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A GIS-Based Spatial Analysis of British-Era Archaeological Sites and Water Sources: A Case Study from District Abbottabad, Pakistan

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Abstract

The paper introduces a quantitative exposition of the spatial association amidst the British era archaeological sites and water sources in the District Abbottabad, Pakistan using Geographic Information Systems. The coordinates of the archeological sites were determined using GPS and secondary sources, and the information on water sources was obtained and interpreted using the topographic maps. Spatial analyses involved nearest-distance, spatial autocorrelation, hotspot identification and terrain analysis using elevation and slope values obtained by Digital Elevation Models (DEM). Findings indicate 43 percent of sites are within 2 km of a water source with near (<500 m) sites found at much lower elevation and on less steep slopes as compared to far sites. The results of hotspot analysis indicated that there was statistically significant clustering of hydrologically rich areas, especially in the center and southeast of the district. The significant differences in slope and elevation were found to be significant with independent samples t-tests between the near and the far sites suggesting that accessibility to water, and conducive terrain were determining variables in the planning of the colonial settlement. Combining hydrological proximity analysis and terrain modeling, this study brings archaeological GIS use in Pakistan beyond documentation, providing a precedent of a predictive framework of heritage mapping. The results can be used in scholarly knowledge of the approaches to settlement in the colonial era and in practice of heritage management, which will allow the use of high-potential areas in the survey and protection.

Keywords: GIS Spatial Analysis, Water proximity, British-era archaeology, Topographic influence, Cultural heritage, Abbottabad District

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Introduction

Water has been an elemental component in determining how human settlements grow, their sustainability and the allocation. Since the beginning of the agricultural societies until more sophisticated urban societies, the location of people has been dictated by the closeness to water bodies like rivers, springs and streams (Wheatley and Gillings, 2002). Such knowledge of the environmental factors and settlement patterns, as an aspect of archaeology, is of critical importance in understanding socio-economic and cultural patterns of the past societies (Kvamme, 1990).

The ancient civilizations (such as Indus Valley) in the South Asian context were highly intertwined with the major river basins (such as the Indus and its tributaries) (Allchin & Allchin, 1982). On the same note, in Pakistan, the Gandhara, Balochistan and Punjab are some of the historically important areas that have high levels of archaeological remains closely located near water bodies. Nevertheless, there are numerous such patterns that have not been well examined with the help of spatial technologies, especially the areas with rich but poorly documented historical landscapes, such as the District Abbottabad in the Khyber Pakhtunkhwa.

District Abbottabad has a lot of archaeological potential as it is a strategic geographical location with diverse topography and has record of historical habitation of prehistoric up to colonial times. Although water is essential in the survival of ancient societies in the area, there is a paucity of research that has employed Geographic Information Systems (GIS) in the quantitative evaluation of the impact of water on site allocation. Indeed, as it has been shown in earlier research, e.g., Ahmad et al. (2025), human societies of South and West Asia, especially Indus Valley, have transformed the landscape significantly due to irrigation and agricultural intensification, which leads to changes in the environment over the long term. These historical changes are still evident in the region in terms of water sources and landforms. The current study will satisfy this gap by using GIS tools to determine the relationship between the known archeological sites and the water sources in the immediate surrounding within District Abbottabad. Through these calculations, which are the measurement of distances, the creation of buffer zones, the analysis of elevation and slope data, this research will assist in identifying the statistical significance of the availability of water in the process of settlement location in the past. The findings may be used to understand the environmental decision-making in the ancient population better and guide future archeological surveys in the area. There is no such study done in the past which quantifies systematically the relation between site placement during the colonial period and water availability in the District Abbottabad using GIS. Although there are prior studies in Pakistan that have used GIS with the main aim of documenting their heritage, none of them have incorporated the aspect of hydrological proximity analysis in conjunction with topographic analysis to comprehend the planning of colonial settlements. The method offers an intervention in historical geography and also offers a predictive heritage mapping framework in under-studied areas. The purpose of the study is to map the British-era archaeological sites and water sources in District Abbottabad with the help of the Geographic Information Systems (GIS) and quantitatively determine the spatial relationship between the two. In particular, it examines the distances between the archeology locations and the closest water bodies, determines the spatial distribution and groupings that could suggest reliance on the presence of water and the impact of topography, such as elevation and slope, on the location of settlements.

Literature Review

The Indus Valley Civilization is a perfect example of this relationship in the South Asian region, where the great urban centers, such as Mohenjo-Daro and Harappa were located along the active rivers that supported not only the farming and water distribution but also trade and communication (Kenoyer, 1998). Theoretically, the Environmental Determinism and Settlement Archaeology highlight the importance of the ecological forces especially the hydrology in their influence on human behaviors and the organization of settlements. Such frameworks have also guided spatial modeling techniques in archaeology particularly when done using Geographic Information Systems (GIS) (Kvamme, 1990; Wheatley and Gillings, 2002). GIS also allows researchers to analyse the locational logic of settlements by combining topographic, hydrological and cultural data and makes multi-variable spatial analyses with hitherto unachievable using conventional methods.

A number of studies have been conducted globally on the application of GIS to investigate the connection between the distribution of archaeological sites and environmental variables. To illustrate this, Parker (2006) used GIS to study the settlement patterns in Jordan where strong associations between the location of site, access to water, and topography were found. Likewise, Bevan and Conolly (2006) applied visibility and hydrology models in the Aegean area to map the Bronze Age settlement preferences. Wheatley (1991) used the early GIS methods to model the spatial organization of the ancient Indian city of Bhita, and demonstrated how the topography and access to water organized the form of the city. Nevertheless, GIS applications in archaeological studies in Pakistan are still not well-developed, even in the light of such progress. Similar research such as Ahmad et al. (2025) have employed GIS to record heritage sites in Khyber Pakhtunkhwa, most of them have involved documentation as opposed to modeling of environmental determinants, e.g. water or slope.

