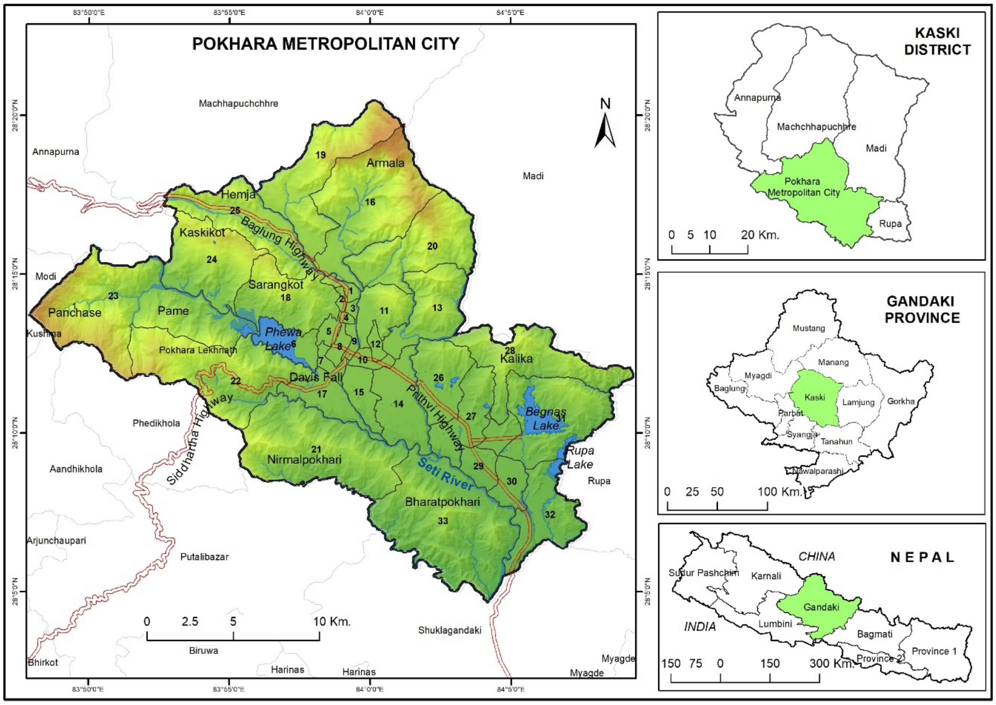


Figure 1: Location Map of the Study Area

The topographical features of the Pokhara area are highly diversified, making settlement distribution quite complicated. Among the 33 wards in the municipality, as many as 17 are low-lying valley wards; and out of these, Ward No. 1 to 10 have relatively flat topography, allowing better facilities and transportation networks. The remaining 7 wards are essentially agriculture-based, with a high value. The remaining 16 wards are hill.

Creating Elevation and Slope Maps

While trying to contextualize the influence of elevation and slope inclination on settlement distribution, consideration was given to topographic factors. The major data involved in mapping were the ASTER DEM data, and such data underwent several processes. Mapping of elevation involved slope analysis, hillshade rendering, and reclassification. The elevation in the Pokhara Metropolitan City varies from 480 to 2705 meters above sea level, hence it was divided into three catagories such as plain (below 800m), plain with low hill (800-1200m), and hill (above 1200m).

Overlay Analysis

Overlay refers to the process of combining data in one layer by superimposition in ArcMap 10.8 software. Many steps in its processing require overlay, like combining data on the boundary of the

Pokhara Metropolitan City, the elevation and slope of the map layers, and the settlement distribution point data with the elevation and slope maps developed earlier to derive a topographically based settlement distribution pattern map.

Nearest Neighbour Index: This method is used to describe the degree of deviation of random distribution. It could be estimated by dividing average distance of nearest neighbour points by average distance of random distribution model (Clark and Evans, 1954). The expected mean of NND could be estimated by manual calculation and automated calculation in the ArcGIS software.

NND = 2D √(N/A) …(1)
Where, N= Total no of settlements

D = Total distance

The formula used to test the randomness is Clark and Evans (1954) is given as:

$$Rn = \frac{\bar{D}(Obs)}{0{\cdot}5\sqrt{\frac{a}{n}}}$$

Where,

D (Obs) = mean observed NND,

... (2) *a = area under study, and* n = number of points.

