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# Landscape change and settlement dynamics in Prehistory and Late Antiquity in the Firuzabad plain (South Fars, Iran); a preliminary consideration

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## ABSTRACT

The Firuzabad Plain in south Fars (Iran) is well known due to the circular city of Ardashir-Xurra, the first Sasanian (220 – 651 CE) capital, built by Ardashir Papakan around 220 CE, but its landscape evolution is not. Firuzabad is a relatively large and well-watered intermediate plain in the Zagros folded belt, about 80 km south of Shiraz. The archaeological record suggests a thin and sporadic prehistoric occupation compared to a dense and planned occupation with extensive land use in Later Antiquity. Historical accounts suggest a drastic and anthropogenically triggered landscape change in the third century CE, during the city's foundation, including draining the swamps and changing the course of the main river to make the supposedly uninhabitable wetlands of Firuzabad into a flourishing plain with a perfectly planned circular city.

Such large-scale projects are known from other areas as part of the early Sasanian Iranshahr concept and have been historically discussed. However, their proposed landscape change has never been investigated using interdisciplinary methods to support or falsify this narrative. Therefore, the Firuzabad Plain has been subjected to a recent interdisciplinary project to comprehend its landscape evolution from Prehistory to Late Antiquity and address this issue with geoarchaeological data.

This paper reports the preliminary results of this project and discusses future steps to address the proposed wetlands of Firuzabad. The authors present the area in geomorphological and archaeological terms and elaborate on geoarchaeological analyses, including surface and sub-surface soil and sediment texture, organic matter, slope, and elevation of the plain, as well as integrated archaeological and historical investigation. Based on these results, the landscape of Firuzabad seems to have changed from its original state of a heterogeneous, poorly drained, and highly eroded plain in Prehistory into a mosaic of well-planned and extensively used anthropogenic landscapes in Late Antiquity. Independent comparisons with regional paleoenvironmental records support those interpretations. This is considered a case study for investigating long-term human-environment interaction within the framework of Niche Construction Theory in the archaeology of the Ancient Near East.

## 1. Introduction

Ever since humans settled in landscapes, they have shaped and changed them according to their needs, in addition to just adapting to them. These interventions have subsequently triggered the landscapes' environmental responses and created new landscapes with traceable human footprints. The human-environment interaction can be studied through the niche-construction theory (Laland 2013; Odling-Smee; Feldman and Laland 2003) and comprehended by the dynamics of settlement patterns and landscape change of the Anthropocene (Crutzen

2006; Edgeworth et al. 2014). In this sense, different landscapes respond differently to the same (or similar) anthropogenic impacts. Their degree of change depends primarily on their equilibrium level, meaning steady and stable landscapes change less in response to human footprint, while delicate landscapes fall out of equilibrium more easily.

One of the most delicate landscape forms is the wetland, which is gradually disappearing globally due to anthropogenic impact. However, this phenomenon is not restricted to modern times. Strong indications exist for a broader range of wetlands being drained intentionally or as an unwanted subsequence of over-exploitation of landforms in the past.

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Many historical accounts in this regard focus on the Mesopotamian cultural sphere in current Iraq from the Early history (Pournelle 2003) to the Middle Ages (Asa Eger 2011) and recent times (Van de Noort 2013, chapter 8). Although several current Iranian wetlands have been studied for their environmental history (Brisset et al. 2019; Darvishi khatooni et al. 2019; Hamzeh et al. 2016; Jones et al. 2015), the archaeological implications of now-disappeared Iranian inland lakes and wetlands have been neglected due to lack of environmental data and otherwise rich archaeological tradition of irrigated landscapes. However, sporadic indications of similar landscape changes also exist in south Iran (Wilkinson 2003; 2012). This paper focuses on one of these areas, the Firuzabad Plain (Fig. 1).

This paper aims to present a preliminary interpretation of the landscape change in two distinctive settlement phases of the Firuzabad Plain. A number of studies have focused on this area due to its archaeological prominence (Daryaee 2010; Huff 1972; 1978; 1999; 2014; Mittertrainer 2020; Rossi 2018). However, the crucial aspect of its landscape has been missing in this regard. The present study investigates the geomorphological phenomenon of landscape change embedded in the archaeological setting of the plain, focusing on two well-known settlement phases. This combination enables a holistic overview of this plain's human-environment interaction in the Iranian Zagros highlands. It crystallizes resource management and land use differences in two different cultural phases confirming the adaptive approach of prehistoric communities compared to the enforced and centralized approach of Late Antiquity's institutional landscape planning.

This paper presents the results of the first phase of a recent interdisciplinary project on the Firuzabad Plain in South Fars. It proposes a first interpretation of the landscape change in the plain's two distinctive settlement phases, the Prehistory (Late Neolithic to Chalcolithic/ fifth to third millennium BCE) and the Late Antiquity (Early Sasanian to Early Islamic / third to eighth century CE), mainly based on remote sensing and integration of archaeological and paleoenvironmental data. The project is ongoing, and further data to examine this interpretation will be published soon.

### 1.1. Question and hypothesis

The Firuzabad Plain has received considerable attention in historical accounts due to the Early Sasanian city foundation of Ardashir-Xurra (Bosworth 1999; Daryaee 2010; Huff 2014; Le Strange and Nicholson 1921; Mashkour 1950; Miri 2009; see Table 1 for a summary of textual evidence). According to these accounts, Ardashir (Wiesehöfer 1986) drained the swamps of the previously uninhabitable Firuzabad Plain and planned his first city as an act of claiming the throne. Traces of extensive water management systems are visible throughout the plain, including a ditch surrounding the circular city, two canals (of about 15 km each) at the right angle crossing the city's center and dividing the plain into four areas, as well as a series of smaller canals, ponds, bridges, aqueducts, and qanats (see the main identified canal traces in Fig. 2).

Based on these historical accounts and known settlement patterns, the Firuzabad Plain seems different from the neighboring areas in South Fars, where other monumental urban Sasanian projects were implemented, such as Bishapur, Istakhr, and Kazerun (see Miri 2009 for these and other toponyms). A hypothetical landscape change and its consequences might explain this difference.

In this regard, several questions arise: First, has the Firuzabad Plain's landscape changed drastically in any time span of its cultural evolution, as historical sources suggest? Second, was this assumed landscape change triggered by direct anthropogenic impact? Third, has the interaction of Firuzabad's population with their landscape in different cultural periods evolved in terms of land use and resource management due to this landscape change? Fourth, are there any geoarchaeologically traceable indications of past and buried wetlands in the plain?

Based on geomorphologic and environmental data, wetlands were predominantly present in the Iranian highlands (see Djamali et al. 2018 for the Marvdasht Plains) in addition to the southwest lowland, north of the Persian Gulf (Pournelle 2003; Wilkinson 2013). However, this fact has been neglected in comprehending and analyzing spatial aspects of settlement patterns in different cultural periods. One reason might be the past century's archaeologists' ignorance of geoscience and environmental data. Unfortunately, this delicate landscape has been disappearing due to both direct anthropogenic impact and gradual climate change in recent centuries (Menotti 2012; Van de Noort 2013).

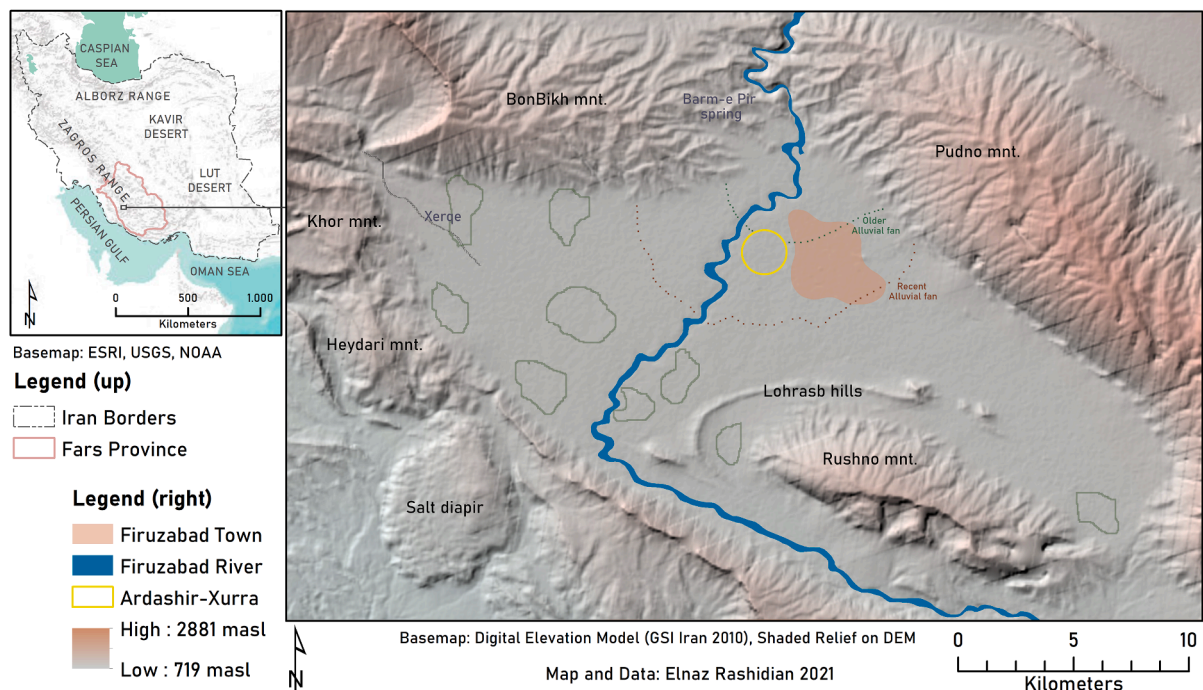


Fig. 1. The location of the study area, Firuzabad Plain, showing the river and the circular city of Ardashir-Xurra (illustrated by the corresponding author).



