Zoning analysis of Iron Age sites using Analytic Hierarchical Process (AHP) methods in the Middle Atrak River Basin, Northeast of Iran

Mohsen Heydari Dastenaei¹, Mohsen Dana²
¹ Department of Archeology, Shahid Chamran University of Ahvaz, Ahvaz, IR; M.Heydari@scu.ac.ir
² Ministry of Cultural Heritage, Handicrafts and Tourism, Tehran, IR; mohsendana@gmail.com

ABSTRACT – Iron Age settlements in the Middle Atrak Basin in Iran have a particular distribution pattern due to environmental, social, and economic variables, among which geographical factors play an essential role in creating and dispersing settlements. Some of these factors play a more effective and stable role than others. The present study examines and evaluates the role of geographical factors in the distribution of Iron Age sites to determine factors that have a more significant role than others. Moreover, the zoning map of the Middle Atrak Basin should be presented using four different types of location, grouped in terms of those with a perfectly suitable, relatively suitable, suitable, and unsuitable location. To achieve this goal, seven natural factors, including the distance of sites from the river, altitude, slope, slope direction, distance from communication routes, soil type, and land use, were selected as influential factors in choosing the location of the Iron Age sites. In this study operating maps were prepared digitally using ArcGIS, and then the weight of each index was determined using the AHP model. The results of this study show that 46.7% of the Iron Age settlements (or 28 sites) were located in a perfectly suitable environment and geography, 24 sites (29.3%) in a relatively suitable location, seven sites (11.4%) in a suitable place, and one site (1.6%) in a completely unsuitable environment. This last type of location in the region’s landscape indicates the choice of different livelihoods, including agriculture and animal husbandry with both seasonal and permanent methods.

KEY WORDS – Iron Age sites zoning; Analytic Hierarchical Process (AHP); Middle Atrak Basin; Northeast of Iran

Analiza coniranja železnodobnih naselbin z metodami analitično hierarhičnega procesa (AHP) v porečju srednjega Atraka, severovzhodni Iran

IZVLEČEK – Zeleznodobne naselbine v porečju srednjega Atraka v Iranu imajo poseben vzorec umestitve zaradi okoljskih, socialnih in ekonomskih sprememljitev, med katerimi igrajo geografski dejavniki ključno vlogo pri nastanku in širitvi naselij. Nekateri od teh dejavnikov so bolj učinkoviti in trajnejši od drugih. V študiji predstavljamo najpomembnejše geografske dejavnike pri porazdelitvi najdišč. Karto poselitvenih območij srednjega Atraka predstavljamo s pomočjo štirih tipov lokacij, razvrščenih glede na popolnoma primerne, manj primerne, primerne in neprimerne pogoje poselitve. Pri tem smo kot ključne izbrali sedem naravnih dejavnikov: oddaljenost najdišča od reke, nadmorska višina, strminja, smer pobočja, oddaljenost od komunikacijskih poti, vrsta tal in raba tal. Digitalne karte smo izdelali s pomočjo programa ArcGIS in obezležili z indeks, ki jih določa model AHP. Rezultati kažejo, da je 46.7 % železnodobnih naselbin (28 lokacij) umestenih v posamezni primeren, 24 (29.3%) v manj primeren, sedem (11.4%) v primeren in ena (1.6 %) v popolnoma neprimeren prostor. Zadnji tip lokacije kaže na izbire različnih vrst preživljanja, tako kmetijstva in živinoreje s stalno ter sezonsko poselitvijo.

KLJUČNE BESEDE – coniranje železnodobnih najdišč; analitični hierarhični proces (AHP); srednji Atrak; severovzhodni Iran

DOI: 10.4312/dp.49.8
Introduction

Archaeological findings show that the development and evolution of past human settlements are closely related to the substrate of the natural and social environment. Environmental and natural substrates create the necessary conditions for establishing settlements, and some create more stable conditions than others. These natural substrates are each region's slope, altitude, geological structure, water resources, and climate. Each of these factors, both individually and in relation to each other, shows differences. The existence of such differences causes the characteristics of different regions (Gholami Rad, Wali Shariatpanah 2013.56). Humans have long tried to settle in the natural environment in such a way that makes the best use of it. In other words, human settlements act as the most basic link between man and the Earth, and reflect human interactions with the environment (Zhang et al. 2014). Therefore, ancient societies lived in places that had favourable conditions for life and development – with environmental factors such as rivers, communication routes, and beds of deltas and river terraces along with foothills or mineral resources – which provided them with raw materials and the possibility of protection against enemies (Maga∏ et al. 2021.21). In addition to these cases, various other factors and forces are involved in the location and formation of rural settlements, which should be considered in any location of settlements. Although the effects of these factors and forces depend to a great extent on the underlying characteristics of the environmental substrate and ecological structures (Zhang et al. 2014.2818), the primary stimulus in this process is the set of motivations that arise to meet basic needs, and the forms of various fundamental demands among different human groups. As such, different forms and varieties of locations, and the locating of human settlements in certain places because of the demands and motivations they are able to satisfy, are realized in different ways. As a result, settlements are structurally and functionally different from one area to another (Rahimi, Hassanpour 2013.14). For example, settlements formed in hilly areas are more affected by natural factors such as altitude, slope, and slope direction. In contrast, settlements formed in lowland areas are more affected by human factors such as communication routes and transportation, surface water networks (hydrography), and agricultural and cultivated lands (Ma et al. 2017.12). Therefore, these factors affect the texture and body of the settlements and the ways of life of their people.