GIS has been widely utilized by past researchers to assess and avert the threats attributed to urbanization, climate change and human impact on heritage sites. As an example, Ahmad et al. (2025) used GIS-based tools, such as buffer analysis and terrain models that were developed using DEM, in order to estimate the risk of the Ashokan Rock Edicts in Mansehra. Their work emphasizes the use of GIS in the identification of areas at risk due to their proximity with infrastructure and setting up a model that can be used to evaluate other similar issues facing the British-era archaeological sites in Abbottabad. Verhagen, (2007) emphasized that the use of GIS can be applied to heritage management in the area of northern Pakistan, yet integrative methods should be adopted to examine the risk factors on a site, such as water erosion and terrain instability. Nonetheless, there are still limited studies in the research that analyze the effects of water availability on site location in a quantitative GIS study. It is also emphasized in current global archaeological studies that patterns of settlement are tightly linked to hydrology and topography, as GIS studies have shown that movement of water and location of sites are closely related in Bronze Age Aegean (Bevan and Conolly, 2006), Late Roman Jordan (Parker, 2006) and in ancient urban centers in South Asia (Wheatley, 1991; Kenoyer, 1998).

Methodology

3.1 Data Sources

Field survey involved the use of handheld GPS to record the coordinates of archaeological sites and secondary records with published literature were added. The data on the water sources were taken using Survey of Pakistan topographic maps, which contained rivers (coded as polylines), along with wells, springs, and water tanks (coded as point features). The slope and elevation values of terrain were determined with the help of Digital Elevation Models (DEMs) downloaded in the USGS Earth Explorer site.

3.2 Software and Tools

The analysis and processing of spatial data were performed on ArcGIS 10.8. The statistical tests were conducted in SPSS version 24. Base mapping and visual verification were done through satellite imagery.

3.3 Data Preparation

Spatial consistency All data sets were transformed to UTM Zone N 43. The archaeological sites were modeled as point features, whereas rivers were modeled as polylines and wells, springs, and tanks as point features. In order to perform a consistent analysis of distance, polylines and points were incorporated in the same water-source layer. To calculate the shortest Euclidean distance between the archaeological site and the closest water source (whichever the geometry type) the ArcGIS Near tool was run. DEM data were clipped to the study area, slope and elevation rasters were created with the help of Spatial Analyst tools.

3.4 Analytical Procedures

3.4.1 Proximity Analysis

The nearest distance (NEAR_DIST) of each archeological site to the nearest water source was calculated by the ArcGIS Near tool. Distance patterns were summarized using basic descriptive statistics and histograms.

3.4.2 Spatial Autocorrelation

The distance values were put through some tests in Global Moran I and Local Moran I in order to determine clustering and spatial dependence.

3.4.3 Hotspot Detection

Getis-Ord Gi+ statistics provided statistically significant site clusters in respect to water rich localities.

3.4.4 Terrain Evaluation

The values of slope and elevation were given to the archaeological sites locations using the Extract Values to Points tool.

3.4.5 Comparative Analysis

The sites were classified as near (less than 500 m) and far (more than 500 m) sites with respect to water sources. The t-tests of SPSS were independent samples to determine whether there was significant difference between slope and elevation between these groups.

Results

The result chapter gives the comparative, spatial and statistical outcome of the analysis, which answers the research questions and objectives mentioned above. The results are summarized in figures 1 to 10 and tables 1 to 5 respectively and the interpretation of the results follows after each set of results is made.

4.1 Spatial Distribution of Archaeological Sites and Water Sources

Figure 1 illustrates the overlaid distribution of archaeological sites of British origin and water sources in District Abbottabad. The visual trend indicates that there are numerous sites that are near rivers, springs, and other water bodies. This implies that one of the environmental factors that were taken into account when planning the settlement in the British era was water availability.

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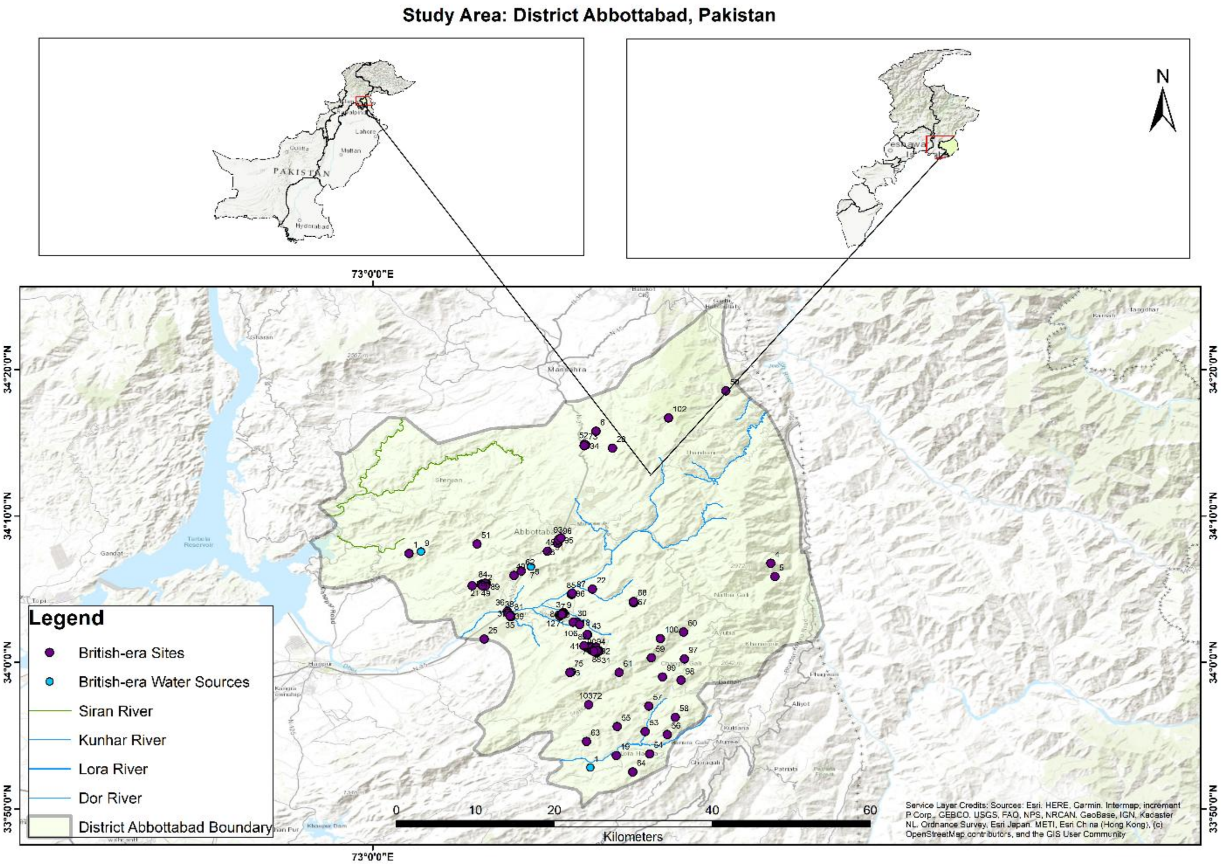