**Table 1**  
List of essential historical and textual data sources for this study.

Source	Type	Description	Relative date
Karnamak	Primary	Middle Persian prose on Ardashir	Sixth century CE
Tabari V	Primary	Volume five of Arabian text "Tarikh-al Rasul val moluk" by Jarir Tabari	Ninth century CE
Istakhri	Primary	Arabian text "Masālek wa'l-mamālek" by Ibrahim Istakhri, the earliest surviving source of descriptive geography of the Islamic world	Tenth century CE
Ibn-e Balkhi	Primary	Arabian text, historical geography of the Fars region, "Farsnama" by Ibn Balkhi, a traveler and geographer	Twelfth century CE
Le Strange	Secondary	English text of "The Lands of the Eastern Caliphate" by orientalist Le Strange based on older textual evidence	Nineteenth century CE
Miri	Secondary	A summarized work on "Historical geography of Sasanian Fars" based on older evidence	Recent
Huff	Secondary	Published and unpublished archaeological reports and interpretations from the 1970 s to 2000 s, by German archaeologist D. Huff (DAI)	Recent
Herzfeld	Secondary	Unpublished drawings and notes by E. Herzfeld from his visit in the 1920 s, available via the Smithsonian Institution	Recent
Nippa	Secondary	Unpublished pottery analysis of a 1970 s survey with the material culture of 24 sites, most of them lost today, by A. Nippa (DAI, Univ. Göttingen)	Recent
Askari, et al.	Secondary	Unpublished internal reports as a maintaining measure of the UNESCO status of the plain, containing new data and geodata	Recent
Norouzi	Secondary	Survey report from 2005, Published in Persian	Recent

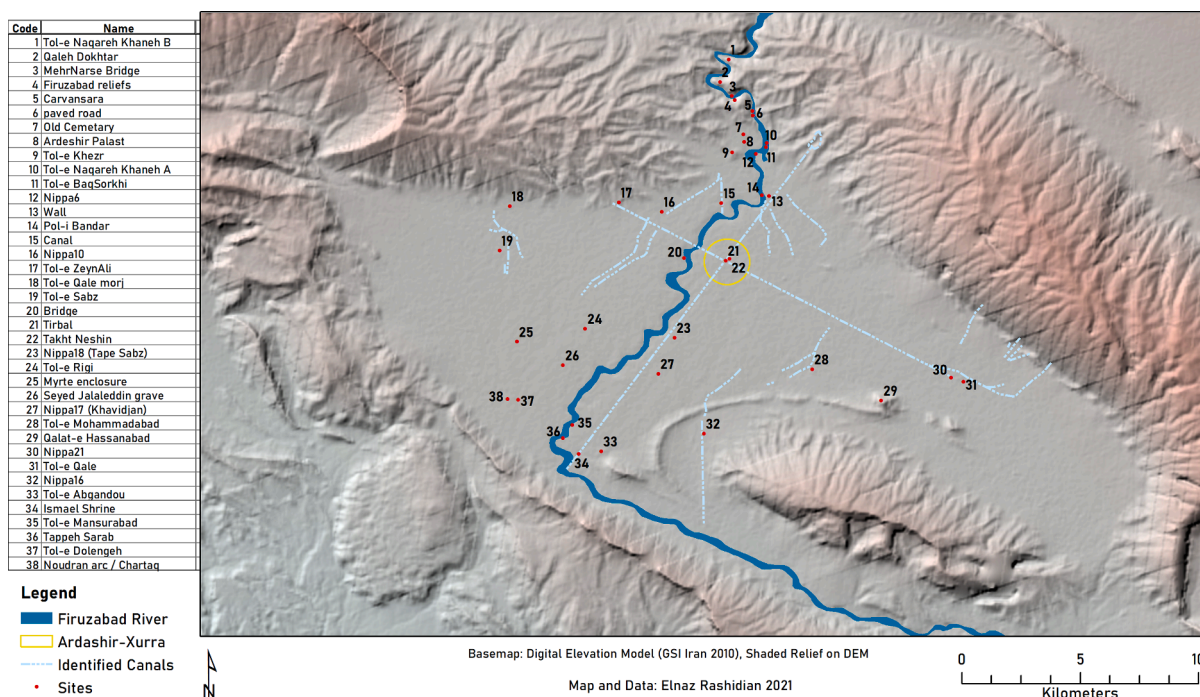
Therefore, it is all the more necessary to study their archaeological implications prior to their complete disappearance.

Playa lakes and freshwater wetlands are rare landscapes in current Iranian highlands. However, the situation might have been entirely different in the past. Relicts of such landscapes are still present in neighboring plains such as Darab, Sarvestan, Farashband, and Bachun. Interestingly, all these areas were subject to large-scale Sasanian urban planning with hydraulic engineering reshaping their landscape. One recent study showed the extent of spring wetlands in the last millennia in the karstic landscape of Persepolis about 100 km to the north of the Firuzabad Plain (Djamali et al. 2018). Here, the authors suggest that the Firuzabad Plain in its lower part was initially dominated by wetlands and, therefore, attractive for prehistoric communities, who considered this resource-rich landscape a blessing. The small Late Neolithic and Chalcolithic communities had access to sufficient land for diverse exploitation, including hunting, gardening, and husbandry. Therefore, they lived and adapted according to the available landscape features.

On the other hand, the Early Sasanian community had to reshape the entire landscape to establish an institutional landscape in the otherwise sporadically populated plain for purely political reasons. For them, the wetlands were not a blessing but a curse, getting in the way of their ideologically planned urban concepts. This tendency becomes evident in the narrative of Ardashir preparing the plain for his urban plan, cited by later historical accounts (Afshar 1961; Le Strange and Nicholson 1921; Mashkour 1950). The authors took an interdisciplinary approach to address these questions and examine the hypothesis via various materials and methods.

In light of landscape change, the possible evolution of land use is of importance. The authors suggest an evolution of land-use practices from small-scale irrigated parcels in the Prehistory to large-scale planned "paradise" gardens with systematic irrigation in Late Antiquity in the Firuzabad Plain. They assume that Sasanian paradises were the most dominant anthropologic landscape beside the cropland in the Firuzabad Plain of Late Antiquity, based on historical reports and extensive traces of irrigation systems in the plain (see Table 1 for sources).

The concept of artificial paradises, e.g., planned gardens, is known from the Early history of the Ancient Near East with prominent examples from Babylonia, Assyria, and Achaemenian capitals (Gondet et al. 2021;



**Fig. 2.** The Archaeological setting of the Firuzabad Plain (illustrated by the corresponding author).



Novák 2002). Since then, the Iranian paradise has been an integral part of monumental Iranian architecture and later evolved into the elaborate “charbaq” of Islamic tradition in the Middle Ages. The vast Sasanian gardens in Firuzabad were mentioned in historical accounts (Afshar 1961, 110-111; Le Strange and Nicholson 1921, 137-138; Mashkour 1950, 18). This element is not limited to the Firuzabad Plain; its conceptual aspects have been discussed (Canepa 2017), and other examples are known (Pope 1933).

## 1.2. Study area

This study focuses on Firuzabad, a relatively large plain of about 430 sq km in south Iran, in the Fars province (Fig. 1), about 80 km south of Shiraz. The Firuzabad Plain is part of the Zagros folded belt, lies on an active transverse structure, and belongs to the central Zagros region (Falcon 1974). The plain is surrounded by mountains from the Asmari formation, dating back to the Miocene era (Fisher 1968; National Iranian Oil Company 1977).

The plain is surrounded by hills of different elevations, Pudno in the north, Rushno in the east, Salbaki in the south, Heydari in the southwest, Khor in the west, and Bonbikh in the northwest. The plain’s eastern part is divided into north and south by the Lohrasb semi-round hill separating a small plain from the main plain between the Lohrasb and Rushno hills. These two hills belong to different geological formations, Lohrasb to the Aghajari and the rest of the hills surrounding the Firuzabad Plain to the Asmari formation (see Fig. 1 for locations). The oldest geological feature in this area is the salt diapir at the southern border of the plain, with xenoliths dating to Precambrian to Cambrian era (National Iranian Oil Company 1977).

The Firuzabad Plain is accessible via the northern Tangab gorge and the southeastern Lohrasb pass. It has a very gentle average slope (0.6 %) from the north towards the south and southeast. The plain is considered semi-arid, with mild winters and hot summers. The annual temperature average has been 20 °C in the last decade, with August being the hottest month on average 31 °C and December being the coldest at 9 °C. Zero temperatures were reached a few times in the last decade but are not the norm in the Firuzabad Plain (Iranian Meteorological Organization 2020). The annual mean precipitation is currently at 400 mm, which falls in the wet and cold seasons, mainly between December and February. The area is presently under intensive agricultural land use, irrigated via a perennial river and underground water sources (Mokhtara and Aram 2017).

The Firuzabad River (Fig. 1) is a meandering one with an average sinuosity of 1.6 (see section 2 for the calculation). Its sources lay north of the plain, in the Salamati and Delow mountains. The river starts there as Hunifan and continues southward into the Tangab gorge as the Tangab river. It enters the plains as the Firuzabad/Buraza River in an incised bed from north-northwest to south-southeast of the plain for about 15 km, then turning to the east and following the southern Lohrasb gorge for about 16 km, leaving the plain from the southeastern gorge, connecting to the Shur Nahr. It then joins Dasht-Palang River, and another stream known as Shur; from there, it is called the Shur-e Dehram River (Jafari 2001, 304). Currently, the riverbed is about 15 m lower than the surrounding floodplain in Firuzabad.

In terms of geomorphology, the Firuzabad River seems to have built at least two distinctive alluvial fans in the Holocene era (see Fig. 1 for location). Note bene that the extent of these fans has been estimated based on existing geomorphological maps and older satellite imagery and shall not be considered accurate in terms of exact measurements. Detailed stratified sampling survey is required to determine the extent and distribution of these two features.

The hydrological regime of this river seems to be unstable at times. Stein (1936) reports a massive flood in the year 1934 on the plain. On the other hand, Google Imagery from recent years (November 2016, December 2018, and September 2019) shows a mostly dry riverbed, even in the rainy season. Recent flash floods in the entire south regions

of Iran have also affected the Firuzabad Plain’s northern part on two different occasions (Spring and Winter 2020) and eroded vast areas of the pediment due to strong precipitation. These heavy flash floods transported an immense volume of sediment from the northern slopes towards the southern part, covering entire agricultural areas with mud.