In this study we use several environmental variables and natural criteria, along with the Analytic Hierarchical Process (AHP) integrated with the Geographic Information System (GIS), for zoning and evaluating the Iron Age sites of the Atrak River Basin to determine: (1) What are the zones in the Middle Atrak? (2) Which of these basins were considered by Iron Age people? (3) What do the Iron Age sites in the different zones reveal?

Theoretical foundations

AHP is one of the most efficient multi-criteria decision-making techniques, and was developed by the mathematician Thomas L. Saaty (1980) in the late 1970s. One of the advantages of the hierarchical analysis method in the context of this study is that it can deal with the various factors that influence the location of human settlements. It prioritizes residential areas by weighting factors with pairwise comparisons (Abdelouhed 2022.11) and the impact rates of each of them (Liao, Kao 2010.571). AHP is an effective and helpful method for solving multi-criteria problems that use a hierarchical structure to show the problem, and a better way to solve such issues and prioritize different options based on user judgment. In other words, this method is used both in reality and theory in decision-making (Toledo-Aceves et al. 2011.975). To be more specific, the ultimate goal of the AHP method is to determine the relative weight of each factor in a system (Yao, Zhao 2022.17). By solving decision problems, AHP allows researchers to focus on several criteria simultaneously and also allows decision-makers to compare quantitative and qualitative criteria (Rodhiah et al. 2021.197). AHP is a multi-objective, multi-criteria decision-making approach that enables the user to reach priorities based on a set of options derived from three principles: parsing, comparative judgment, and prioritization (Abdul Rahaman, Aruchamy 2017.3).

The AHP method has three basic steps: (1) creating a hierarchy, which is the essential part of the hierarchical analysis process (Cimren 2007.369); (2) determining the importance coefficients of variables and criteria using pairwise comparison methods; (3) assessing the consistency of judgments according to the percentage of consistency (Saaty 1980.287).

As discussed above, AHP can be used for relative measurements by pairwise comparison of criteria and data, or measurement of data according to criteria and variables. Ranking mode and preferences
include a pairwise comparison of criteria according to purpose. Ranking levels and preferences – such as excellent, very good, good, average, poor, and very poor – are then determined for each criterion. In the next step, pairwise comparisons are made between the ranking levels of each criterion to obtain a set of priorities (weights) for these levels. For each criterion, scaled weights are considered, and each option is assigned a ranking level and will be scaled (Bahurmoz 2004).6

Materials and methods

This research was carried out using a descriptive-analytical method to consider the issue of land suitability and its analysis with regard to settlement selection. Accordingly, after collecting the required information and also reviewing the status of the Iron Age settlements in the Middle Atrak Basin, using AHP and going through the steps in ArcGIS – including entering variables and criteria, preparing informa-

Fig. 1. Maps of the locations of Iron Age sites with regard to environmental factors. 1 distance of sites to water sources; 2 distance of sites to communication routes; 3 degree of slope; 4 height above sea level; 5 location of the site on soil type; 6 land use.
Zoning analysis of Iron Age sites using Analytic Hierarchical Process (AHP) methods in the Middle Atrak River Basin, Northeast of Iran

Geography and ecology of the Atrak River Basin

Although there is no long-standing accurate climate record of the northeastern region of Iran for the Iron Age, studies by researchers have shown that, contrary to popular belief, there were stages of sudden climate change during the Holocene. There is a consensus that such phenomena are pervasive, and their results can be generalized to different parts of the world (Hejebri Nobari et al. 2021.298). Towards the end of this period, especially from the beginning of the first millennium BC, the tendency of temperature changes tended to be colder (Shaikh Baikloo Islam, Chaychi Amirkhiz 2020.40). The same cold and humid climate phenomenon are seen in all parts of the Tibetan Plateau (Callegaro et al. 2018) and West Central Asia (Fouache et al. 2020.92). The most recent long-term climate studies have been carried out near the study area of Jazmourian Playa (Vaezi et al. 2019) and Hamoon Lake in Sistan (Hamzeh et al. 2016), and the coast of Gorgan (Kakroodi et al. 2015). The decrease in temperature caused the inhabitants of arid/semi-arid regions, such as north-central Iran (Shaikh Baikloo Islam, Chaychi Amirkhiz 2020.40), to adapt to the cold climate, in addition to agriculture. They also chose a nomadic-herding livelihood system, and a number of the areas covered in this article confirm this.

The Atrak basin, one of the largest water basins in northeastern Iran with an area of 33 890km², originates from the mountains of Hezar Masjed in the north of Quchan. About 26 500km² of this basin’s area is located in the political area of Iran, and the rest in Turkmenistan (Fig. 3). The Atrak basin is bounded by Turkmenistan in the north, Gorgan and Kalshor basin in the south, the Qaraqum basin in the east, and the Caspian Sea in the west (Noori et al. 2011.160). This basin consists of two parts, plains and mountains. Its climate is barren or continental. Rainfall is less than 200mm in the plains and up to 500mm in the highlands. The maximum altitude of this basin at the site of Tabarak River is about 2903m, and a minimum of 22m above sea level is estimated (Sheikhvahed et al. 2011.5). The main waterway of the basin can be divided into three parts: upper, middle, and lower (border) Atrak. After crossing the plains of Quchan, Shirvan, and Bojnourd (Upper Atrak), the river continues its route in Maneh, Ghori Meidan, and Maraveh Tappeh, then runs to the border of Iran and Turkmenistan (Middle Atrak). After connecting to the Sumbar branch at the Chat site and forming the Border Atrak (Lower Atrak), it finally flows into the Caspian Sea. The study area includes the middle part of the Atrak River with a length of approximately 150km (the boundary between Rezabad Gharbi and Sisab villages on the border of Shirvan and Bojnourd cities to Ghazan Ghayeh village.