Figure 1: Distribution of British-era archaeological sites and water sources in District Abbottabad.

4.2 Distance to Water Sources Analysis of Sites

The nearest-distance analysis of the archaeological sites and water sources results are shown in Figure 2. On all the sites, the average distance to nearest water source was 2.76 km (SD = 2.64 km) with lowest distance of 42.23 m and highest distance of 11, 054.47 m. More than a large percentage of sites are within 500 meters of the water source with an average distance of about 172m to this group. Only a small fraction of the locations is located further than 2 km, which may reflect alternative sources of getting water or defense and visibility location. A graph of these distances (shown in Figure 3) shows that the sites tend to cluster around lower values of distance.

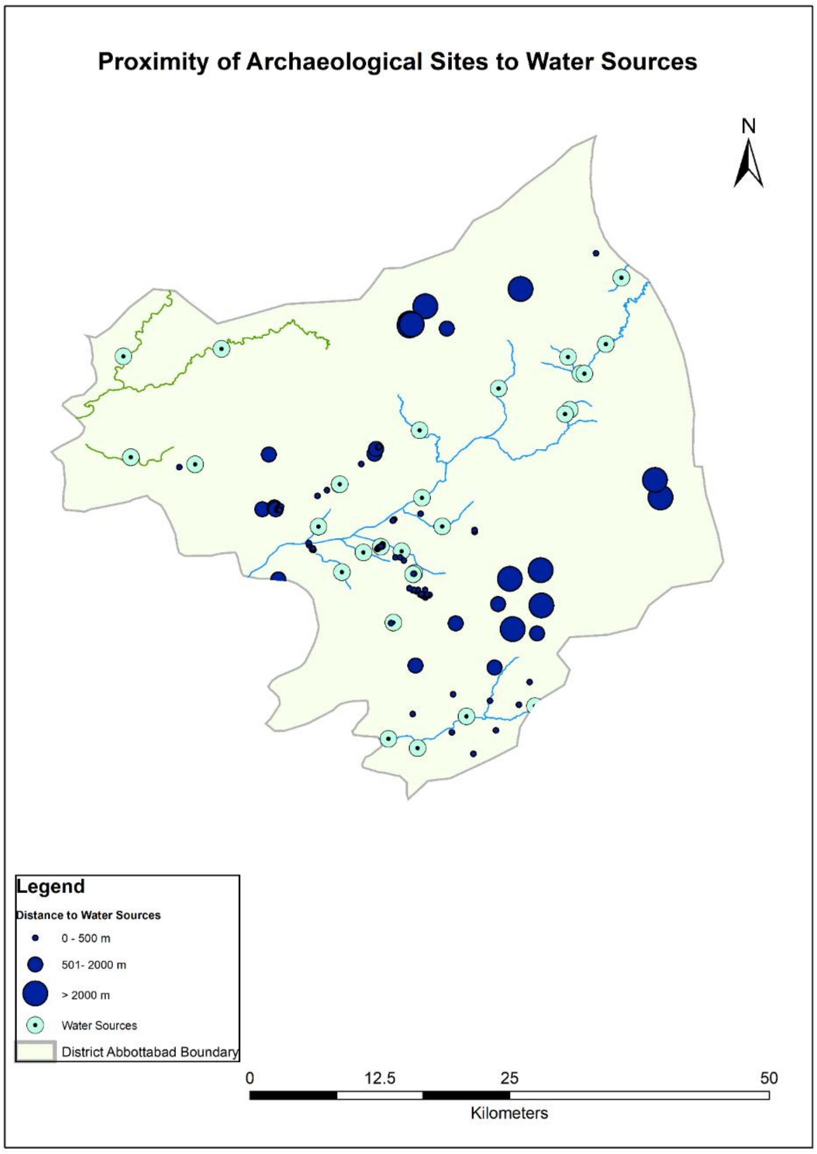

Figure 2. British-era archaeological sites distance to water sources

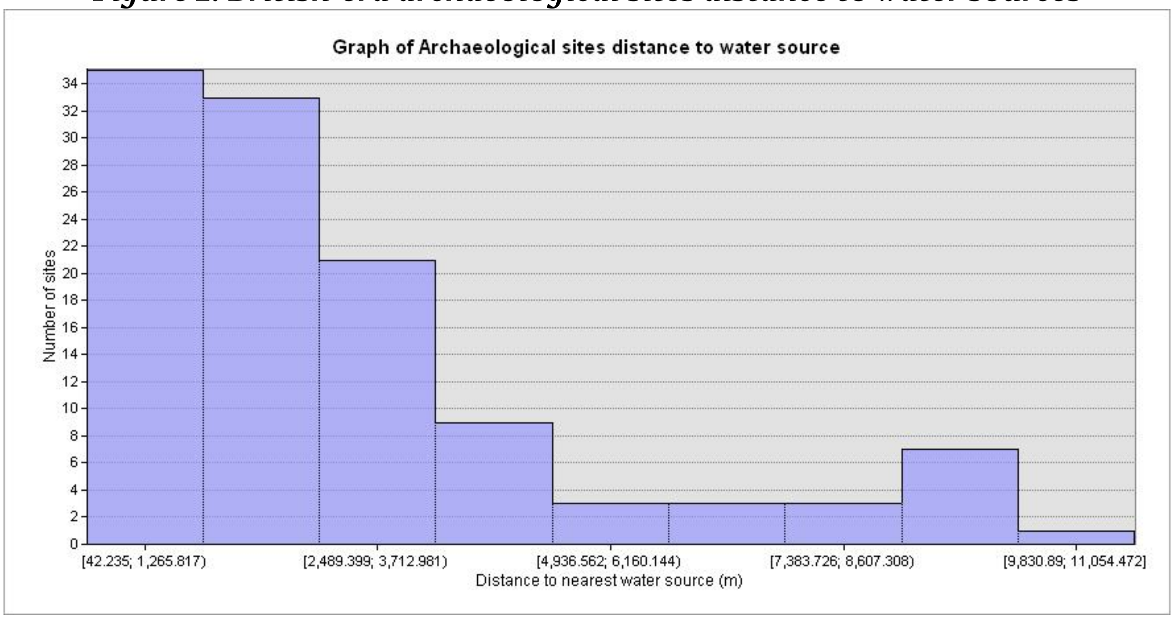

Figure 3. Graph of British-era Archaeological sites distance to water sources