In terms of sediment series, the Firuzabad River divides the plain into an eastern and western part, both cultivated and affected by their elevation. The western part consists of low-level fans of Pleistocene age on the hillslopes, and unconsolidated piedmont deposits, consisting of gravel with accessory silt, clay, and sand of Holocene age. The eastern part consists of high-level fans, including boulder, gravel, sand, and silt on the hillslopes of Pleistocene age, and floodplain deposits, consisting of clay, sand, and silt of Holocene age (National Iranian Oil Company 1977). These differences in sediment series affect the topsoil texture and shape the possible landscape responses to temperature and moisture variations.

The Firuzabad River has never been the sole water source of the Firuzabad Plain if one considers other available forms of water supply (qanats, cisterns, and springs). A seasonal river named Xerqe (Kherqe) (see location in Fig. 1) brings run-off and snowmelt water from the western hillsides into the plain, irrigates a straight canal and vast gardens in the west, and joins the Firuzabad River at the plain’s most southern part. An incised seasonal stream, Lahanjir, brings run-off and floodwater from the eastern Rushno hills at the Lohrasb gorge into the northeastern part of the plain. Three main springs are known in the plain, Barm-e Pir (Ardashir) at the northwestern hills in front of the Early Sasanian Ardashir Palace (see location in Fig. 1), Par-e Baqe Kohak at the southern end of the plain, and Khadonbeh on the northeastern hills. On the hills outside of the plain, at least seven springs are known (according to the National Cartographic Center) with considerable water volume, which bring water into the edges of the plain in the eastern and western parts. In summary, the plain can be considered well-watered, although it is located in the semi-arid climate area of central Zagros.

A number of other smaller springs are known throughout the plain, mostly of karstic nature. One recent study focused on the landscape manipulation of the Barm-e Pir spring-fed pond in front of the Ardashir Palast in the plain’s northwest Hills (Djamali, Rashidian, et al. 2021). Based on the sedimentology of seven cores and 57 C<sub>14</sub> dated samples, the physical evolution of this pond was reconstructed. The study has shown that a wetland existed at the outlet of this spring at least since 4500 BP. An anthropogenic impact corresponding to the foundation of the Ardashir-Xurra and the building of the Palast was evident from the samples. Furthermore, the data suggested a revival of natural sedimentation after the Sasanian era, corresponding to the abandonment of the Palast as a royal residence (see Figs. 6 and 7 in Djamali, Rashidian, et al. 2021). This very example shows the existence of wetlands as an initial landform in the Firuzabad Plain and their anthropogenic manipulation during Late Antiquity. However, their distribution and their spatial relation with the settlements in the plain must be studied further. This paper aims to explore this question.

## 2. Materials and methods

Different data sources were documented and compiled into an interactive geodatabase for further analysis (the planned stratified sampling survey for obtaining soil profiles and dating samples from different depths in the selected hotspots was halted due to the pandemic and will commence soon. Results of this step will be reported in the near future). Geodata on landscape features, soil formation processes, and sediment regime of the hydraulic features was produced using available remote sensing data and recently produced drone imagery (Table 1). Historical and archaeological data were extracted from different available sources and complemented during the project. In this process, a number of previously unknown data sources were obtained and georeferenced for further use (Table 2). Additionally, recent secondary

publications were considered to comprehend the current landscape of the study area and draw comparisons with historical sources.

### 2.1. Historical and textual evidence

The plain's landscape and its intentional hydrological change have been mentioned in the historical accounts and textual evidence (Table 1). One of the most crucial sources is Karnamak, a prose in Middle Persian concerning the life of Ardashir Papakan, the founder of the Sasanian dynasty, where the foundation of the Ardashir-Xurra city in an otherwise marshy area is explained as a heroic act. This work is dated to the sixth century CE based on its linguistic elements but relies on older versions of the same story based on its mythological character (Mashkour 1950, 18; Nöldeke 1879).

The royal act aspect of Ardashir's city foundation has been reported in detail in Tabari's prominent universal history of the Middle Ages in the ninth century CE (Bosworth 1999). The same story has been reported by Istakhri, a tenth-century geographer, who mentions the ruins of the Sasanian city alongside a detailed hydraulic plan to drain the Firuzabad swamps and enable an urban center as the first Sasanian capital (Afshar 1961, 110-111). A geographical history of the Fars region in the twelfth century CE, named Farsnama, details the story of draining the Firuzabad marshes in the course of building the Ardashir-Xurra city. Ibn-e Balkhi

**Table 2**  
A list of geodata used in this study.

Type	Description	Source	Availability
Raster & vector data	Geomorphologic base maps of the area on 30 m resolution	Geographical Survey of Iran (GSI)	Purchased
Satellite imagery	LandSat 7 1999 to 2013 and SPOT 1989 (30 m resolution)	United States Geological Survey (USGS)	Free
Satellite imagery	VHR imagery (December 2018), multispectral 8-band <i>ortho-ready</i> TIFF	MAXAAR	Purchased
Orthophoto	High-resolution drone imagery on selected hotspots (Winter and Spring 2021)	Project	Produced
Raster data	Estimated soil classes on different depths based on ISRIC (World Soil Information) on 250 m resolution	SoilGrids	Free
Raster data	Estimated rock-type, relief, land cover, and wetness index based on processed imagery on 250 m resolution	OpenLandMap	Free
Vector data	Known sites of different (un)published sources and recently (2018–2021) recovered traces of settlements	Project	Produced
Vector data	Georeferenced and digitalized visible traces of landscape/ anthropogenic features based on imagery, older drawings, and analog maps (watercourses, qanats, canals, sinks, routes, outcrops, etc.)	Project	Produced
Imagery	Documented soil profiles on selected hotspots	Project	Produced
Imagery	Notes and drawings of an archaeological survey from the 1970 s (D. Huff, A. Nippa)	German Archaeological Institute (DAI) Tehran Archive	Free (with permission)
Imagery	Notes, drawings, and reports from British intelligence	Qatar Digital Library (QDL)	Free

mentions the heroic plan of Ardashir's genius engineer to dig a tunnel through the blocked river channel, turn the river to its rightful place and restore the hydraulic balance of the plain (Le Strange and Nicholson 1921, 137-151). This tunnel could be the one still active in the south-eastern part of the plain, connecting the geologically separated Lohrasb plain (see location in Fig. 1) to the main Firuzabad Plain.

These elements were still known and reported by nineteenth-century orientalist such as Le Strange, who mentions two interesting points based on older texts: first, the myth of an older Achaemenian city in the Firuzabad Plain destroyed by Alexander of Macedonia via turning the river to flood the plain; and second, the story of Ardashir's genius engineer resolving this issue and draining the plain to make it habitable again (Le Strange 1905, 256).

Other secondary evidence contains reports on the later evolution of the plain's settlement history during the Late Antiquity (Miri 2009). The extracted data from these textual accounts was implemented into the ArcGIS geodatabase to elaborate on the patterns and anomalies otherwise lost.

### 2.2. Geodata collection

In this study, geodata was both obtained and produced to elaborate on the essential characteristics of the study area. A geodata collection (Table 2) was established in the project to further implement the geodatabase in the GIS environment.

The mentioned geodata was combined and refined by various preliminary analyses to prepare them for spatial analysis. Georeferencing analog material was time-consuming but proved helpful as it provided otherwise lost data. The different resolutions of available data on the plain's soil and elevation had to adapt to enable a high-quality spatial analysis of data from different sources. Therefore, the most used geodata resolution is between 100,000 and 250,000. Obviously, higher resolution data is desired for final analysis and is in planning.

As the next step, a series of spatial analyses were conducted via ArcGIS (standard desktop version 10.6) to extract patterns of available landscape features and their gradual or drastic evolution in the study area. They were interpreted by adding the known settlements of each phase to extract possible spatial patterns. This step elaborated on the mentioned correlation between geomorphologic and archaeological data. In this process, nine areas were identified (see green outlines in Fig. 1), which could bear traces of buried wetlands. These were then documented in orthophotos in detail for further analysis and sampling via a drone (technical elements: drone model Phantom4 pro v2 (DJI); GPS receiver model TS02 (Leica); camera model D750E (Canon) with a 85 mm lens).

Three datasets were chosen to study the landscape in its elemental characteristics based on their implications for the existence of wetlands according to the main aim of this paper, discussed in section 4. "Slope" and "elevation" are two known elements driving the landscape evolution, especially due to their impact on the degree of erosion. This has been discussed in length for its role in site formation process in Archaeology (for example in Wilkinson 2003). These two factors contribute significantly to the emergence and evolution of wetlands, especially in semi-arid areas (Menotti 2012). Often, relief is considered an indicator for landscape evolution. Here, we use the term elevation, because it includes both the relative height difference between two locations in the landscape (relief) and the absolute height of a location in accordance with the mean sea level.

The third one is the "bulk density" for its implications of structural change in soils and the subsurface water flow (see Vepraskas and Craft 2016, 75, 175–176 for a discussion). The degree of bulk density directly relates to the mineral/organic ratio of the soil (Vepraskas and Craft 2016, 232), thus is useful as an indirect measurement for the organic matter in subsurface soils. This factor is crucial in recognizing areas with potential buried wetland soil in landscapes.

### 2.3. Other materials

Secondary literature on the plain and its settlement history, as well as current characteristics, were also considered. One consists of a recent archaeological reconnaissance project, identifying 16 mound-sites, 13 ponds and water cisterns, 9 forts, 9 caravanserais, 2 bathhouses, 7 bridges, 7 shrines, 4 chartaqs, 1 mosque, 3 rock-reliefs, 1 ossuary, 5 watermills, 3 palaces, 3 site-complexes, and 3 towers in the entire plain and surrounding hills. Most of them belong to the Late Antiquity cultural phase (Norouzi 2005). Although not sophisticated, this survey provides more details on a number of less-known sites and structures in the plain and helps fill the gaps on the archaeological map and avoid misinterpretation.