Fig. 2. The structure of the hierarchical analysis process used in the research.
on the border of Mane and Solmaghan cities with Maraveh Tappeh) (Yamani et al. 2010).

The Middle Atrak Basin is geographically located between the Hyrkani Plain in the west and the land of Khorasan in the east. The high mountains of Alborz in the west separate it from Hyrkani, and the mountains of Kopah Dagh in the north separate it from the Qarehquom desert. With the Aladagh-Binalood Mountains in the south, the Middle Atrak Basin is safe from the central desert of Iran. The not-so-high altitude set separates this basin from the upper Atrak valley, and such a situation has made the central Atrak basin a relatively independent and closed basin. This feature has a significant impact on the climate of this region, which is something between the humid climate of Hyrkani and the cold and dryness of Khorasan. The western parts of this basin, especially in the Solmaghan plain, sometimes find a climate similar to the Gorgan plain, such as in summer. Especially since the Aladagh Mountains, overlooking the Solmaghan plain, have a relatively dense forest cover. However, in higher latitudes (northwest of the central Atrak basin) this part is warmer and very poor in terms of vegetation and water resources, due to the impact of the Turkmen Sahra lowlands in the west on the one hand and the soil of the region on the other.

**Background of archaeological research**

The first archaeological activities in the area of the Middle Atrak were the studies and work of Faegh Tohidi, which led to the arena determination of some sites. However, the first scientific excavation in this basin was carried out on the Tape Qaleh Khan, which showed an extended sequence from the Neolithic to the contemporary period (Garazhian 2011; Garazhian et al. 2014; Garazhian, Askarpour 2018). Exploration reports on the Tape Ashkhaneh Bimarestan (Dana et al. 2017; Dana, Hejebri Nobari 2018), Tape Ashkhaneh Rivi (Jafari, Thomalsky 2016), and Tape Eshgh Bojnourd (Vahdati 2014), along with efforts to determine the area and boundaries of the tape Kalateh Mostofi Bojnourd (Yazdani 2015), Tape Bruski Ashkhaneh (Adine 2012) and Kohnekand Bojnourd (Dana et al. 2019), have also been published with regard to this basin. However, studies of the cities of Shirvan (Mirzaei 2008), Bojnourd, Raz and Jirgalan (Rajabi 2013), Mane and Solmaghan (Garazhian 2007; Ateei 2009; Zare 2011) in this area have not been published yet.

**Iron Age sites of the Middle Atrak Basin**

In the study and identification work carried out in the Middle Atrak Basin, over 360 archaeological sites...
from all periods have been identified. Seventeen sites have been identified in Shirin Darreh springs (a tiny part of Shirvan city), which are located in the middle Atrak area (Mirzaei 2008); 143 sites have been identified in Bojnourd city, which is completely located in the Middle Atrak Basin; 43 sites have been found in Raz and Jarglan city, about half of which is located in the Middle Atrak Basin (Rajabi 2013); and 160 sites have been identified and introduced in Mane and Solmaghan city, which are completely located in the Middle Atrak Basin (Garazhian 2007; Ataei 2009; Zare 2011) (see Table 1). Of these, 61 sites were inhabited during the Iron Age.

Environmental factors survey

**Water resources factor**

Human settlements are usually located where access to surface water is possible, and thus water is an essential factor in the emergence of human habitats and the most crucial factor in their growth and development (Heydari Dastenaei, Niknami 2020, 316). The land type and topographic status of each location significantly impacts water storage and flow. Accordingly, villages are established where there is enough water to meet the needs of the inhabitants (Molarjem, Siasar 2017,58). Atrak and its tributaries (Fig. 1.1), as a permanent and reliable water source, would be present many attractive locations in this regard. Suitable soil and altitude are also crucial for avoiding periodic or seasonal river floods when locating settlements. As shown in Figure 4, 80% of the Iron Age sites are located within 1000m from running water, indicating the connection between the ancient sites and water resources.

**Communication routes factor**

Communication routes are another essential variable in the formation of ancient sites, especially in the Bronze Age and beyond, when we see the formation of cities with long-distance and trans-regional trade relations in the Greater Khorasan region. In the past, ancient roads were usually built based on natural paths and systems of valleys and plains (Hejebri Nobari et al. 2021,301), and this region follows this due to its mountainous nature. Communication routes in mountainous areas usually pass from the bottom of the valleys. What we have in mind today as a communication route is very different from what existed in the past. Before the creation of modern roads, people used gorges and the cuts caused by geological activity to travel. Due to the mountainous location and the forested nature of the focal area, the only passable routes were inevitably the same cuts and the lengths of other valleys located between relatively high and steep mountains that were used as paths (Vosogh Babae, Mehrfararin 2018,197). This also applies in historical times, even in adjacent areas such as Dargaz, and historic sites have sometimes been formed adjacent to the main communication routes. This communication role is one of the essential factors in securing the economy of the inhabitants of these cities and rural areas (Nami, Mousavinia 2019,239).

There are 42 sites (69%) in the range of 0 to 1000m from the communication routes in this area, seven sites (11%) at a distance of 1000 to 2000m, eight sites (13%) at a distance of 2000m to 3000m, and four sites (7%) located 3000m or more from the communication routes (Fig. 5). Among these, only one site – Tape Dâşhâd (IAMA60) – is located c. 9000m away from the communication routes. More than 70% of the sites are located at the bottom of the valleys, in the middle of the mid-mountain plains, and next to the communication routes (Fig. 1.2).