4.3 Proximity Frequency Distribution

Figure 4 presents a histogram of the proximity of site to water sources. It is skewed towards the right with more sites being close. The proximity analysis shows that 43 percent of the archaeological sites are less than 2km close to water source (Table 1 has the mean values of the distance). This means that availability of water was a factor of significant influence on the site location, but few of them were found much farther away, it might have been because of defensive reasons or topography.

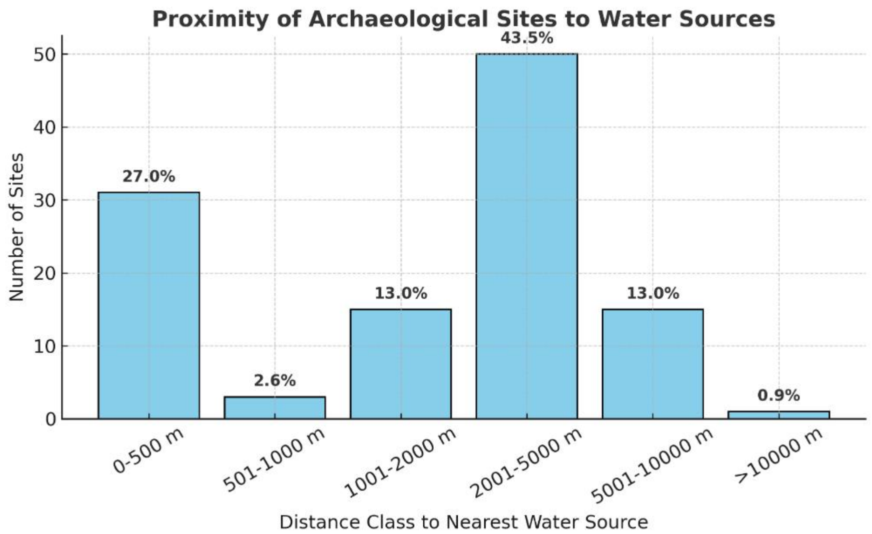

Figure 4. Histogram of proximity of British-era Archaeological sites to water sources

Table 1

Statistics	Distance (m)
Count:	115
Minimum:	42.23
Maximum:	11054.47
Sum:	317675.04
Mean:	2762.39
Standard Deviation:	2649.28

4.4 Spatial Autocorrelation

The spatial autocorrelation results, as shown in figure 5 reveal that sites are not randomly distributed. The trend shows that there is positive spatial autocorrelation, i.e. the occurrence is clustered as opposed to being uniformly distributed on the terrain.