Hydrological features were also investigated using geodata. For example, the River Sinuosity has been estimated at different locations to determine the possible nature of the channel. Sinuosity is the ratio of channel length to down valley length. In this case, for the upper part of the Firuzabad River, the valley length is about 15 km, and the actual channel length is about 25 km, resulting in a sinuosity of 1.6. Generally, any watercourse with a sinuosity larger than 1.5 is considered meandering.

Furthermore, the location of villages and geomorphologic (and hydrologic) elements, such as springs, were ascertained based on GSI databases and analog maps of the area. The location of the archaeologically known settlements was of utmost importance in this regard. Most of the documented sites have fallen victim to the recent land use intensification of the plain, and therefore extremely important to be added to this database for a complete settlement pattern of different phases.

### 3. The archaeological setting of firuzabad

The Firuzabad Plain was occupied in different periods with different intensities (Fig. 2). Based on available data, the plain's past settlement history can be categorized into two distinct cultural phases, here called Prehistory and Late Antiquity, for the sake of simplification. In this paper, Prehistory includes the Late Neolithic, Chalcolithic, and Early Bronze Age (from the fifth to third millennium BCE). The Late Antiquity consists of the Early Sasanian to Early Islamic period (from the third to the eighth century CE). The Firuzabad Plain seems to have the most intensive occupation in these two phases, excluding the modern occupation of the plain, which is the most intensive one, but not a subject of this archaeological study. Therefore, it seems reasonable to examine the plain's landscape and settlement dynamics in these two phases and compare them in terms of changes and patterns.

There are no known Paleolithic traces in the plain and its environs. This might be due to the lack of systematic surveys in the region, for the foothills are suitable for such occupations as known in the neighboring areas (Conard et al. 2013, 35, 41–44).

The earliest known traces of human occupation in the Firuzabad Plain belong to the Neolithic period at a mound named Tol-e Sabz, west of the plain (see no. 19 in Fig. 2). It was briefly mentioned in the 1930 s (Stein 1936, 129) but recently documented as a prehistoric site based on surface pottery. The site is currently about 4 m high and approximately 1.8 ha in size. The published surface pottery and the chert blades, among other tools, belong to the late seventh and early sixth millennia BCE, similar to the material culture from Qasr-e Ahmad, Tol-e Bashi, Nurabad, and Jari in Fars (Mansouri and Ahmady 2015).

Other sites with prehistoric occupation are known in the area. The Chalcolithic period is known from the site named Tol-e Rigi (Kamalabad) (see no. 24 in Fig. 2), first visited and examined in the 1930 s (Stein 1936, 121). Other than pottery and stone tools, a significant structure of poorly burned bricks has been found during the brief sounding and was interpreted as a drain for run-off water. Traces of similar walls and burials were also reported (Stein 1936, 127–129). It could alternatively be part of a building. This mound also lies in the west part of the plain. It

is elevated about 4 m from the environs. According to a study of this site's pottery (Sumner 1994), it consists of the phases Bakun (Early Chalcolithic) to Lapui/Banesh (Late Chalcolithic to Early Bronze Age). Based on discovered stamp seals and tokens from the Bakun period in Rigi, some assume that this settlement could have been an administrative center for trade between the highlands and lowlands of Fars or between pastoral and sedentary communities in the area (Alizadeh 2006, 33 and 97).

There are currently no visible traces of any settlement from the Achaemenian period in the Firuzabad Plain. However, a platform of dark polished stone in the tradition of Parseh and a typical round and smooth column base of dark stone, similar to the ones found in Borazjan's Achaemenian palaces (Zehbari 2020), have been reported near one of the recent shrines inside the circular Sasanian city (Sami 1960, 160–161), which could indicate an earlier structure before the Sasanian city foundation. Their location approximate to the Sasanian temple may bear an earlier religious building at this place. A dark stone fluted column fragment in Achaemenian tradition *in situ* has also been reported in the 1920 s. A drawing with measurements of such a column is conducted by E. Herzfeld, the original drawing is the courtesy of the Freer Gallery of Art and Arthur M. Sackler Gallery Archives in Smithsonian Institute (identification code: FSA.A.06, Item FSA A.06 05.1202). According to this drawing, the column is 65 cm in diameter and of dark stone. This has not been published anywhere, to the authors' best knowledge. Until the 1970 s, some structural remains, such as columns, existed on the surface. This is supported by the existence of one photograph by W. Kleiss from 1972, archived in the German Archaeological Institute (item: D-DAI-EUR-TEH-DIA-AWK-11511), showing a piece of white stone fluted column remarkably similar to the Achaemenian items known from Parseh. He does not mention any of this in his published works, to the authors' best knowledge.

Unfortunately, these traces have been lost in the last decades, so that a reconnaissance of this presumed Achaemenian structure at the heart of the Sasanian city seems impossible. However, elements of Achaemenian tradition are traceable in the innovative architecture of Ardashir-Xurra (Canepa 2018, 573). An earlier settlement of some kind with less importance possibly existed on the northern part of the plain during the Achaemenian period, which might explain the myth of its destruction by Alexander, reported by Ibn-e Balkhi (Le Strange and Nicholson 1921, 137), among others.

Post-Achaemenian and Arsacid (Parthian) settlements (third century BCE to third century CE) and material culture are completely absent in the plain at the current state of research. Some scattered pottery from Tol-e Khezr (see no. 9 in Fig. 2) might date to pre-Sasanian periods (Huff 1974, 157), but they are not diagnostic, so this remains highly speculative (based on personal communication with A. Askari-Chavrdi, 2020). Therefore, nothing can be stated regarding this historical phase in Firuzabad. If one accepts the reports of already mentioned historical accounts (see section 2.1), the whole plain must have been a marshy and uninhabitable area prior to the arrival of Ardashir in the Early third century CE.

The most prominent archaeological traces in the area belong to the circular city of Ardashir-Xurra (later Gur and Firuzabad), the first capital of the Sasanian era, founded by Ardashir Papakan around 220CE (Mousavi and Daryaei 2012, 1079). The city itself is planned as a circle with about 2 km diameter and four main (north–south and east–west) axes (with a 20° shift to the east) leading to four main gates, and three concentric walled circles, resulting in twenty distinct radial sections, probably serving as city neighborhoods (see schematic plan in Huff 2014, 158; see the main axes as identified Sasanian canal traces in Fig. 2).

Inside the city's inner circle, ruins of a 30 m high tower with a 9 m square base stand, called Tirbal (Minar) or Ivan-i Gird (see no. 21 in Fig. 2). Its original form has been a matter of much dispute (Huff 1969/70), but it seems to contain external stairs spiraling around the cubic shape of the main body. This architectural element has been interpreted



as functional and ideological, the former regarding the implementing the concentric urban plan in the plain, and the latter as a symbol for the ruler's centralized power (Canepa 2018, 127).

The other remaining structure in the city's inner circle is most probably a prominent fire temple, currently known as Takht-i Nishin (see no. 22 in Fig. 2). The building was initially mistaken as a Chartaqi but seems to be a four-Ivan 27 m square base structure with a 14 m-diameter brick dome (Huff 1972). In the east and south of this large building with smooth-cut stones, two ponds (or cisterns) seem to be located (see locations in Huff 1972, 518), which might support its function as a public religious building. Early visitors have reported these two water basins or ponds in the nineteenth century (Wilson 1916, 165).

Outside of the city, two prominent palaces exist; one in the northern

Tangab gorge, the so-called Qal-e Dokhtar palace-fortress (Huff 1978; 2006) as the very first Early Sasanian known building (see no. 2 in Fig. 2), and another on the city's nearby western hills overlooking the plain, the Ardashir Palace (see no. 8 in Fig. 2) with an impressive three-domed architecture (Huff 1999) and an integrated circular pond as the prototype of the later architectural standard elements including Ivan and semi-domes (Canepa 2018). The nature of this pond was subject to detailed geoarchaeological investigation. The results are recently published elsewhere (Djamali, Rashidian, et al. 2021).

Recently, another well-preserved circular pond with probable palatial architecture has been uncovered in the current village of Dehbarm (Rashidian and Askari-Chaverdi 2022) near the existing ruins of a satellite settlement (see no. 16 in Fig. 2). This pond is similar in