**Slope degree factor**

One of the influential environmental factors in the human settlement distribution system is the height and slope criterion. The slope is one of the essential factors in the transformation of land surface roughness (Akbar Aghalli, Velayati 2007,48), and thus it affects human life and activities such as agriculture, keeping livestock, and even some human settlements

| Middle Atrak Basin based on city | Number of identified sites | Percentage of identified sites | Percentage of Iron Age sites |
|---------------------------------|---------------------------|-------------------------------|-----------------------------|
| Shirvan                         | 17                        | 5%                            | 2%                          |
| Bojnord                         | 143                       | 39%                           | 23%                         |
| Raz and Jarglan                 | 43                        | 12%                           | 3%                          |
| Mane and Solmaghan              | 160                       | 44%                           | 72%                         |
| Total                           | 363                       | 100%                          | 100%                        |

*Fig. 4. Location of Iron Age sites in terms of distance from water sources.*

*Tab. 1. Location of Iron Age Sites based on counties.*
on the slopes either directly or indirectly (Zomorrodian 1995.25).

The degrees of the slopes in the region were classified into nine separate groups. The lowest slopes (0–5 degrees) were determined as the first group, and the highest slopes were classified as group 9. Since the best slope for establishing human habitation is a slope of 0–10 degrees (Anabestani 2011), we examined the location of the sites on the slopes. The slope degree of the location of ancient sites is an essential factor that affects the area due to its economic impact. Among the sites of this period (Fig. 1.3) 18 (28%) were on slopes of 0–5 degrees, 20 sites (32%) on slopes of 5–10 degrees, 12 sites (18%) on slopes of 10–15 degrees, and 14 sites (22%) on slopes of more than 15 degrees (Fig. 6).

**Altitude from sea level factor**

Altitude from sea level can cause climate changes and, consequently, changes in lifestyle and some climatic features (Qazanfarpour et al. 2013.129). In addition, it directly affects ecosystems, vegetation, animals, and livelihood choices (Duckstein et al. 1973.22). The central Atrak region’s sea-level altitude varies between 226m and 2962m. The location of the sites in terms of altitude (Fig. 1.4) shows that about 60% of the sites are located at an altitude between 226m to 819m above sea level (Fig. 7). In this region, the average annual rainfall in meteorological stations is about 250mm, which is suitable for rainfed cultivation. However, it should be noted that despite the appropriate rainfall and altitude, the soil type is also crucial for cultivation. Sufficient rainfall and humidity at altitudes of about 600m above sea level and above allow optimal rainfed cultivation (Kirkby 1979. Tabs. 83–84). However, the annual rainfall is a more critical factor for rainfed cultivation. The minimum annual rainfall suitable for rainfed cultivation is about 200mm (Adams 1981.12), indicating that this area is suitable for rainfed agriculture due to having more rainfall.

**Soil type factor**

Today, geoarchaeological studies have found a special place as a helpful tool in archaeological research and explaining ancient Quaternary environments (Maghsoudi et al. 2020.2). Soil is a non-dense organic matter that has been created over many years under the influence of various factors, such as climate, vegetation, and elevation (Salmanpour et al. 2013), and soil type affects the livelihood structure of an area (Estelaji, Ghadiri Masoum 1995.126). As can be seen on the map, large areas of the western parts of the Middle Atrak Basin are geologically calcareous and unsuitable soils that are also very poor in vegetation. The Iron Age sites of the region are in the category of Incepti soil/Entisols rocky outcrop soils with a small amount of Incepti soil (Fig. 1.5). In this area, 42 (68%) of the Iron Age sites are located on Incepti soil, seven sites (12%) are located on Incepti soil with rocky outcrop soil, and 12 sites (20%) are located in areas with enti soil with rocky outcrop soil (Fig. 8). The presence of fine-grained and fertile sediments usually provides suitable materials for agriculture, pottery, and other economic activities and acceptable conditions for developing settlements (Maghsoudi et al. 2020.7). Incepti soils are spread all over the world, and research shows that they are suitable for agricultural and non-agricultural uses, and can be widely used for crop culti-
Zoning analysis of Iron Age sites using Analytic Hierarchical Process (AHP) methods in the Middle Atrak River Basin, Northeast of Iran

Land use factor
Land use results from a combination of human activity and the capabilities of a place. Although Land use is the result of population activities, it is also in some ways a reason for the existence of certain capabilities and the possibility of using the capabilities of the natural environment (Sadr Mousavi et al. 2018.734). The cultivability of land is one of the factors that is influenced by many important criteria, such as altitude, presence or absence of surface water, soil type, human manipulation of the environment, and climate. However, this human manipulation can also have a decisive role on the erosion rate. Most importantly, the land cultivability and type of vegetation can also be a very determining factor in the type of livelihood of those living in the related settlements. As such the settlement or use of many shelters in an area, especially in association with raising livestock, depends on land cultivability and type of vegetation (Afifi 2018.636). To this end, the purpose of land surveying is to determine the land value from the location point of view (Rahimi, Hasanpour 2011.21).

The map of the area based on land use (Fig. 1.6) shows that about half of the sites are located in areas that are currently used for agriculture, whether irrigated or rainfed, and the other half are in areas that are located in a pasture or forest areas (Fig. 9). This local difference in the sites should be considered as related to the livelihood of the residents. This means that in pasture areas the sites indicate that nomads used them for temporary settlement or cemeteries, and that the sites on suitable agricultural land belonged to sedentary farmers.