Similarly, average nearest neighbour ratio is computed using distance calculated as stated above and automatic index based on the average distance from each feature to its nearest neighbouring feature computed under pattern analysis.

$$ANN = \frac{\bar{D}_O}{\bar{D}_E}$$

Average Nearest Neighbour Ratio expressed is as: …(3)

$$\bar{D}_O = \frac{\sum_{i=1}^{n} d_i}{n}$$

where, $\bar{D}o$ *= Observed mean distance between each feature and its nearest neighbour:*

…(4)

$$\bar{D}_E = \frac{0.5}{\sqrt{n/A}}$$

and $\bar{D}_E$ *= Expected mean distance* for the features given in random pattern:…(5)

In the equation mentioned, d_i represents the distance between feature i and its closest neighbouring feature. n denotes the total number of features, while **A** refers to either the area of features or a user-defined area value.

$$z = \frac{\bar{D}_O - \bar{D}_E}{SE}$$

$$SE = \frac{0.26136}{\sqrt{n^2/A}}$$

The average nearest neighbour z-score test for cluster, random and dispersal is calculated as:

Z Score: … (6)

$$z = \frac{\bar{D}_O - \bar{D}_E}{SE}$$

$$SE = \frac{0.26136}{\sqrt{n^2/A}}$$

where, …(7)

If the index (average nearest neighbour ratio) is below 1, it indicates a clustered pattern. Conversely, if the index exceeds 1, it suggests a tendency towards dispersion.

Results and Discussion

History of Urban Settlement in Pokhara

Pokhara Metropolitan City falls in the Gandaki Province. The city contains varieties of characteristics in its growth comprising commercial, industrial, administrative, social, and educational facilities that give Pokhara a distinct urban area. Unlike the hill forts around it, Pokhara was never much more relevant in history, although parts of the valley, like Batulechaur and Bindhyabasini temple, were moderately famous.