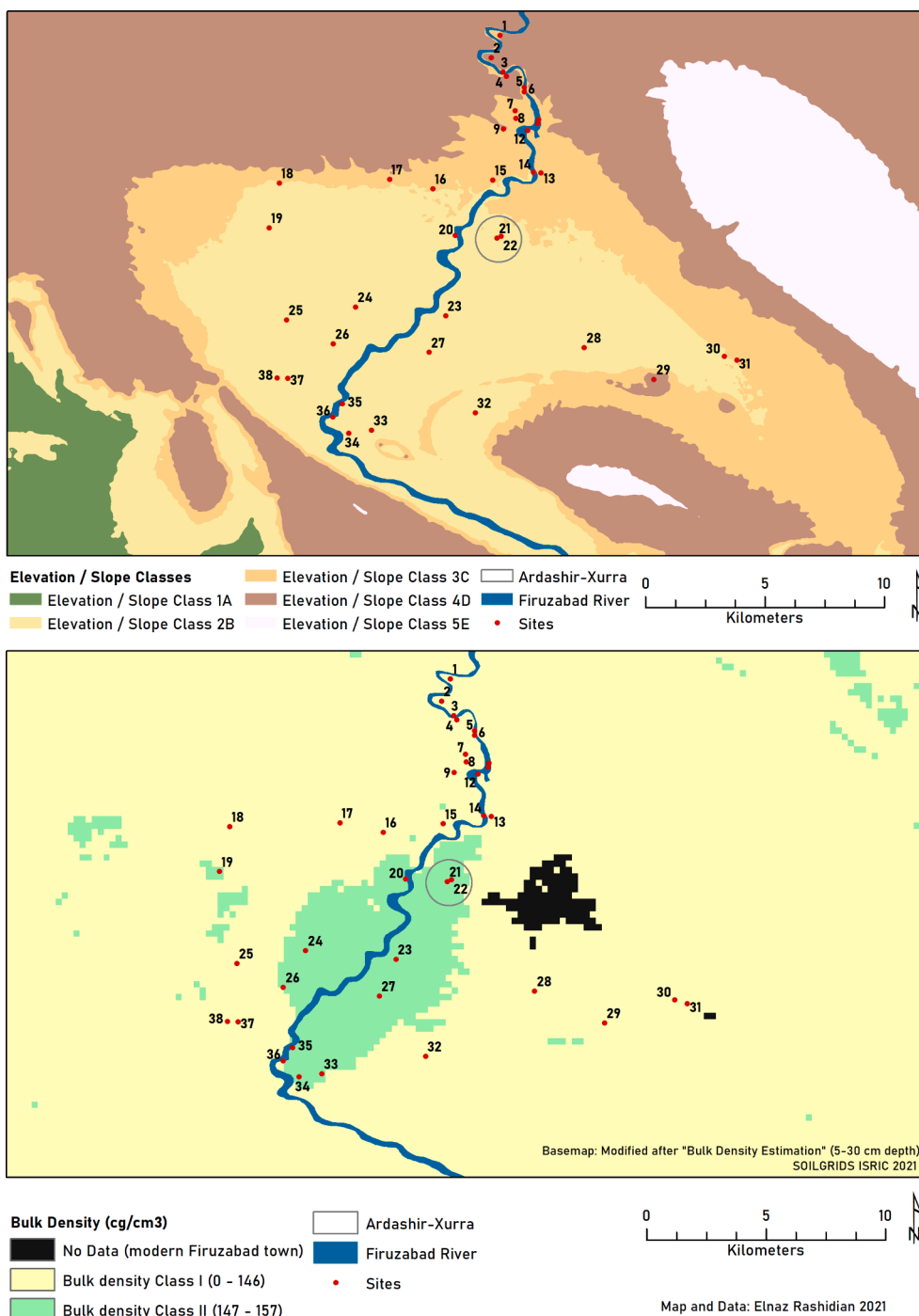


Fig. 3. The Firuzabad Landscape in geomorphologic terms (see section 7 for classes and analysis) (illustrated by the corresponding author).

construction technique and spatial integration into the whole large-scale plan of Ardashir-Xurra. Further excavation is planned to explore its immediate surroundings. However, the stone masonry structure and the unearthed material culture *in situ* indicate an early Sasanian chronology (Rashidian and Askari-Chaverdi 2022, Fig. 2).

Further extensive traces of the Early Sasanian urban planning are evident throughout the plain (Huff 1972; 1974; 1999; 2008; 2014; Mittertrainer 2020; Mostafavi 1964, 98-104; Norouzi 2005; Rossi 2018). They include satellite settlements (chartaqs/temples, villages and cemeteries, fortifications, caravanserais), hydraulic works (qanats, canals, cisterns, ponds, tunnels), and infrastructure (routes, ways, bridges, dams, defensive walls), among other forms (Fig. 2).

The Firuzabad Plain flourished as a productive agricultural center in the Early Islamic era with additional urban planning such as forts (Qale Pesar in the Tangab gorge, Qale Sohrab (or Sahara) and star-shaped Toll-e Qale in east), holy shrines (two Imamzadeh shrines in the inner city, Kherqeh and Qadamgah-e Khezr in west) and routes (see locations in Fig. 2), especially during the Buyid period where the former name Gur was officially changed into “Firuzabad” (Huff 1999; Le Strange 1905, 255-256; Nagel 1990) and became a prominent production center for rose water and pomegranate. The downfall of the Siraf port in the twelfth century CE probably led to the decline of Firuzabad (Brunner 1983, 751; Rossi 2018). Nevertheless, the road from Shiraz to Bushehr port at the Persian Gulf coast has crossed Firuzabad Plain ever since and remained a crucial area for trade, even bearing regular conflicts in the nineteenth and twentieth centuries (Wilson 1916, 28-30).

Based on the mentioned archaeological setting, two prominent occupational phases are identified on this plain, the Prehistory (Late Neolithic to Chalcolithic/ fifth to third millennium BCE) and the Late Antiquity (Early Sasanian to Early Islamic / third to eighth century CE). With this summary of the available archaeological record, the present study’s hypothesis can be examined via geoarchaeological methods.

#### 4. Analysis and results

At first stance, the Firuzabad Plain seems to be mostly homogeneous. A detailed look at its landscape (Fig. 3) shows another picture based on three crucial geomorphologic factors: slope, elevation, and bulk density.

Based on this analysis, the plain can be divided into two distinctly different areas in geomorphologic terms: the upper part a with a steep slope and higher elevation, and the lower part, including the west and southwest of the plain with less slope and lower elevation. The former is directly influenced by the erosion of foothills and the fluvial regime of the main perennial river, with an incised bed entering the plain from its narrow gorge in the north. The latter has a less dynamic sediment regime, shaped by high groundwater table and gradually decreasing slope, as well as the slow flow of the downstream shallow riverbed. Both areas are intensively affected by current land use.

The archaeologically known settlements are distributed all over the plain. By categorizing the settlements into their occupational periods (Fig. 4), a pattern becomes clear regarding the settlements from the two mentioned categories. While the prehistoric settlements are found in the (south)western part of the plain, the main settlements of Late Antiquity are found in the upper part of the plain, with satellite settlements stretching alongside arranged lines of water management throughout the south and east of the plain.

By comparing these two analyses, a correlation seemed highly likely. This correlation was further examined by analyzing a series of landscape and geodata, including the fluvial sediment regime, soil classes, and sub-surface sediment texture. These are shown in the following.

One crucial geo factor of the plain is the Firuzabad River (Table 3), a perennial watercourse with an incised and meandering bed, which enters the plain from a narrow gorge in the north and flows in the south direction through the landscape. At the south end of the plain, the river turns to the southeast and exits the plain through another narrow pass to join the Shur river just outside of the plain and change direction anew.

Inside the plain, the Firuzabad River consists of two distinct parts: the part crossing the plain in the south direction and the one flowing in the narrow southern pass towards the southeast. The first part is of utmost importance regarding the fluvial sediment regime of the plain. A series of profile sections (Fig. 5) were studied to analyze the fluvial sediments and their impact on the landscape. Profile AB sections alongside the river channel and shows the slope and its decrees from north to southwest. Profiles CD and EF are cross-sections of the riverbed for a detailed analysis of the fluvial sedimentation and its slope. These profiles were chosen due to available data and in a buffer zone of the

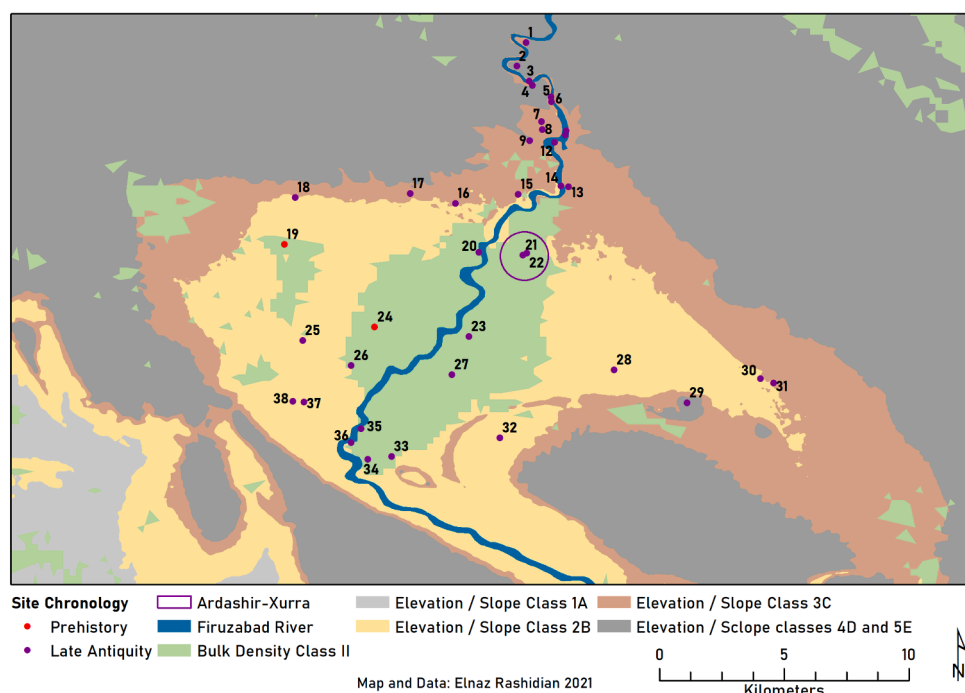


Fig. 4. The archaeologically known sites in the Firuzabad Plain based on classes from Fig. 3 (see section 7 for classes and analysis).