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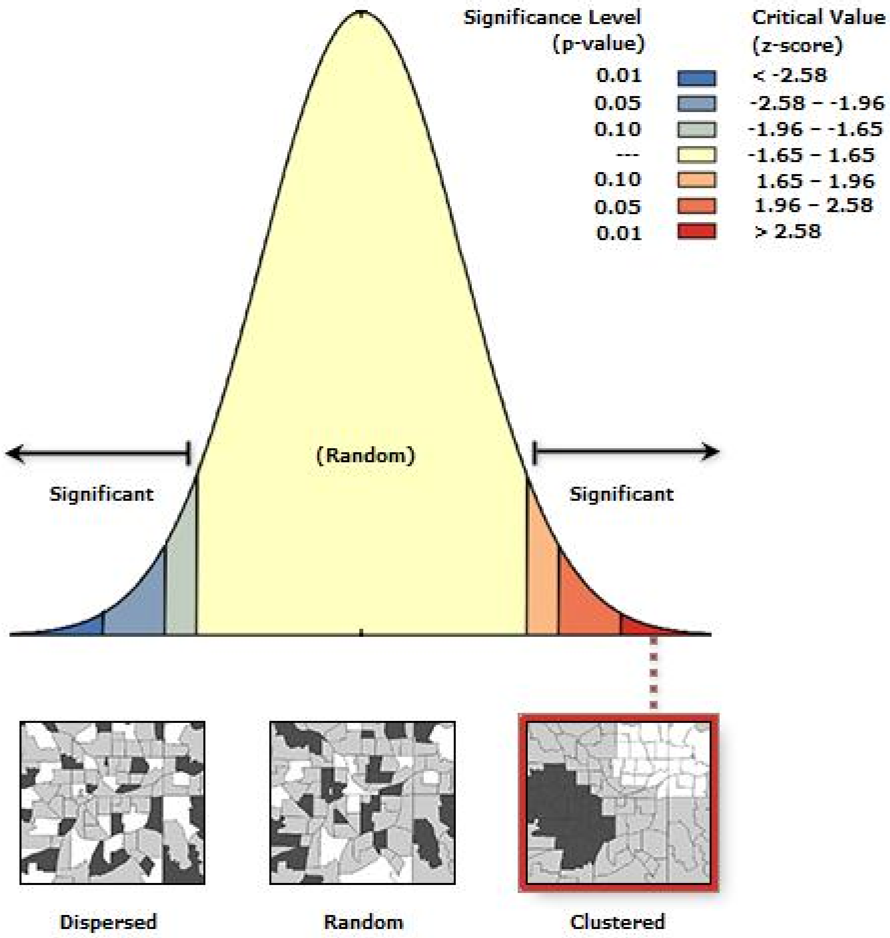

Figure 5. Spatial autocorrelation of British-era archaeological sites and water sources

4.5 Hotspot Analysis

Figure 6 shows the outcome of the Getis-Ord Gi* hot spot analysis. Hot spots (90-99% confidence) are hot in the central and the southeastern regions of the district with the cold spots mainly found in the northwest. There are numerous hot spots and sources of water.

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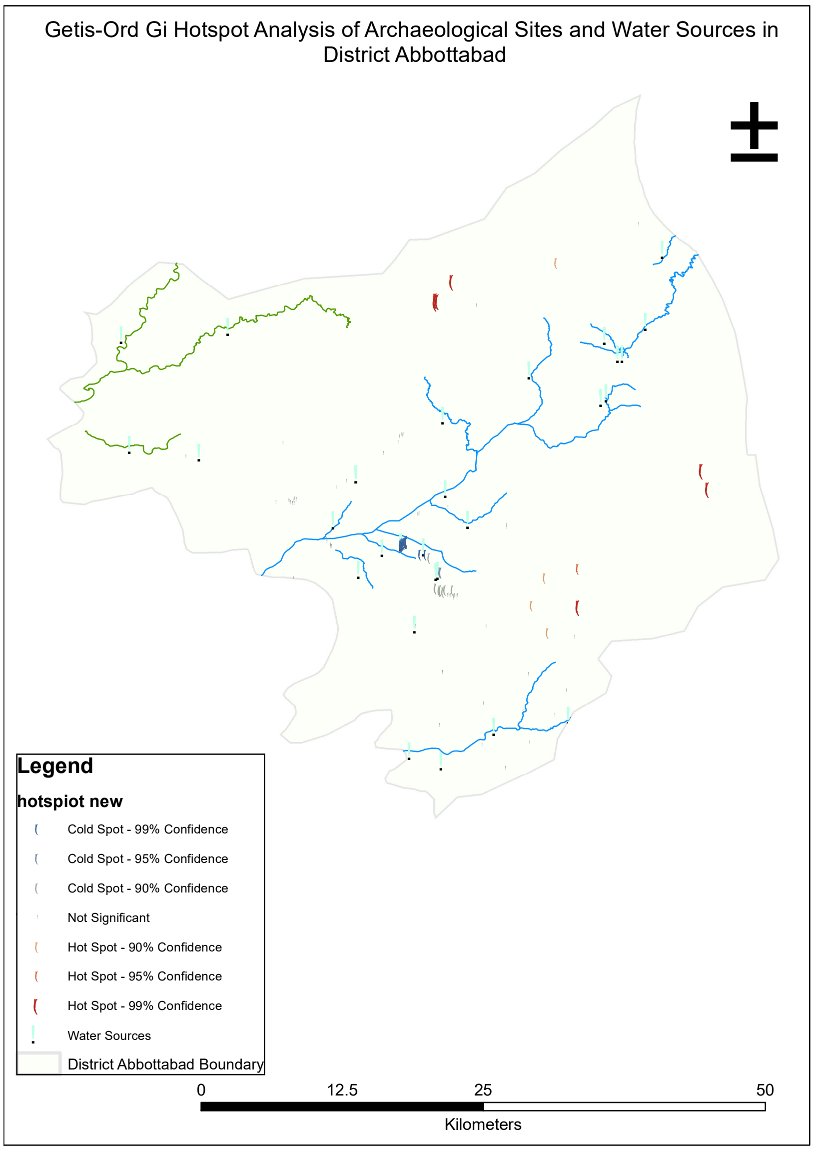

Figure 6. Hotspot analysis of sites and water sources

4.6 Patterns of Elevation and Slope

Figure 7 is the spatial pattern of the sites by the elevation and Figure 8 by the slope. In Table 2 the mean and median of distance to water, slope and elevation have been given in all the sites. The slope has an average of 12.37 and the elevation is 1249.08 m (1193 m median).