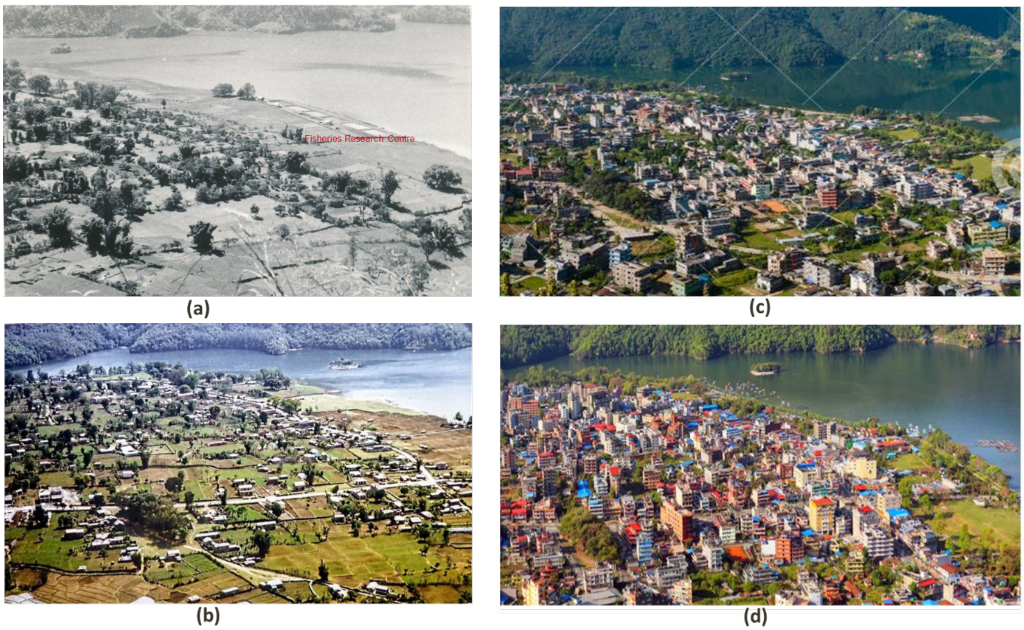


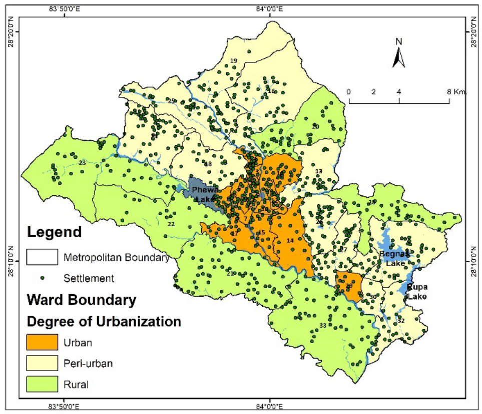
Photo: Urban development example of Lakeside since 60 years. (a) 1962 (by Sunil Ulak), (b) 1980 (by Kemja Kepkes), (c) 2002 (by Dreamstime.com), and (d) 2022 (by author, KR Poudel)

The Newar immigrants who came in 1752 brought with them a host of architectural styles and a sense of mercantile culture that constituted the bedrock for Pokhara's urbanization. It is this cultural and economic bedrock that has been gradually shaping this settlement, with the Newars playing the lead role in sustaining the urban fabric made up of public buildings, temples, and roadways.

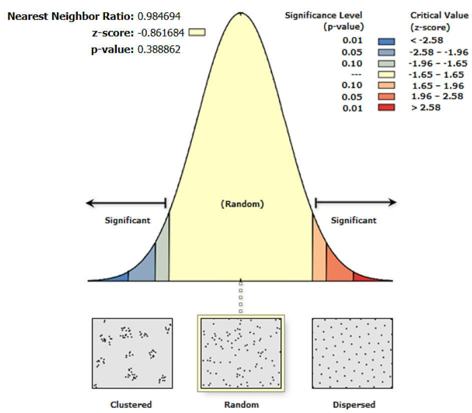
The settlement history of Pokhara can be differentiated into two periods: pre-1950 and post-1950. Before 1950, it was architecturally set by the Newar community who engaged in various trades and maintained distinct housing styles. In addition, there were scattered groups from other castes that contributed to the social and economic life of the city. While the Rana regime lost power in 1950, announcement as a municipal corporation in 1960 saw the dawn of massive infrastructure development in Pokhara. The construction of educational institutions, hospitals, highways, and other governmental offices boosted fast growth in the urban centres. This very city started developing rapidly and is becoming a modern city nowadays. Infrastructure like new roads and residential areas within the city is growing these days; similarly, private land development is also influencing future settlement patterns.

Spatial Distribution of Settlements in Pokhara Metropolitan City

Analysis of the nearest neighbour ratio (NNR) gives a quantitative assessment of the spatial arrangement of settlements. The settlement pattern is highly dense in the central urban area, particularly within wards 1-10, which has demonstrated evidence of a focused urban core. Such agglomeration is liable to be brought about by economic opportunities, well-developed infrastructure, and amenities attracting high population density. Moving outwards in the peri-urban and rural areas, it becomes dispersed. It is very typical of transition areas from urban to rural environments where land availability increases as population density reduces. The settlement pattern in peri-urban zones is less dense than in the core urban area but more populated compared to fringes regarded as rural, showing a trend of urban sprawl. However, throughout the city, the settlement pattern does not indicate significant clustering or dispersion that may be clear indications of the overall random distribution of settlements.



(a)



(b)

Figure 2: Pokhara Metropolitan City and Result of Nearest Neighbour Ratio derived from ArcGIS software

Data Source: Settlement and ward data from Department of Survey, 1998

Thus, after calculating the distance between the 866 selected settlements in Pokhara Metropolitan City, including the average distance between the settlements and the total area of the city, the Rn value was estimated to be 0.985. The settlement pattern is very close to randomness according to the NNR value. Although the negative z-score of -0.861684 shows the slight tendency of the settlement to be clustered, the p-value of 0.38862 revealed that the clustering does not hold statistical significance.

Spatial Analysis of Settlement Pattern based on Topography

Settlements are those places where communities are residing and undertaking all sorts of activities. Topographically, settlement and the development in settling into patterns are said to be closely influenced by physical and non-physical elements (Sari et al., 2024). In the Pokhara area, the distribution of settlements is intricately shaped by the varied topography of the region. Along the riverbanks and low-lying valleys, there is a high concentration of settlements, especially in Ward no. 1-10. This is reflected by the number of settlements in each ward, as shown in Table 1. This follows that this topography translates into a linear pattern of settlement along the ridgelines and periphery of the valleys, areas where more stable land can be found together with better accessibility. The distribution of settlement interacting with topography thus has a reason for physical landscape features to be set forth as key determinants in the spatial organization and morphology of urban and rural settlements (Sari et al., 2024).