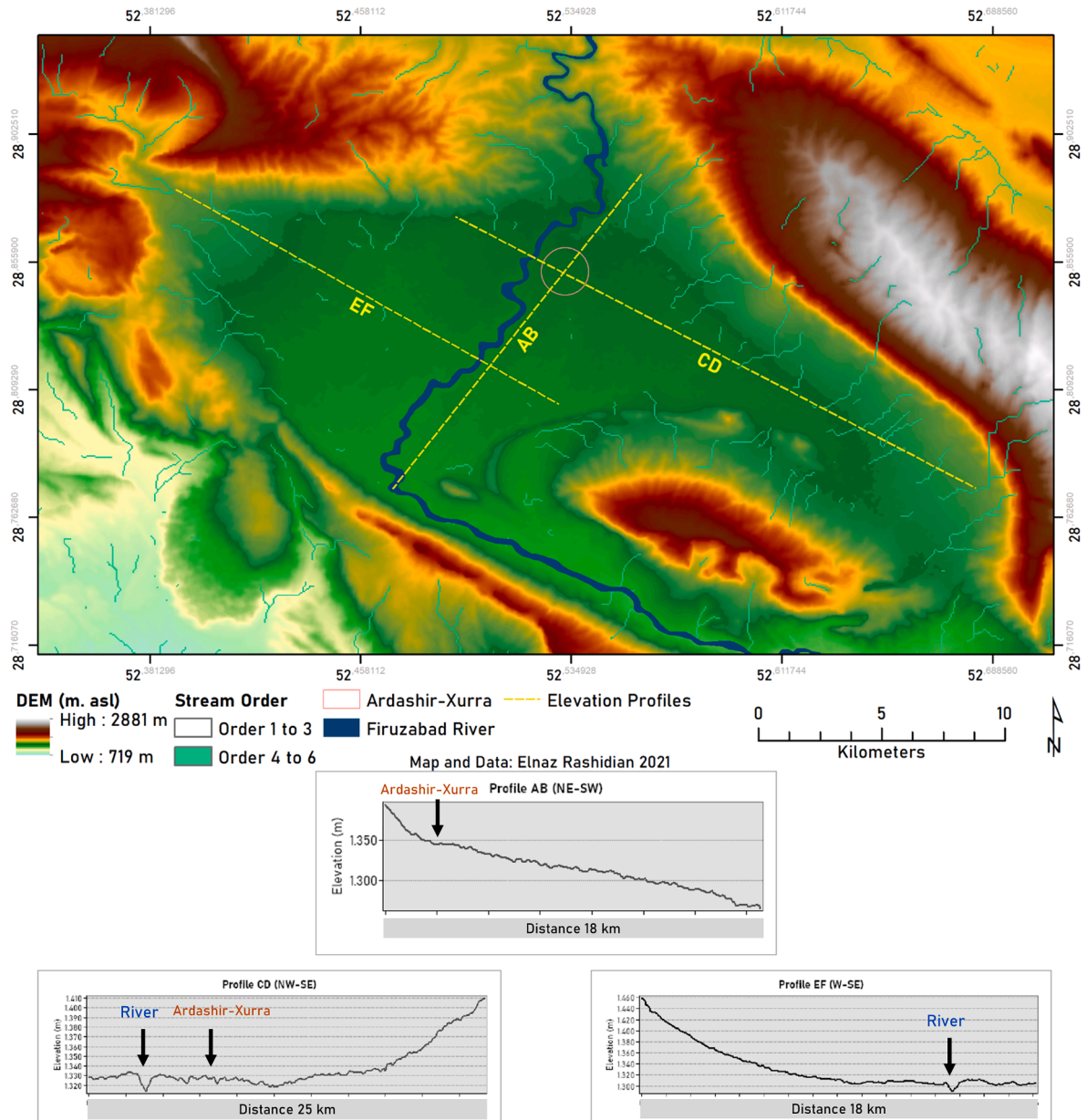


Fig. 5. Profile sections across the main flow of the Firuzabad River and the extent of estimated seasonal and run-off flows (see section 7 for classes and analysis) (illustrated by corresponding author).

main river channel.

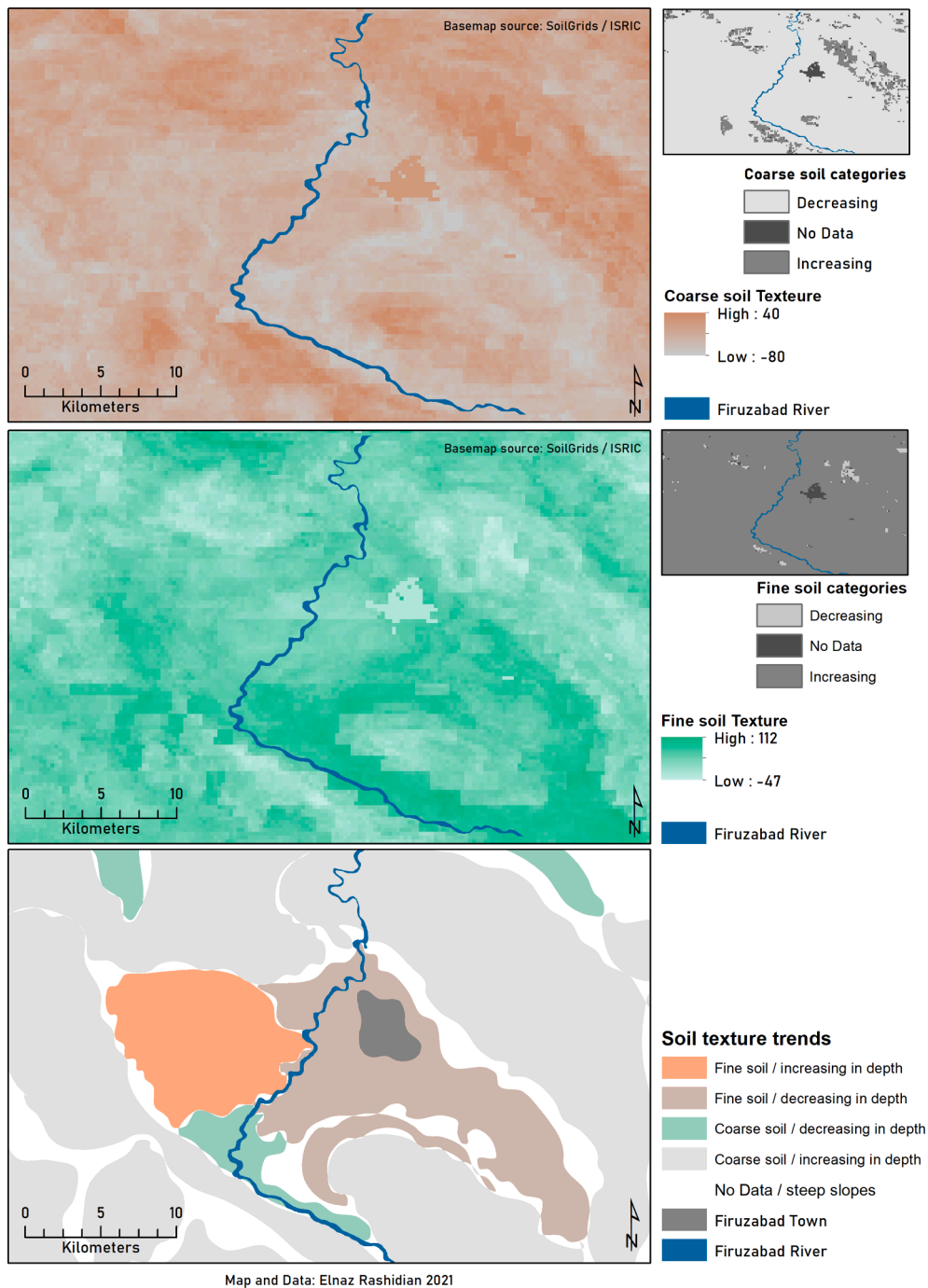
As shown here (Fig. 5), the AB section stretches from the northeast to the southwest. The marked data shows the profile crossing the circular city. Furthermore, the CD section shows the elevation from the northwest to the southeast of the plain, crossing the city at the marked point. The profile of the river is visible in the west. The EF section stretches parallel to the CD section at the southern part of the plain. The profile of the river as well as small streams, is visible in this section. These analyses illustrate the extent of the fluvial impact on the upper and lower parts of the plain and further correlate with the mentioned two-part geomorphology of the plain.

In the absence of detailed geodata regarding the fluvial regime of the Firuzabad River, the mentioned analyses contribute to our understanding of its sediment regime. In addition to its annual volume, the river's discharge is directly affected by the seasonal water availability of the surrounding anticlines. This must be considered in analyzing the sediment freight of the river.

Besides the Firuzabad River, a series of seasonal watercourses are available on the plain. These are affected by both surface water available during the wet season, including snowmelt, run-off, and stream flood, and karstic springs with strikingly high volume (see their flows in Fig. 5 as stream order). The former affects the pediment areas of the anticlines to the north and west of the plain, and the latter is concentrated on the northwest and west of the plain. One prominent spring is the one integrated into the Early Sasanian Palace of Ardashir at the northwest edge of the plain, which contributes to the water availability of Firuzabad by a perennial outlet flowing towards the river. This water source was intentionally modified during the construction of the Early Sasanian Place and evolved into a spring-fed pond for the palatial gardens. There is strong evidence that the area surrounding the spring was a seasonal wetland with a regular sediment regime prior to this anthropogenic change (Djamali, Rashidian, et al. 2021).

Heavy stream- and flash floods are common in the Firuzabad Plain and regularly occur in the wet season (November to March). Their





Map and Data: Elnaz Rashidian 2021

**Fig. 6.** Trends in soil texture in the Firuzabad Plain on the surface and two depths (see section 7 for classes and analysis) (illustrated by the corresponding author).

intensity is directly affected by the annual precipitation and the current wetness index of the soils at the pediments. Therefore, the most destructive flood events happen in highly wet years, flowing through a series of highly dry years. Due to the higher bedrock depth, higher slope degree, and lower coarse soil on the upper part of the plain, these events affect this area at most. This estimation is supported by the empirical data from the last decades, such as floods and erosion events.

The soil classes of the Firuzabad Plain are another factor worth analyzing for two reasons: (i) to identify the patterns of soil formation processes in the plain, (ii) to examine the possibility of fossil and buried wetland horizons. The ability of the soil to store and (or) carry water is crucial to these two questions. This ability is affected directly by the particle size distribution and soil texture (see [Tiner 2017, 78](#); [Goldberg](#)

[and Macphail 2006, 13](#)). Therefore, these factors were analyzed based on available data.

Based on these factors, the soils were divided into two categories for their texture: fine and coarse. These categories were witnessed in the soil horizons on the surface and in two depths (100 and 200 cm). The results ([Fig. 6](#)) show four main trends regarding the plain's soil texture: coarse soil with (a) decreasing or (b) increasing degree in depth, fine soil with (c) decreasing or (d) increasing degree. This analysis illustrates the spatial pattern of soils with a high probability of wetland formation, including very-fine textured soils and soils in areas with a steep slope and poor drainage.