Slope direction factor
As a general concept, direction is a well-defined feature for the linear effects of a phenomenon in geometry. In the context of this study it also includes other concepts, such as slope and geological slope (Heydari Dastenaei, Niknami 2020.320). Slope direction determines the amount of solar energy that the soil receives. This energy determines the temperature of air and soil and the amount of available water in the soil, which are the factors that cause differences in the vegetation of different slopes. In mountainous areas slopes facing the sun seem to be more suitable for settlement, while in tropical areas this is the case for slopes that do not face the sun. In the Middle Atrak Basin the southern slopes are the most important and the northern slopes the least, because the former receive the lowest heat in summer and the most heat in winter. The eastern and western slopes are less important than the southern slopes, and are used in spring and autumn (Heydari Dastenaei 2018.7). Surveying the location of Iron Age sites indicates that the northern slopes contain more settlements and the southern slopes are less used (Fig. 10). Accordingly, 12 sites are located on northern slopes, 11 sites on the north-east, two sites on the east, six sites on the southeast, six sites on the south, two sites on the southwest, eight sites on the west, and 12 sites on the west areas.

Zoning of Atrak River Basin
Potential zones for the placement of Iron Age settlements have been determined by weighting and classification of the abovementioned criteria and environmental factors, including communication routes, distance from water resources, land use, slope, slope direction, altitude, and soil type. The layers’ weights, which are the same factors as determined in the model, were evaluated according to the available options, and finally the total weight of the layers was obtained using the calculation formulas. The weight of each layer according to the preference options is shown in Table 2.
In AHP, in addition to considering the factors and combining their different levels, the rate of the number of achieved priorities and the accuracy of weighting results can be trusted due to the method of calculating the comparisons’ compatibility with regard to the studied layers, and determining the overall compatibility rate. In this research, the value of the compatibility rate is calculated as 0.4, which indicates the appropriate compatibility of the studied layers. According to Table 3, it can be seen that altitude, distance to a water source, distance to a communication route, slope, and soil type have the highest weights, and land use and slope direction have the lowest weights.

In Table 4, according to the results obtained from the final weight of the factors affecting the creation of ancient sites, it can be seen that altitude is in the first place with a weight of 0.26, distance to rivers is in the second place with a weight of 0.19, distance to communication routes is third with a weight of 0.15, slope direction is fourth with a weight of 0.14, soil type is fifth with a weight of 0.08, land use is sixth with a weight of 0.08, and in seventh place is slope, with a weight of 0.07.

In the next step, GIS is used to prepare layers to select areas with a higher priority. The final map is obtained by stacking the existing layers in terms of weight, as extracted from Table 4. According to the results obtained in this section, those areas with a higher potential for locating settlements have lighter colours, while those with a lower potential for this settlements have darker colours.

More specifically, those valuable areas that have the most potential for establishing settlements are the relatively limited areas shown in green. These have an area of 2235km², equivalent to 10% of the total area, with a low slope of about five degrees and a suitable slope direction, land use, suitable vegetation, and rich soil, and are generally suitable for the development of settlements (Fig. 11). This area has 28 Iron Age sites, accounting for 46.7% of the sites.

Moreover, the areas marked in orange with an area of 12 550km², equivalent to 47% of the total area, also have relatively good values. These areas are geographically hilly, suitable for growing rainfed plants, and also a good place for livestock grazing. This section includes slopes up to 13 degrees, rainfed agricultural uses with an almost suitable soil type, and a short distance to water sources and communication routes. Twenty-four sites (39.3%) are located in this area.

The dark brown areas with an area of 7900km², equivalent to 22% of the total, have a relatively low value for settlement. These areas are hillsides with steep vegetation and steep slopes, and the land is used only for pasture. In addition, the type of soil and even the soil depth in these areas is low, and they are far from permanent water sources such as rivers, as well as communication routes. It is noteworthy that seasonal water springs are usually seen in these areas, and this type of area is used only for livestock.

---

**Tab. 2. The binary preference matrix of the components.**

|                     | Slope direction | Landuse | Slope degree | Distance to roads | Distance to rivers | Above sea level | Type of soil |
|---------------------|-----------------|---------|--------------|-------------------|-------------------|----------------|--------------|
| Slope direction     | 0.69            | 0.177   | 0.234        | 0.037             | 0.052             | 0.079          | 0.052        | 0.071        |
| Landuse             | 0.023           | 0.058   | 0.323        | 0.026             | 0.081             | 0.093          | 0.017        | 0.087        |
| Degree of slope     | 0.153           | 0.013   | 0.074        | 0.025             | 0.085             | 0.151          | 0.25         | 0.141        |
| Distance to roads   | 0.154           | 0.182   | 0.238        | 0.081             | 0.046             | 0.098          | 0.248        | 0.155        |
| Distance to rivers  | 0.239           | 0.13    | 0.156        | 0.316             | 0.179             | 0.113          | 0.09         | 0.192        |
| Above sea level     | 0.278           | 0.222   | 0.156        | 0.263             | 0.502             | 0.317          | 0.125        | 0.266        |
| Type of soil        | 0.083           | 0.216   | 0.019        | 0.018             | 0.054             | 0.159          | 0.063        | 0.087        |

**Tab. 3. Normalized matrix of preferences.**
grazing. Seven ancient sites in this area can be seen, accounting 11.4% of the sites.

Finally, the dark red areas, with an area of 393 km² and equivalent to 15% of the total area, do not have any settlement value. These areas have steep slopes and rocky, non-agricultural lands, with poor rangeland vegetation. Thus, due to their high altitude and steep slopes, unsuitable terrain for agriculture, and distance from communication routes, these areas are often unsuitable for settlement. However, an Iron Age site (IAMA 44) (1.6%) is located in this area, which seems to have been a short-term seasonal establishment.