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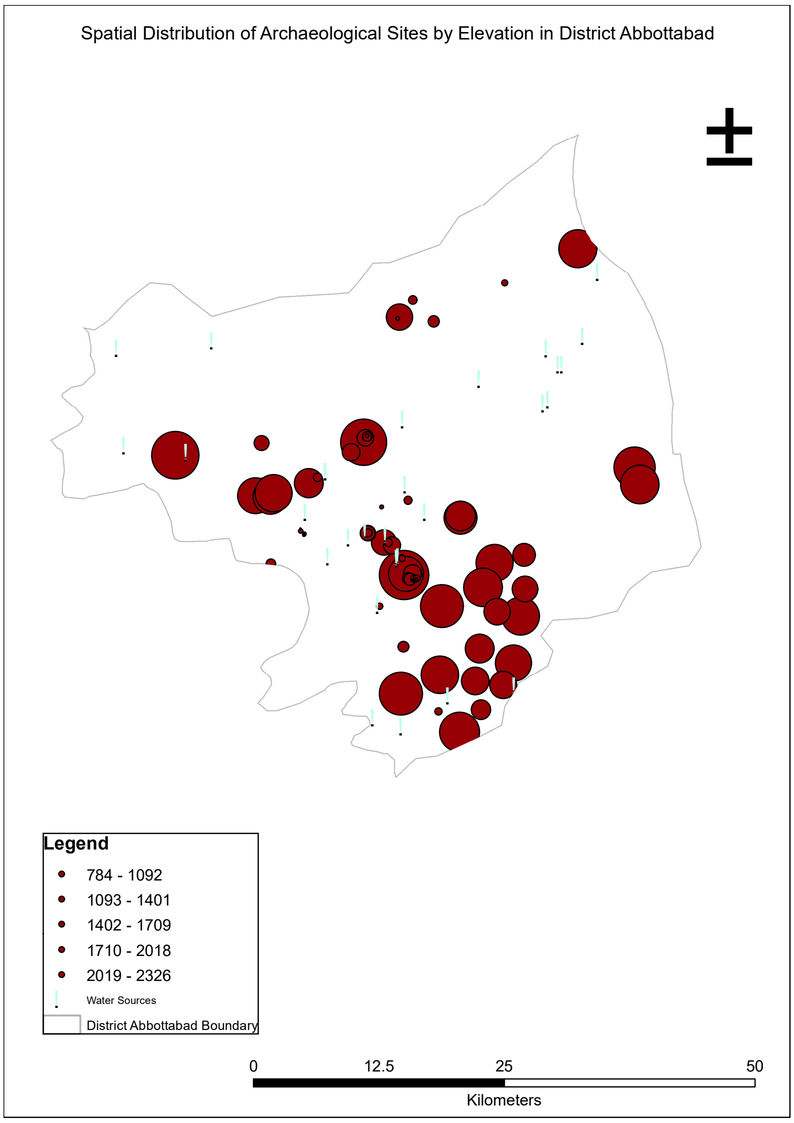

Figure 7. Spatial distribution of british-era archaeological sites by elevations

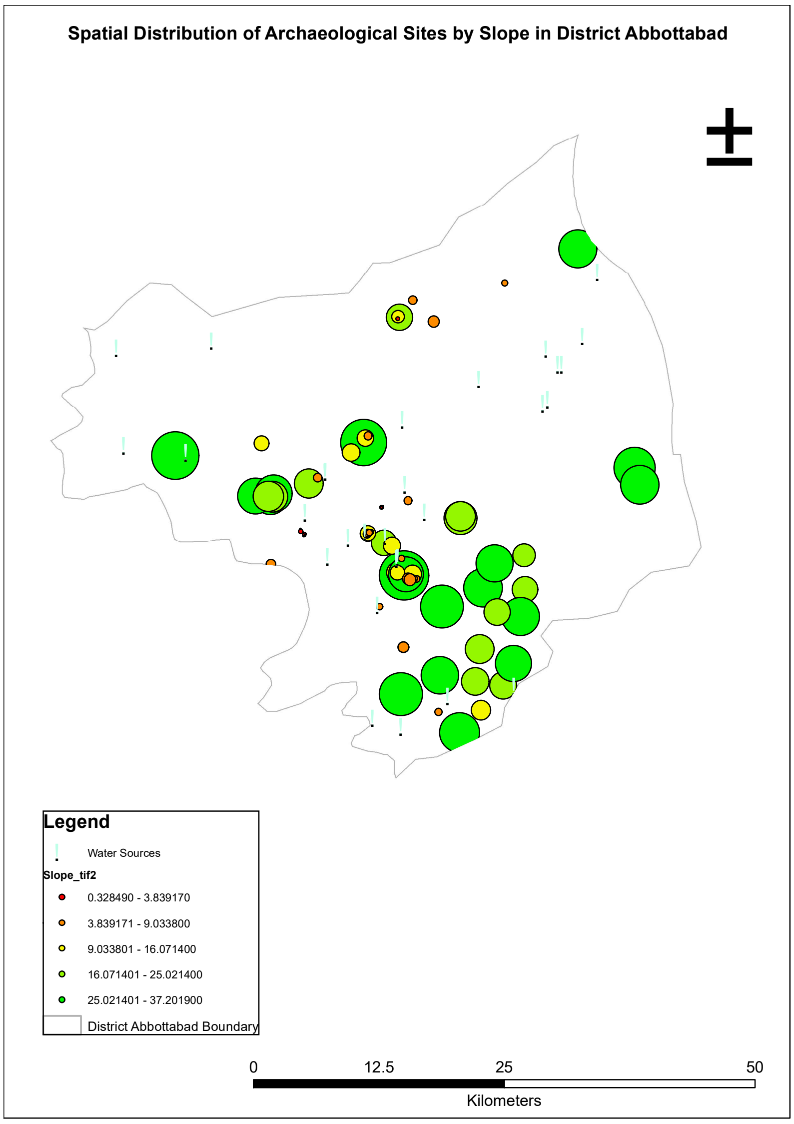

Figure 8. Spatial distribution of British-era archaeological sites by slope

Table 2

Variable	Mean	Median
Distance to water (m)	2762.39	2235.62
Slope	12.37°	7.34°
Elevation	1249.08	1193