Wetland soils are subject to gleying due to their high water content and low bulk density ([Vepraskas and Craft 2016, 177](#)). Their relatively

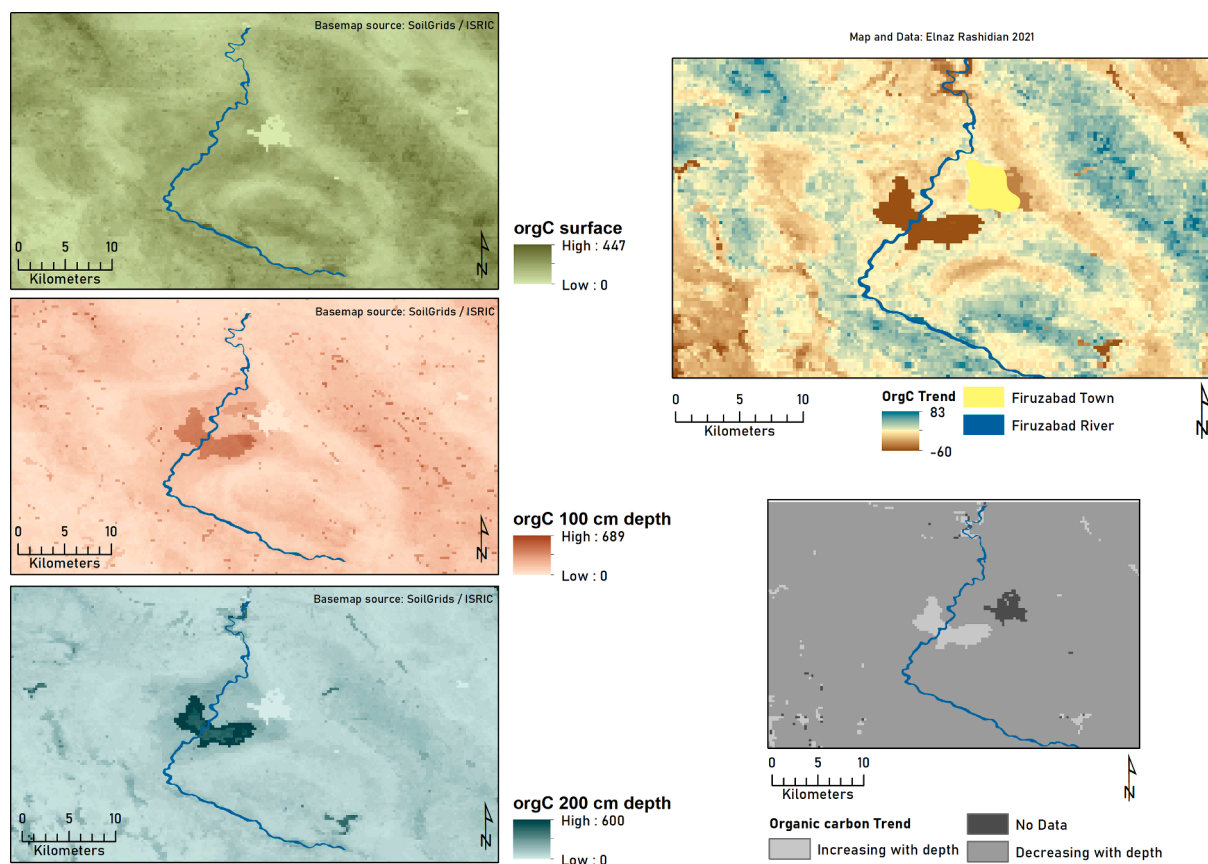


Fig. 7. Trends for Firuzabad soils' organic matter with depth (see section 7 for classes and analysis) (illustrated by the corresponding author).

**Table 3**

Key data on Firuzabad River (summarized after Official reports of Iranian Statistics 2020).

Annual discharge (cubic m)	103,000,000		
Catchment area (ha)	High Altitude	43,437	70,667
	Low plains	27,230	
Length in Firuzabad Plain (km)	45		
Sinuosity index	Upstream	1.6	1.4
	Downstream	1.2	

high organic matter is another indication. Wetlands generally consist of organic and mineral soils, which are sandy or non-sandy in texture (Tiner 2017, 445). The available data on the Firuzabad soils' organic matter was analyzed for its combination and its changing degree in depth. A classification of Firuzabad soils for their organic matter with depth (Fig. 7) shows that organic soils exist in most of the plain, but they concentrate in the central lower part if their increasing degree in accordance with depth is considered. These areas were compared to the distribution of fluvial soils to extract the direct impact of the river from the soil texture. Fluvients form where repeated fluvial sedimentation blocks any horizon development (see Vepraskas and Craft 2016, 330 for their role in identifying buried wetland soils). The results of soil texture and organic matter are mostly in accordance with each other, indicating a shared causality.

This analysis shows that the organic matter of the Firuzabad Plain probably evolved in two distinct phases; the (deeper and) older soil horizons with high organic matter, which were buried by fluvial and colluvial sediments, and younger soil horizons with anthropogenic indications for irrigated land use. The former is found in the west and central parts of the plain. The latter is found in all the sub-surface soils.

An active event for the soil formation process in the plain is the regular stream flood events. Their destructive force affects the upper

part of the plain directly. However, they indirectly influence a possible wetland landscape on the south part because they transport a high volume of sediments in a relatively short time towards downslope. Such events might cover a wetland's surface with new fluvial deposits in the absence of vegetation (Vepraskas and Craft 2016, 66). The current fertile and leveled soil of the plain's south and southwest areas concentrated on the upper 200 cm of the soil profiles might be traced back to this process. This also explains the buried nature of wetland soils in the Firuzabad Plain.

The presented analyses show that soils with wetland characteristics exist in Firuzabad at a depth of 150 to 250 cm below the current surface, concentrated in the plain's west and south central parts (Fig. 6; Fig. 7). These soils are considered "stratified layers," referring to their discontinuous nature as high organic matter soils are buried under fluvial and alluvial sediments (Vepraskas and Craft 2016, 249). Although more detailed soil profiles must be produced by stratified soil sampling surveys in the future, this preliminary analysis indicates another correlation with the mentioned twofold categories of the Firuzabad landscape.

## 5. The paleoenvironmental context

The number of paleoenvironmental investigations in southern Zagros has been increasing in the last decades (Aubert et al. 2019; Brisset et al. 2019; Djamali, de Beaulieu, et al. 2009; Jones et al. 2015; Rigot et al. 2021). One study focused on Lake Maharlou is relevant to compare with the paleoenvironment of Firuzabad (Brisset et al. 2018). This is an inland playa lake (ca 100 km north of the Firuzabad Plain (Brisset et al. 2019; Djamali et al. 2009). Based on chronologically well-constrained sedimentary and geochemical records, several contrasting hydrological episodes have been identified for nearly the last four millennia. One of the striking finds of this study is that during the second and third centuries CE, the terrigenous sediment input by river systems into the lake and the

inferred flood frequencies were at their lowest levels (Brisset et al. 2019, Fig. 5). At the same time, the gypsum precipitation in the lake reached a peak showing lower lake levels and relatively drier conditions compared to the first centuries BCE and CE.

These events are contemporary to the foundation of Ardashir-Xurra and have direct implications for the landscape of the central-south Fars region, including the Firuzabad Plain. First, less flowing water would lead to the wetlands' gradual or seasonal desiccation or shrinkage, changing their nature from an attractive biodiverse landscape with useful flora and fauna to a still-water or water-logged area impassable and prone to harmful insects. This could be the origin of the narrative of "unhabitable lands" attested in the historical accounts regarding Firuzabad in the Early third century CE, referring to the southern parts of the plain. In a recent paper, we showed the presence of an analogous water-logged environments in the vicinity of the Palace of Ardashir during the second and first millennia BCE (Djamali, Rashidian, et al., 2021). Second, fewer flooding events at the same time could have changed the originally unattractive northern part of the plain and paved the way for the foundation of the circular city at this location, where regular flooding had been the case before that time.

Furthermore, large-scale paleoclimate data suggest drier conditions around 2000 BP, which have led to an incision of riverbeds and spatially "fixed" the hydrological channels in the neighboring areas (Rigot, et al. 2021). It is safe to assume a similar scenario by the incision of the Tangab/Firuzabad River in our study area, as the current riverbed is 15 m lower than its surrounding alluvial plains. Commonly, an incised riverbed has spatially limited drainage and allows less waterlogged soils in its floodplain compared to a braided river. This might be another indirect indication of drained wetlands in Late Antiquity.

## 6. Discussion

Currently, the Firuzabad Plain is a populated area consisting of a town and several villages, covered mainly by agricultural landforms. This landscape mosaic is heavily affected by the Early Sasanian's centralized urban planning. This paper argues that this was not always the case. Two distinct cultural phases were identified based on the archaeological record of the plain. Indications for buried landscapes were examined, and their spatial interaction with the settlement patterns was highlighted. Here, the presented data will be summarized, and statements regarding the hypothesis will be made.

Based on the presented preliminary analyses, the existence of wetlands in the Firuzabad Plain in earlier times is supported by the following indications: (i) the concentrated organic matter in sub-surface soils with an increasing degree in depth, (ii) the differences between the upper (north) and lower (southwest) in soil texture, elevation, and slope and their impact on the soil's water capacity. Furthermore, the paleoenvironmental context provides conditions for wetland emergence and evolution in this area.

A simple chronological order of the known settlements shows the distinctions between favorable landscapes in Prehistory and Late Antiquity. The known prehistorical settlements fall into poorly drained soils and probable wetlands, while the major Late Antiquity remains, including the first Sasanian capital, are located in the area with high fan development and well-drained soils.

Intensification of land use in Late Antiquity is witnessed throughout the plain, including large-scale water management systems, planned satellite settlements, and garden areas. This supports the historical accounts of Early Sasanian settlement plans for the plain, which continued successfully throughout Late Antiquity into the Middle Ages.