Discussion and conclusion

The use of GIS and geostatistical techniques can be a useful, practical tool in archaeology. These tools make it possible to apply complex mathematical equations to maps. On the other hand, using the existing interpolation methods in the field of statistics, statistical and spatial analysis can be carried out in different places based on the locational and geographical situation of the phenomena. In the present study, we tried to evaluate the effects of environmental factors on the formation of Iron Age settlements. The results showed that environmental conditions in the form of slope characteristics, slope direction, altitude, distance from communication routes, access to water resources, soil type, and land use all positively affect the distribution and density of site in the area being studied.

In the first step, in order to determine the importance of each layer using the AHP method, indicators were compared pairwise with each other, and each indicator was weighted. According to the results of the AHP model, the highest weight is related to the altitude index with a weighted score of 0.26, and the lowest weight is related to the slope direction, with a score of 0.07. In the next step, the layers were standardized into four levels and a zoning

| Layers          | Abnormal weight | Normalized weight |
|-----------------|-----------------|-------------------|
| Slope direction | 0.0500158       | 0.071450106       |
| Landuse         | 0.0611772       | 0.087396017       |
| Degree of slope | 0.0987156       | 0.1405536         |
| Distance to roads| 0.1083421     | 0.154775398       |
| Distance to rivers| 0.1342631    | 0.181802997       |
| Above sea level | 0.1863892       | 0.266270269       |
| Type of soil    | 0.061098        | 0.087282862       |
| Total           | 0.7             | 1                 |

Tab. 4. Calculation of final weights based on preferences with regard to the environmental factors.

Fig. 11. Iron Age zoning map.
map of the Iron Age areas of the Middle Atrak Basin was prepared. The results show that one site is in a zone with no settlement value, size sites are in a low importance zone, 24 sites are in a relatively appropriate zone and 28 sites are in a very important zone.

The results of analyses show that the locations of the sites in different zones indicates different kinds of livelihoods were pursued there. Based on zoning analysis, it is determined that the areas that are located in Zone 4 (show in dark colours) are villages that engaged in irrigated and rainfed agriculture. The areas located in Zone 3 are areas that used both highland resources and plain agricultural resources. Such sites had a combined economy of livestock and agriculture, and also engaged in trade. Sites in Zone 3 are sites at the foot of the mountains and seasonal sites with livestock. Finally, Zone 1 is not suitable for settlement at all, and for this reason only one site is located in this area, and this site, like those in Zone 3, is a seasonal site.

References

Abdelouhed F., Ahmed A., Abdellah A., Yassine B., and Mohammed I. 2022. GIS and remote sensing coupled with analytical hierarchy process (AHP) for the selection of appropriate sites for landfills: a case study in the province of Ouazarzate, Morocco. Journal of Engineering and Applied Science 69(19): 1–23. https://doi.org/10.1186/s44147-021-00063-3

Abdul Rahaman S., Aruchamy S. 2017. Geoinformatics based landslide vulnerability mapping using analytical hierarchy process (AHP), a study of Kallar river sub watershed, Kallar watershed, Bhavani basin, Tamil Nadu. Journal of Modeling Earth Systems and Environment 3(1): 1–13. https://doi.org/10.1007/s40955-017-0298-8

Adams R. M. 1981. Heartland of Cities: Surveys of Ancient Settlement and Landuse on the Central Floodplain of Euphrates. University of Chicago Press. Chicago.

Adine O. 2012. Soundings for determination boundary at Tappe Boruksi, Ashkhane, Northern Khorasan. Abstract the 11th Annual Symposium of Iranian Archaeology, Tehran. Cultural Heritage Research Institute. Tehran: 53.

Afifi M. E. 2018. Analyze the Impact of Natural Factors in the Spatial Distribution of Urban and Rural Settlements of Khonj County. Journal of Studies of Human Settlement Planning 13(3): 629–646.

Akbar Aghalli F., Velayati S. 2007. Investigating the position of natural factors in the establishment of rural settlements. International and Scientific Journal of Iranian Geography Association 12–13: 45–66.

Anabestani A. A. 2011. The Role of Natural Factors in Stability of Rural Settlements (Case Study: Sabzevar Country). Geography and Environmental Planning 40(4): 89–104.

Ataei T. 2009. Report on Archaeological Surveys in Mane & Samalghan County (Northern Khorasan), First Season. Iranian Center for Archaeological Research. Tehran. Unpublished. (In Persian)

Bahurnoz A. M. A. 2004. The Analytic Hierarchy Process: A Methodology for Win-Win Management. Journal of King Abdulazziz University – Economics and Administration 26(1): 3–16. https://doi.org/10.4197/ECO.20-1.1

Callegaro A., Battistel D., Kehrwald M. N., +5 authors, and Barbante C. 2018. Fire, vegetation, and Holocene climate in a southeastern Tibetan lake: a multi-biomarker reconstruction from Paru Co. Climate of the Past 14(10): 1543–1563. https://doi.org/10.5194/cp-14-1543-2018

Çimren E., Çatay B, and Budak E. 2007. Development of a machine tool selection system using AHP. International Journal of Advanced Manufacturing Technology 35: 363–376. https://doi.org/10.1007/s00170-006-0714-0

Dana M., Hejebri Nobari A. 2018. Site Formation Process as Seen from Tappe Bimarestan-e Ashkhane Excavations Data. Journal of Archaeological Studies 10(2): 83–97. https://doi.org/10.22059/jarsc.2019.68527.