Table 1: Settlement Distribution Pattern on the basis of Topography

	Topography	Area (Km^2)	Total Dist.(Km)	Total Settlement	Ḋ (Obs mean dist)	Ḋ (Exp mean dist)	Rn Value	Z-Score	Pattern
Altitude (m)	Pokhara all	464.24	312.18	866	0.36	0.37	0.99	-0.86	Random
Plain	Below 800	136.75	136.68	215	0.46	0.40	1.15	4.20	Dispersed
Plain with low hill	800-1200	210.46	177.61	507	0.35	0.32	1.09	3.77	Dispersed
Hill	Above 1200	115.11	59.86	144	0.42	1.61	0.96	-1.20	Random
Slope (Degree)									
Gentle	Below 10^o	145.05	157.82	401	0.39	0.30	1.31	11.83	Dispersed
Moderate	10^o - 20^o	97.34	125.43	200	0.63	0.35	1.80	21.59	Dispersed
Moderately steep	20^o - 30^o	121.49	114.43	160	0.72	0.44	1.64	15.52	Dispersed
Steep	30^o - 40^o	74.70	90.12	81	1.11	0.48	2.32	22.67	Dispersed
Very Steep	Above 40^o	23.71	47.63	24	1.98	0.50	3.99	28.05	Dispersed

Data Source: ASTER DEM and Settlement Data from Survey Department -1998. Data calculate by author using ArcGIS 10.8.

Settlement distribution Pattern Based on Altitude

The Plain (below 800 meter): The low terrace, plain area of 136.75 km² has an R_n value of 1.15, indicating that the settlement pattern is random and very slightly dispersed. At this altitude, the general topography greatly flat to accommodate the majority of the settlements and they are evenly distributed.

Plain with Low Hill 800-1200 meters: This is the most extensive area represented, 210.46 km², and it also has yielded an R_n of 1.09. The value of R_n is a bit lower than for the below 800 meters altitude, implying a greater constraint posed by the terrain, but these constraints do not lead to clustering. The continued random distribution, though of less dispersed and shows a transition from plain to low hills.

Hill more than 1200 meters: The hilly area of 115.11 km², the settlements in a highland area are going to be clustered, as indicated by an R_n value of 0.93. The change can be interpreted that with increasing in altitude, the suitable area becomes scare leading to clustering. The expansion of settlements at these altitudes is most probably restricted by very harsh environmental conditions, combined with disadvantageous topography. Such clustering at this altitude reflects the adaptation of human settlements to the constraints imposed by the physical landscape.