4.7 Comparison of Slope and Elevation between Sites Far and near to Water Sources

The mean elevations of archaeological sites are compared in figure 9 according to their distance to water sources. Those sites within 500 meters of water are usually found at a lower altitude whereas those over 500 meters are found on a higher altitude. This allocation is an indication of the level of water availability affecting the site selection with respect to the topographical environment. Figure 10 demonstrates the mean slope values of the archaeological sites oriented on the distance to the oceans. The closer to water (less than 500 m) the site is, the more likely it is located on a lower slope, sites located more than 500 m are connected with steeper slopes. This implies that convenience of accessibility and geographical convenience played a huge role in the settlement location.

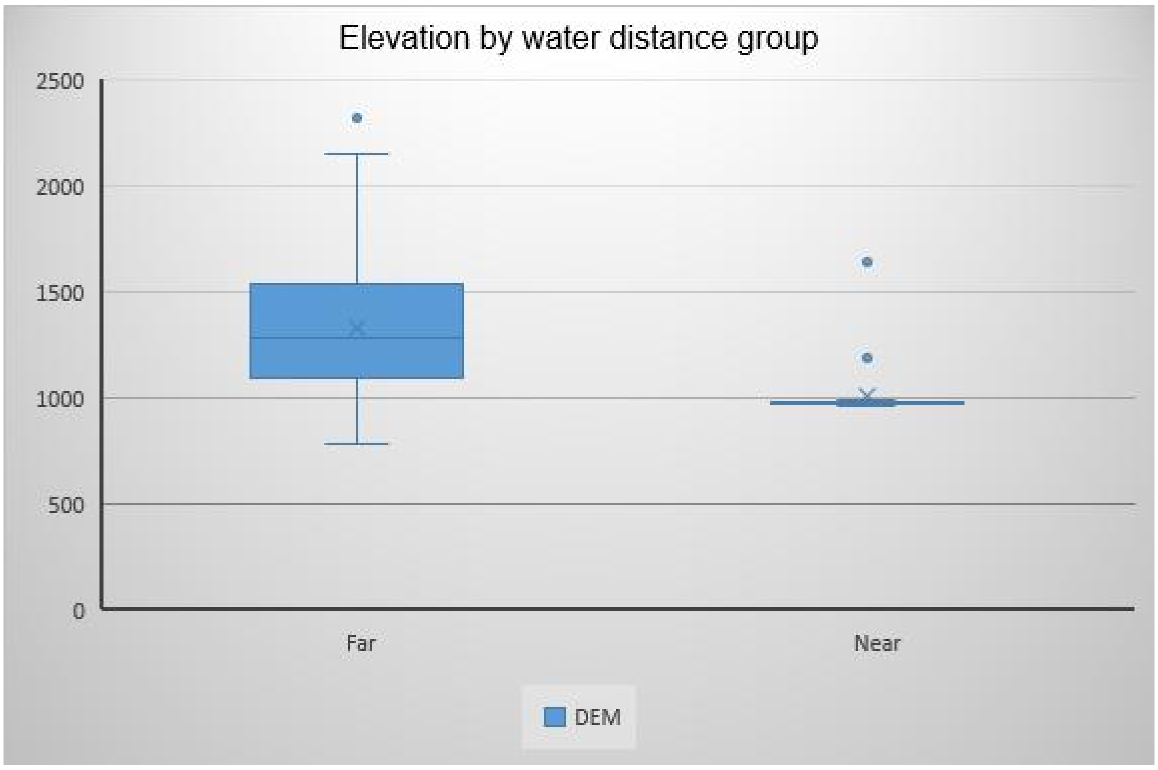

Figure 9. Average elevation of British-era archaeological sites located close to (<500 m) and far from (>500 m) water sources.