Dana M., Hejebri Nobari A., and Mousavi Kouhpar M. 2017. Excavation at Tappe Bimarestan Ashkhaneh; an Iron Age Graveyard in the North of Khorasan. Architecture and Modern Information Technologies (AMIT) 49: 151–167.

Dana M., Hozhabri A., and Rahmati M. 2018. Kohne Kand Bojnord, a Parthian Site with local characteres in North Khorasan. In M. H. Aziziz Kharanaghi, M. Khanipour, and R. Naseri (eds.), Second International Symposium of Young Archaeologists. Iranology Fondation 2. Tehran: 795–854.

We are grateful to Norouz Rajabi, Shahram Zare, Mohammad Taghi Alaei, Omran Garazhian, and Azita Mirzaei for providing their unpublished data.
Duckstein L., Fogel M. M., and Thames J. L. 1973. Elevation effects on rainfall: A stochastic model. *Journal of Hydrology* 18(1): 21–35. [https://doi.org/10.1016/0022-1694(73)90023-1](https://doi.org/10.1016/0022-1694(73)90023-1)

Eselaji A., Ghadiri Masoum M. 1995. Investigating Geographical Factors in the System of Rural Settlements with Emphasis on Quantitative Techniques (Case Study: Wilkij District of Namin County). *Journal of Geographical Researches* 37 (53): 121–136.

Garazhian O. 2007. *Report on Surface Surveys of Samalghan Plain, Northern Khorasan*. Iranian Center for Archaeological Research. Tehran. Unpublished. (In Persian)

Garazhian O. 2011. *Sunding for Stratigraphy and Documentation of Architectural Remains of Tappe Qal’e Khan, Mane and Samalghan County, Northern Khorasan Province*. The 9th Annual Symposium on Iranian Archaeology. Iranian Center for Archaeological Research. Tehran: 145–159.

Garazhian E., Askarpur V. 2011. *Trends in Evolution of Pottery in Qal’eh Khān, Bojnūrd*. *Journal of Archaeological Studies* 3(1): 107–132.

Garazhian O., Jafari J., and Hozhabri A. 2014. Report of Archaeological Researches for Documentation of Architectures at Tappe Qal’e Khan, Khorasan, emphasize on the Historical Period. *Modares Archaeological Research* 3: 161–199.

Garazhian O., Papoli Yazdi L., and Fakhre Ghaemi H. 2014. *Qaleh Khan a Site in Northern Khorassan and the Neolithic of North Eastern Iranian Plateau*. *Architecture and Modern Information Technologies (AMIT)* 46: 21–50.

Gholami Rad Z., Wali Shariatpanah M. 2013. Investigating the position of natural factors in the establishment of rural settlements in Kermanshah province based on AHP hierarchical analysis process model using GIS. *Geographical territory* 10(37): 55–76.

Hamzeh M. A., Mahmudi-Gharaie M. H., Alizadeh-Lahijani H., Mousavi-Harami R., Djamali M., and Naderi-Beni A. 2016. Paleolinomology of Lake Hamoun (E Iran): Implication for Past Climate Changes and Possible Impacts on the Human Settlements. *PALAIOS* 31: 1–14. [http://dx.doi.org/10.2110/palo.2016.055](http://dx.doi.org/10.2110/palo.2016.055)

Heydari Dastenaei M. 2018. The effect of environmental factors on the Prehistoric sites in the southern Zayandeh-Rud by using the Pearson correlation. *Journal of Iran Pre-Islamic Archaeological Essays* 2(1): 1–14.

Heydari Dastenaei M., Niknami K. A. 2020. *Analysis of the Relationship between the Formation and Continuity of Neolithic Period Settlements with their environment in the Sarfīroz Abad Plain of Kermanshah, West Central Zagross*. *Physical Geography Research Quarterly* 52(2): 313–331. [https://doi.org/10.22059/jphgr.2020.285488.1007418](https://doi.org/10.22059/jphgr.2020.285488.1007418)

Jafari J., Thomalsky J. 2016. The Iranian-German Tappe Rivi Project (TRP), North-Khorasan: Report on the 2016 and 2017 Fieldworks. *Architecture and Modern Information Technologies (AMIT)* 48: 77–120.

Kakroodi A. A., Leroy S. A. G., Kroonenberg S. B., Lahijani H. A. K., Ali Mohammadian H., Boomer I., and Goorabi A. 2015. *Late Pleistocene and Holocene sea-level change and coastal paleoenvironment evolution along the Iranian Caspian shore*. *Marine Geology* 361: 111–125. [https://doi.org/10.1016/j.margeo.2014.12.007](https://doi.org/10.1016/j.margeo.2014.12.007)

Khrosroshahi M., Abbasi H. R., Khashki M. T., and Abtahi M. 2013. Determination of Iran Desert Lands Based on Soil Attributes. *Journal of Desert Management* 1(1): 27–38. [https://doi.org/10.22054/jdmal.2013.17098](https://doi.org/10.22054/jdmal.2013.17098)

Kirkby M. J. 1979. *Land and Water Resources of the Deh Luran and Khuzistan Plain*. In F. Hole (ed.), *Studies in the Archaeological History of the Deh Luran Plain*. University of Michigan Press, University of Michigan Museum of Anthropological Archaeology. Michigan: 251–288. [https://doi.org/10.3998/mpub.11395563](https://doi.org/10.3998/mpub.11395563)

Liao Ch. N., Kao H. P. 2010. Supplier Selection Model Using Taguchi Loss Function, Analytical Hierarchy Process and Multi- Choice Goal Programming. *Computers & Industrial Engineering* 58(4): 571–577. [https://doi.org/10.1016/j.cie.2009.12.004](https://doi.org/10.1016/j.cie.2009.12.004)