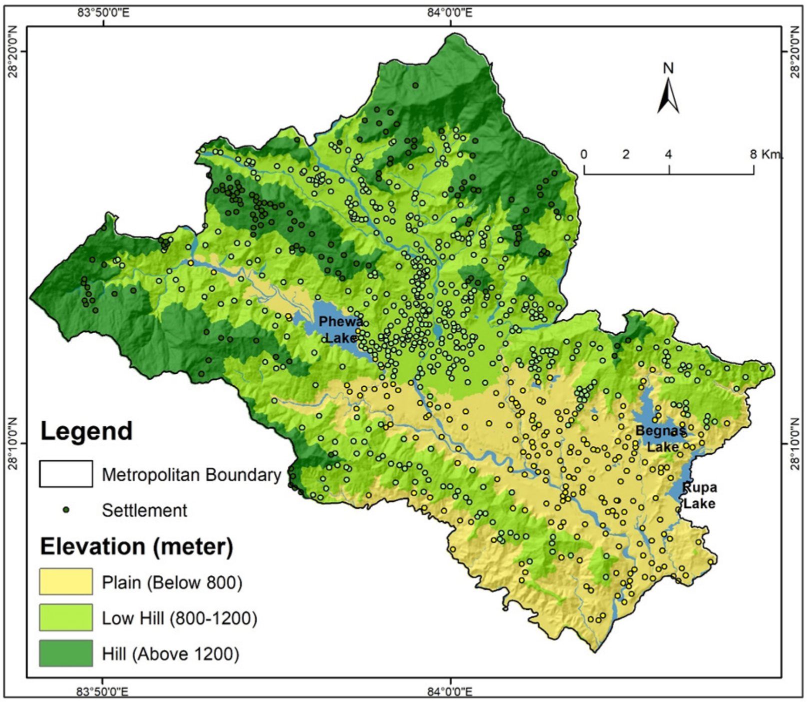


Figure 3: Map of Settlement Distribution Patterns Based on Altitude

Settlement distribution Pattern Based on Slope

The gentle slope area is 145.05 km² and has a random settlement pattern with the high value of Rn amounting to 1.31. This indicates that the gentle slope does not significantly limit the distribution of settlements. The higher value of R_n denotes that settlements are not clustered but rather dispersed, likely due to the fact that these areas are more feasible regarding constructibility and accessibility. The favorable terrain here creates conditions that are conducive for residential and commercial development; hence, it takes on a dispersed but random pattern.

Moderate slope (10°-20°): The settlement pattern is random with an increase in the value of Rn to 1.80 for a moderately steep slope of 97.34 km². This signals a stronger trend towards dispersion, or in other words, the steeper terrain pulls apart the settlement pattern. Most probably, the heightened difficulty of building on slopes leads to more scattered settlements less clustering.

Steep to very steep slope (Above 30°): When the slope gets even steeper, especially above 30°, settlement highly disperses. For localities under steep slopes ranging between 30° to 40°, the R_n value is 2.32, while for very steep slopes, this value goes up as high as 3.99 in the areas above 40°. These are indeed the most dispersed types of settlement. Such reliefs reduce the places of settling to the very minimum; these settlements are found highly dispersed. The extreme slopes reduce amount of land and also make difficult in development of infrastructural facilities.

It is observed from the settlement pattern that slope is the major determinants of spatial arrangement of settlement in the Pokhara Metropolitan City. While lower altitude and gentle slopes facilitate a more random and dispersed settlement pattern, higher altitude and steep slopes result in either clustered or dispersed patterns, depending on the degree of physical constraint. The NNR data reveal the spatial behaviour of human settlements in response to the harsh nature of geography, as evidenced by the close relationship between the distribution of communities and the underlying topography.