The most prominent question of this paper was one of the wetlands. This question has been addressed here from three aspects: the physical, geomorphological, and archaeological aspects. Considering the physical aspect, the plain has a very gentle slope with remarkably poor drainage. The Firuzabad River and its dependent streams flow from the northern parts and jam in the southern parts prior to leaving the plain in a shallow

bed. This phenomenon results in an imbalance of surface and near-surface water availability between the northern and southern parts of the plain, making the southern part a suitable candidate for wetland formations.

Considering the geomorphological aspect, subsoils with high organic matter and traces of reduction exist in the southern part and are absent in the northern part of the plain. A comparison of exemplar soil profiles shows a trend of different subsoils in north and south evolving into homogenized topsoil in the entire plain. This fact shall be further examined via coring and detailed laboratory analysis. Nevertheless, this supports the existence of different past landscapes, one with frequent flooding in the north and the other with permanent water saturation in the south.

Considering the archaeological aspect, the only prehistoric settlements were found in the lower parts (west and middle of the plain), supporting the hypothesis that the prehistoric population was dependent on the particular landscape of the lower part and avoiding the flood-ridden upper part. The dependency of fifth to third millennium populations of Fars on wetlands (including spring-fed water resources) is also reported by others in the neighboring areas, especially evident in the Bakun phase settlement patterns (see Alizadeh 2006, 29 for Kur River basin, and 92 after Sumner 1994), and in southwest Zagros in the Dehloran plains (Neely and Wright 1994).

Based on the summarized data, the following statements regarding the presented case study and hypothesis may be made:

- (i) "Wetlands of Firuzabad": based on the analysis of geo-factors such as slope, subsoil classes, and soil texture trends with depth, the existence of wetlands in the lower part of the plain is highly possible, while the upper part seems to be shaped by seasonal floods and physical erosion and occasional landslides. Detailed analysis of the mentioned nine areas documented with drone imagery and further soil sampling surveys should elaborate on this point. However, the drastic distinction of the subsurface and surface soil, especially regarding drainage and organic matter, is undeniable. This might support the hypothesis of an anthropogenically triggered and drastic landscape change.
- (ii) "Turning the river": based on the analysis of alluvial fans in the plain, it is unlikely that the entire Firuzabad River might have been turned from its channel twice in the course of a millennium, once by Alexander in the fourth century BCE and then by Ardashir in the second century CE, as historical accounts seem to suggest. However, the river has built two distinct alluvial fans in the northern part (see their extent in Fig. 1), meaning a drastic change of sedimentation freight some time in its evolution. Dating the relevant sediment logs shall confirm a hydraulic event sometime in the last three millennia. Considering the archaeological remains in the southeast part, this assumed change in the river by digging a tunnel into the mountain could be assigned to the Lohrasb area.
- (iii) "Paradises / Sasanian gardens": A comprehensive analysis of surface and sub-surface soil horizons (soil profiles/coring), including pollen data, shall bring light to this question. However, the archaeological remains of planned gardens integrated into the large-scale water management system of the plain are evident. There are indications on the role of wetlands in "paradise" landscapes in other areas (Canepa 2018, 350). The supposed gardens of Parseh are also studied, elsewhere (Gondet, et al. 2021). A brief look at the known archaeological sites reveals that satellite villages are located carefully alongside the two canals which are centered in Ardashir-Xurra, while the religious structures are found in the southern and western part of the plain (see no. 25, 33, 38 and identified canals in Fig. 2), where the drainage is not favorable, and the hydraulic situation is unstable at times. This might further support the idea of planned gardens in areas



with stable water availability and low stream and slack water probability.

The authors emphasize the preliminary nature of these statements and the necessity for further detailed analysis to support this hypothesis. Coring in the identified wetland areas is of utmost importance to fully support this hypothesis and provide an absolute dating for the supposed disappearance of this landscape and identify its anthropogenic triggers. Furthermore, detailed laboratory analysis on the assumed sediment horizons shall provide certainty in this aspect. The assumed sediment horizons are the initial wetland (Prehistory), the secondary sedimentation after drainage efforts (Late Antiquity), and the sedimentologic response to these landscape changes (recent). However, the results of our recent study of the spring-fed wetland of Ardashir Palast in north-western edge of the plain (Djamali, Rashidian, et al 2021) correlates with this hypothesis and hints at this direction.

In the section 1.1, four questions were raised. Based on the reported preliminary analysis, the following answers can be formulated. First, a drastic landscape change can be assumed based on the identified sediment horizons in the entire plain. Second, despite the absence of absolute dating, this assumed landscape change can be traced to be relevant to the same topsoil at the time of the third-century CE city foundation. Therefore, a correlation is logical to assume.

Furthermore, extensive hydraulic reshaping of the plain (see evidence in Huff 1974; 2014) supports the assumption of this change being triggered by intentional anthropogenic impact. Third, the archaeological setting shows the strict spatial differences of the settlement patterns in the two defined cultural phases. The prehistoric settlements were mostly dependent on their available resources and landscapes, while the Late Antiquity settlements were actively shaping their landscapes according to their needs and ideological concept. Therefore, an evolution of land use can be assumed. Fourth, indirect indications of wetlands as a prominent landscape in the southern part of the plain were presented here. Traceable and physical evidence of wetlands is yet to be discovered in the plain's lower part to support the hypothesis and provide solid evidence for this assumption. This is the next step in the current project.

The above scenario fits into the concept of NCT (see also Wilkinson et al. 2012 for a similar discussion). There are four different ways of NC in general (Laland and O'Brien 2010, Table 1; Odling-Smee et al. 2003). The settlement dynamics of Firuzabad Plain in Prehistory can be regarded as "counteractive relocation" meaning that the population moved away from the steep slopes of the northern foothills to avoid the hazards of stream floods and extreme erosion and chose to settle in the environs of the western and southern wetlands to exploit their rich resources and their water stability. On the other hand, the settlement development of the Late Antiquity shows clear signs of "inceptive perturbation" as the population has intentionally and actively modified the landscape in physical terms according to their pre-planned concept in a successive manner. These changes included reshaping the landscape surface by modifying the drainage and plain's hydraulics, and building structures (such as canals, walls, and qanats) to avert slack water and avoid soil erosion or landslide.

These different approaches to the landscape have resulted in the evolution of the Firuzabad Plain from a heterogeneous environment of two distinct areas – low plain wetlands and high elevated eroded slopes – with sporadic settlements in the Prehistory to an intensively populated mosaic of anthropogenic landscapes such as city, helmets, gardens, and sanctuaries in the Late Antiquity.

## 7. Conclusion

Today, Firuzabad is a densely populated and ecologically prosperous plain with well-watered fields and fertile soil. The intensive land-use practices since Late Antiquity have evolved the plain's surface into a mosaic of anthropogenic landscapes. This paper argued that this was not always the case. It discussed two different phases of the landscape

change in Firuzabad, one in the prehistorical period, during the fifth to third millennium BCE, and the other in the Early Sasanian period, from the beginning of the third century through the eighth century CE. It showed how one particular landscape – wetlands – played a positive role in securing the sustainability of the settlements at the former phase but was considered hostile and intentionally removed in the latter period. This case study is still in progress, and detailed data is in the making, yet it argues for a direct human role in this evolution.

Wetlands in Prehistory were a source of food and building materials (still the most important services of wetland ecology to human societies). Settlements were arranged around these areas in the south and southeast of the plain. At the same time, the upper part of the plain was not favorable for dwelling because of its regular stream floods caused by higher and steeper slopes and high sediment transport. These settlements had access to various resources, making them ecologically sustainable. They were engaged in an intra-regional exchange with settlements of neighboring plains, such as the Kur river basin and Mamassani.

This had to change in the Early Sasanian period because planned urban centers and their satellites required a different landscape with good drainage, leveled fields, and safe from floods. Therefore, the once much-appreciated landscape was no longer attractive and was considered an obstacle. Paleoenvironmental data from neighboring areas indicate a drier period which probably drained the wetlands to some degree and made them less productive and stable landscapes for human dwelling (see section 5). Therefore, wetlands were considered problematic at the time. The emphasis on draining the swamps and freeing the land for people in the historical narratives (see Table 1 for sources) as kingly acts might hint at the wetland's less appreciated existence in this period. The "problem" was solved with an engineered and intentional reshaping of the landscape by fixing the drainage and managing the sediment freight. The settlement pattern was entirely based on these landscape changes, optimizing every bit of the plain for an interconnected urban system. The settlements stretched to every corner of the plain, even previously unoccupied areas.

The Firuzabad landscape's case clearly illustrates how the human-environment interaction can be studied with geoarchaeological means. It further emphasizes the importance of ecologically sensible landscapes such as wetlands (see best-fit definition in Tiner 2017, 14) and their gradual disappearance in the semi-arid regions due to anthropogenic impacts such as land use intensification since the Late Antiquity.

The presented data is not final nor flawless. *Nota bene* the incomplete nature of the archaeological record, especially regarding the earlier periods, which affects the reliability of the interpretation. An essential missing step is establishing a reliable chronology of the suggested landscape change based on absolute dating of different horizons, including the buried wetland soils and the drastically changed hydrologic features of the plain. Another challenge is the extreme landscape changes in the recent decades in the study area due to intensive land use and population growth in the plain. This has entirely changed the surface of the plain and made a reconnaissance of archaeological features extremely difficult. This challenge was met mainly through evaluating older data, including (un)published intelligence reports from the nineteenth century and archaeological reports from the twentieth century.

Further studies shall elaborate on the impact of the proposed landscape change on the environment after the abandonment of the Ardashir-Xurra/Firuzabad city in the twelfth century CE. As the water management system was neglected in the absence of administrative relevance, collapse and gradual filling of underground water systems (qanats) and a revival of the river channel into a more natural riverbed seems possible. Today, the plain's population receives most of its available water from deep wells, which negatively affects the groundwater table and endanger the region's soil stability (Mokhtara and Aram 2017), especially in the light of occasional and seasonal floods with high erosive potential. Therefore, a reconnaissance of past water management systems' successes and failures can ensure a more sustainable

landscape in Firuzabad for future generations.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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