Magaś L., Gajski D., Dziegielewksa-Gajski K. 2021. Spatial multi criteria Approach to the evaluation of Archaeological Sites. *GIS Odyssey Journal* 1(1): 21–35. [https://doi.org/10.57599/gisoj.2021.1.1.21](https://doi.org/10.57599/gisoj.2021.1.1.21)

Ma L., Guo X., Tian Y., Wang Y., and Chen M. 2017. *Micro-Study of the Evolution of Rural Settlement Patterns and Their Spatial Association with Water and Land Re-*
Distribution of Rural Settlements (Case Study: Sahneh)

Sadr Mousavi M., Talebifard R., and Niazy C. 2018. Investigating the Role of Natural Factors in the Geographical Distribution of Rural Settlements (Case Study: Sahineh County). Journal of Studies of Human Settlement Planning 12(4): 731–749.

Salmanpour A., Senmar M., and Bakhtiari A. 2013. The role of soil on archaeological analysis and studies. The First Symposium of Archaeology of Iran. Birjad.

Shaikh Baikloo Islam B. 2020. Holocene climatic events in Iran. Journal of Climate Change Research 1(4): 35–47. https://doi.org/10.30488/ccr.2020.244327.1017

Shaikh Baikloo Islam B., Chaychi Amirkiz A. 2020. Adaptations of the Bronze and Iron Ages Societies of North Central Iran to the Holocene Climatic Events. Journal of Climate Change Research 1(2): 39–54. https://doi.org/10.30488/ccr.2020.111121

Sheikhvahed B., Bahremand A., and Mushekhian Y. 2011. A Comparison of Trends in Hydrologic Variables in the Atrak River Basin Using Non-Parametric Trend Analysis Tests. Journal of Water and Soil Conservation 18(2): 1–23.

Sharifi A., Pourmand A., Canuel E. A., +7 authors, and Lajhani H. A. 2015.Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: The hand that rocked the Cradle of Civilization? Quaternary Science Reviews 123: 215–230. https://doi.org/10.1016/j.quascirev.2015.07.006

Stevens L. R., Ito E, Schwab A., and Wright Jr. H. E. 2006. Timing of atmospheric precipitation in the Zagros Mountains inferred from a multi-proxy record from Lake Mirabad. Iran. Quaternary research 66(3): 494–500. https://doi.org/10.1016/j.quares.2006.06.008

Tolga E., Demircan L., and Kahraman C. 2005. Operating system selection using fuzzy replacement analysis and analytic hierarchy process. Journal Production economics 97(1): 89–117. https://doi.org/10.1016/j.jpe.2004.07.001

Toledo-Aceves T., Meave J. A., González-Espinós M. and Ramírez-Marcial N. 2011. Tropical montane cloud forests: Current threats and opportunities for their conservation and sustainable management in Mexico. Journal of Environmental Management 92: 974–981. https://doi.org/10.1016/j.jenvman.2010.11.007

Vaezi A., Ghazban F., Tavakoli V., +4 authors, and Kylin H. 2019. A Late Pleistocene-Holocene multi-proxy record of climate variability in the Jazmurian playa, southeastern Iran. Palaeogeography, Palaeoclimatology, Palaeoecology 514: 754–767. https://doi.org/10.1016/j.palaeo.2018.09.026

Vahdati A. A. 2014. A BMAC Grave from Bojnord, North-Eastern Iran. Iran 52: 19–27. https://doi.org/10.1080/05786967.2014.11834735
Verga Matos P., Cardadeiro E., da Silva J. A., and De Muyl-der C. F. 2018. The use of multi-criteria analysis in the recovery of abandoned mines: a study of intervention in Portugal. *RAUSP Management Journal* 53: 214–224. https://doi.org/10.1016/j.rauspm.2017.06.005

Vosogh Babae E., Mehrafarin R. 2018. Analysing the Role of Environment in the Parthian Settlements Distribution: A Case Study in the Chelchay River Drainage, Minodasht, Golestan, Iran. *Pazhuhes-ha-ye Bastanshenasi Iran* 16: 183–202. https://doi.org/10.22084/nbsh.2018.14420.1635

Yamani M., Dolati J., and Zarei A. 2010. The effect of hydrogeomorphic factors on temporal and spatial changes in the middle part of the Atrak River. *Geographical Researches* 99: 1–24.

Yao X., Zhao F. 2022. A quantitative evaluation based on an analytic hierarchy process for the deterioration degree of the Guangyuan Thousand-Buddha grotto from the Tang Dynasty in Sichuan, China. *Heritage Science* 10(19): 1–18. https://doi.org/10.1186/s40494-022-00655-z

Yazdani A. 2015. *Soundings for determination boundery at Kalate Mostowfi (Bojnourd, Iron Age)*. Iranian Center for Archaeological Research. Tehran. Unpublished. (In Persian)

Zare Sh. 2011. *Report on Archaeological Surveys in Mane & Samalghan County (Northern Khorasan), Second Season*. Iranian Center for Archaeological Research. Tehran. Unpublished. (In Persian)

Zhang Zh., Xiao R., Shortridge A., and 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

Zhang R., Jiang D., Zhang L., Cui Y., Li M., and Xiao L. 2014. Distribution of nutrients, heavy metals, and PAHs affected by sediment dredging in the Wuji’gang River basin flowing into Meiliang Bay of Lake Taihu. *Environmental Science and Pollution Research* 21: 2141–2153. https://doi.org/10.1007/s11356-013-2123-x

Zomorrodian M. J. 1995. *Application of natural geography in urban and rural planning*. Payam Nur Publications. Tehran.