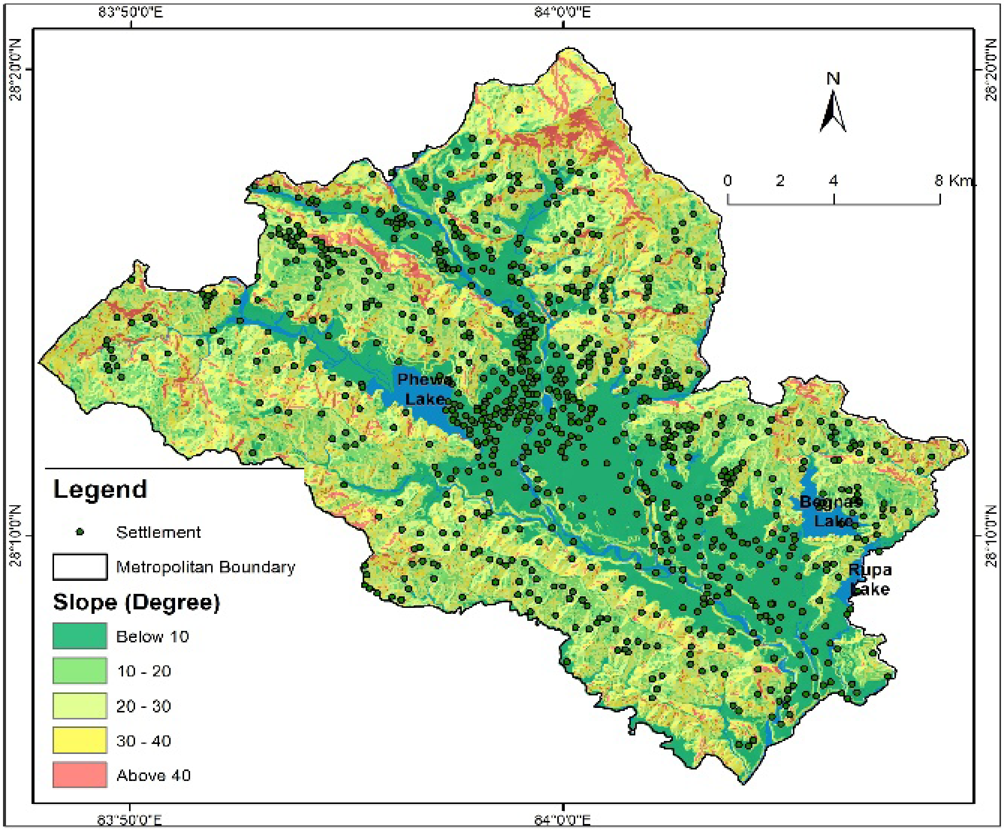


Figure 4: Map of Settlement Distribution Patterns Based on Slope

Conclusion

The study on settlement pattern of the Pokhara Metropolitan City shows interrelations between topography and human habitation in a very complex manner. It also shows the role of altitude and slope variations in regulating settlement location patterns. From this study, it shows that topography with its varied landscapes, plays a major role in determining which areas of settlement communities exist.

The altitude and slope analysis of Pokhara Metropolitan City give a considerable information in finding the distribution of settlements. For elevation below 800 meters, settlements are random with some dispersion due to flat terrain, whereas for above 1200 meters, the pattern changes to clustering. Hilly areas depict limited land and not-so-easy living conditions. The city is slightly clustered.

Slope analysis confirms these interpretations, since slope angles less than 10° show random settlement with slight dispersions. As the slope gets steeper, the pattern of settlement becomes more dispersed, and the slope above 20° becomes increasingly difficult to build on.

The study has shown that lower altitude and gentler slopes offer open and random settlement patterns, while higher altitudes and steeper slopes result in clustering or high dispersion based on the degree of physical constraint. The information on nearest neighbour ratio data really explains how human settlements adjust to geographical barriers. This is an intriguing observation from an urban and rural planning perspective considering that topographical aspects should be taken into consideration for sustainable development of a settlement.

References

Arbia, G. (2016). Spatial econometrics: A broad view. *Foundations and Trends in Econometrics*, 8(3–4), 145–265. https://doi.org/10.1561/0800000030

Boots, B. N., & Getis, A. (1988). *Point Pattern Analysis*. Newbury Park, Calif.: Sage Publications. https://www.css.cornell.edu/faculty/dgr2/_static/files/R_PDF/exPPA.pdf

Boots, B.N., & Getis, A. (2020). *Point Pattern Analysis*. Reprint. Edited by Grant Ian Thrall. WVU Research Repository. https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1013&context=rri-web-book

Borruso, G. (2008). Network density estimation: A GIS approach for analysing point patterns in a network space. *Transactions in GIS*, 12(3), 377–402. https://doi.org/10.1111/j.1467-9671.2008.01107.x

Clark, P.J. and Evans, F,C. (1954). Distance to Nearest Neighbour as a Measure of Spatial Relationships in Populations, *Ecology*; 35:445-53. https://doi.org/10.2307/1931034

Fort, M., Adhikari, B. R., & Rimal, B. (2018). Pokhara (Central Nepal): A Dramatic Yet Geomorphologically Active Environment Versus a Dynamic, Rapidly Developing City in Urban Geomorphology: *Landforms and Processes in Cities*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-811951-8.00012-6

Fotheringham, A. S., & Rogerson, A. P. (1993). GIS and Spatial Analytical Problems. *International Journal of Geographical Information Systems,* 7(1), 3–19. https://doi.org/10.1080/02693799308901936

Gatrell, A. C., Bailey, T. C., Diggle, P. J., & Rowlingson, B. S. (1996). Spatial Point Pattern Analysis and Its Application In Geographical Epidemiology. *Transactions of the Institute of British Geographers*, 21(1), 256–274. http://www.dpi.inpe.br/gilberto/references/gattrel_paper.pdf

Goodchild, M. F. (1980). Fractals and the Accuracy of Geographical Measures. *Journal of the International Association for Mathematical Geology*, 12(2), 85–98. https://doi.org/10.1007/BF01035241