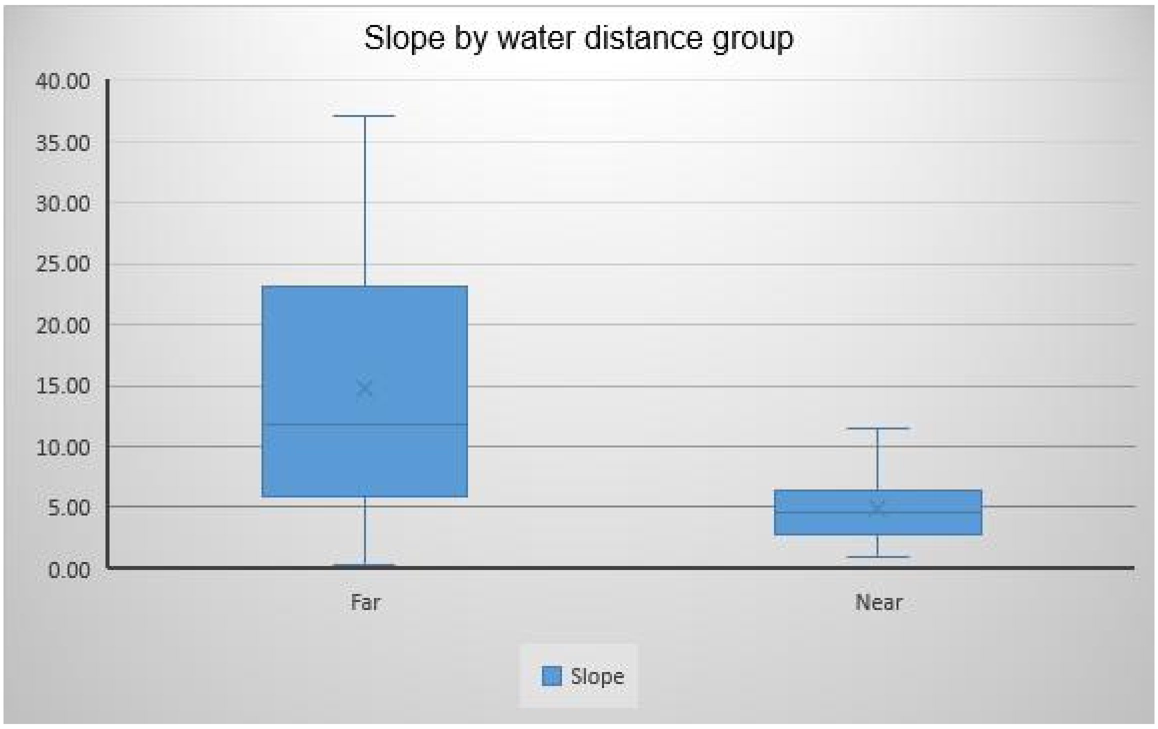

Figure 10: ***Average slope of British-era archaeological sites located close to (<500 m) and far from (>500 m) water sources.***

4.8 Comparative analysis Near vs. Far Sites

Table 3 is a comparison of mean slope and elevation between the sites near (<500 m) and the distant ones (>500 m) water sources. Near sites contain mean slope of 4.82 o and mean elevation of 1,014.71 m whereas far sites have mean slope of 15.16 o and mean elevation of 1,335.58 m.

Table 3

Group	Mean Slope	Mean Elevation
Close (<500m)	4.82	1014.71
Far (>500m)	15.16	1335.58

4.9 Statistical Testing: t-tests

The independent samples t-test of slope is displayed in table 4. Near and far sites are statistically significantly different t (107) = -8.19, p =.001. There is a significant difference in steepness of far sites (M = 15.16 o, SD = 10.57) and near sites (M = 4.82 o, SD = 2.86). The t-test of elevation is indicated in table 5. Far sites have much higher elevation (M = 1,335.58 m, SD = 311.57) than near sites (M = 1,014.71 m, SD = 129.12), t (111) = 7.80, p =.001.

Table 4: ***Independent Samples t-test for Slope: Near (<500 m) vs. Far (>500 m) Sites***

Group	*n*	*M*	*SD*
Near (<500 m)	31	4.82	2.86
Far (>500 m)	84	15.16	10.57

Table 5: ***Independent Samples t-test for Elevation: Near (<500 m) vs. Far (>500 m) Sites***

Group	*n*	*M*	*SD*
Near (<500 m)	31	1014.71	129.12
Far (>500 m)	84	1335.58	311.57

5. Discussion

The result of this paper confirms the hypothesis that the water availability was a major method used to determine settlement locations in the spatial distribution of the British-era settlements in District Abbottabad. This has been experienced in South Asia in which the great urban centres of Indus Valley Civilization were found along the perennial streams (Kenoyer, 1998; Possehl, 1990). The clustering effect on the hot spot analysis shows that not only were settlements concentrated around areas of water but they also seemed to form agglomerations of settlements in the areas of the rich resource availability as the spatial settlement theory in archeology predicted (Chang, 1968; Trigger, 1967). The great difference in the inclination and the height of the close and the distant location give further data concerning the colonial settlement patterns. These were lower grounds and softer slopes and the steep and elevated ones could be placed as strongholds or as administration areas. The trends are congruent with other GIS-related studies that have established that hydrology, as also, topography exert a very strong influence on settlement choice (Bevan and Conolly, 2006; Parker, 2006). This is also the opinion of the environmental determinism views and also concerned with the geographic limitations of the human activities (Semple, 1904; Huntington, 1924). The GIS application in the study demonstrates that this technology can be used in archaeological research in Pakistan, and the application of spatial modeling is not well-developed (Ahmad et al., 2025). This research is a repeatable form of researching environmental determinants of site distribution by means of a merger of proximity analysis, terrain modeling, and statistical testing. Besides that, the methods applied in the case can be applied to train predictive models in order to find unexplored colonial and earlier period sites to facilitate the heritage management process in Khyber Pakhtunkhwa. The current study has been founded on the available registered sites and sources of water; the unknown sites or seasonal water sources can alter the current trends. The weaknesses will include the precision of GPS and the probability of absence of seasonal source of water in the data.

6. Conclusion

This paper involves the quantitative analysis of the spatial relationship between the archaeological sites of the British in District Abbottabad, Pakistan and the water sources with the help of GIS. The percentage of locations close to water sources was relatively high (43) which indicated that sites with hydrological access had a significant effect on settlement location. The ones nearer to water tended to be on the lower levels as well as on easier terrain. Examination of hotspots showed that there was a strong tendency to cluster around hydrologically rich areas, and water accessibility and good terrain had a decisive role in the planning of colonial settlements. This study enhances the archaeological GIS studies in Pakistan by incorporating the proximity analysis, terrain modeling, and statistical testing into the study, allowing the archaeologists to go beyond documentation to analytical modeling of the environmental determinant. This methodological approach is repeatable and can be modified to other historical periods and regions providing a great tool of predictive heritage mapping. These discoveries do not only add to the scholarly knowledge of the settlement strategies of the colonial period, but they are also practically applicable in terms of heritage management. The recognition of regions of great archaeological interest can be used to direct the survey, focus efforts on conservation in vulnerable regions, and aid evidence-based cultural resource policy. In future research, other environmental and socio-political factors should be included in the study alongside unrecorded or seasonal water sources in order to perfect and extend the current model.

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