Haggett, P. (1994). Prediction and Predictability in Geographical Systems. *Transactions - Institute of British Geographers,* 19(1), 6–20. https://doi.org/10.2307/622443

Linkha, T. R. (2020). Spatial Distribution of Settlement Pattern in Dhankuta District, Nepal. *International Journal of Recent Advances in Multidisciplinary Research*, 7(September), 6299–6305. https://www.ijramr.com/sites/default/files/issues-pdf/3056_0.pdf

Philo, C., & Philo, P. (2022). 2.15 or Not 2.15? An Historical-Analytical Inquiry into the Nearest-Neighbor Statistic. *Geographical Analysis*, 54(2), 333–356. https://doi.org/10.1111/gean.12284

Portnov, B. A., Adhikari, M., & Schwartz, M. (2007). Urban Growth in Nepal: Does Location Matter? *Urban Studies*, 44(5–6), 915–937. https://doi.org/10.1080/00420980701258118

Poudel, K. R., & Hamal, R. (2021). Assessment of Natural Hazard in the Himalayas: A Case Study of the Seti River Flash Flood 2012. *Prithvi Journal of Research and Innovation*, 3(1), 12–25. https://doi.org/10.3126/pjri.v3i1.37432

Rogerson, P.A.(2001). *Spatial Methods for Geography*, Sage Publication, London.

Sapkota, K. (2017). Humanistic Geography: How It Blends with Human Geography Through Methodology. *Geographical Journal of Nepal*, 10, 121–140. https://doi.org/10.3126/gjn.v10i0.17394

Sari, D. D. S., Jumadi, & Anton. (2024). Analysis of Settlement Distribution Pattern Based on Topography in Balik Bukit Subdistrict, West Lampung Regency. *E3S Web of Conferences*, 500. https://doi.org/10.1051/e3sconf/202450002020

Shrestha, S. (2019). Scale and Spatial Representation: Restructuring of Administrative Boundary and GIS Mapping in Bajhang District, Nepal. *Geographical Journal of Nepal*, 12, 25–40. https://doi.org/10.3126/gjn.v12i1.23413

Thapa, R. B., & Murayama, Y. (2009). Examining Spatiotemporal Urbanization Patterns in Kathmandu Valley, Nepal: Remote Sensing and Spatial Metrics Approaches. *Remote Sensing*. https://doi.org/10.3390/rs1030534

Xi, C. bai, Qian, T. lu, Chi, Y., Chen, J., & Wang, J. chen. (2018). Relationship between Settlements and Topographical Factors: An Example from Sichuan Province, China. *Journal of Mountain Science,* 15(9), 2043–2054. https://doi.org/10.1007/s11629-018-4863-z

Yang, Y., Wang, D., Yan, Z., Zhang, S., Niu, H., Silva, E. A., Hu, S., He, Z., Wu, L. L., Yin, L., Xu, Y. Y., Cui, H., Chen, J., Gao, J., Yuan, F., Pokharel, R. P., Khanal, N. R., Clapp, J. M., Cohen, J. P., … Chidi, C. L. (2020). Measuring Urban Landscapes for Urban Function Classification Using Spatial Metrics. *Sustainability (Switzerland)*, 11(3), 1–18. https://doi.org/10.1016/j.ecolind.2019.105722

Yuan, Y., et. al. (2020). *Point Pattern Analysis. The Geographic Information Science & Technology Body of Knowledge* (1st Quarter 2020 Edition), John P. Wilson. https://johnwilson.usc.edu/wp-content/uploads/2018/03/gist_bok2_pasadena_report.pdf

Zhang, Z., Xiao, R., Shortridge, A., & Wu, J. (2014). Spatial Point Pattern Analysis of Human Settlements and Geographical Associations in Eastern Coastal China - A Case Study. *International Journal of Environmental Research and Public Health*, 11(3), 2818–2833. https://doi.org/10.3390/ijerph110302818

Zhou, G., He, Y., Tang, C., Yu, T., Xiao, G., & Zhong, T. (2013). Dynamic Mechanism and Present Situation of Rural Settlement Evolution in China. *Journal of Geographical Sciences*, 23(3), 513–524. https://doi.org/10.1007/s11442-013-1025-7