Zoning the Echus Chasma Region on Mars for Settlement Location Selection according to Topographic and Surface

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This study proposes zoning for one of the regions called Echus Chasma on Mars, aiming to open the discussion on selecting the settlement locations for Mars urban planning. The literature on Mars architecture has been an important discussion topic and is increasing in the architecture discipline. On the other hand, planning the Mars areas must be another research focus to understand spatial organization on an urban scale. The Echus Chasma region is selected for the Mars surface's zoning tasks. This selection is because it is considered a past water source region of Mars, and habitable spaces on Mars must also consider the possible water supply. The study applies the Gaussian mixture model algorithm to predict the different zones. The features in clustering for zones are slope, aspect direction, and normalized difference water index. According to AIC and BIC values of clustering nine clusters are obtained, and cluster 2, is the best candidate for settlement zone within the scope of this research. The result of the study can only be hypothetical with its limited number of features; however, the study contributes to the literature and future works with its methodology.

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Keywords: Mars, Echus Chasma, Settlement Location, Clustering, Zoning.

Mars'taki Echus Chasma Bölgesinin Yerleşim Yeri Seçimi için Topografya ve Yüzey Suyu Özelliklerine Göre Bölgelenmesi

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Bu çalışma, Mars kent planlamasında yerleşim için konum seçimi konusunu tartışmaya açmak amacıyla, Mars'ta Echus Chasma bölgesinin yerleşime uygun alanlarının tanımlanmasını önerir. Mars mimarisine ilişkin literatür, mimarlık disiplininde önemli bir tartışma konusudur. Öte yandan Mars alanlarının planlanması, kentsel ölçekte mekansal organizasyonu anlamak için başka bir araştırma odağı olmalıdır. Echus Chasma Mars'ın geçmişteki su kaynağı olarak tahmin edilen bölgesidir. Mars' taki yaşanabilir alanların konumlanmasında olası su kaynaklarının konumu önemli bir girdi olması nedeniyle Echus Chasma alanı çalışma alanı olarak seçilmiştir. Bu çalışmada, Echus Chasma' nın farklı alt bölgelerini tahmin etmek için Gauss karışım modeli algoritması kullanılır. Bölgelerin tahmini için kümeleme probleminde kullanılan özellikler; eğim, bakı yönü ve normalize edilmiş su indeksi olarak seçilmiştir. Sonuçlar, Echus Chasma bölgesinin verilen özelliklere göre ve kümeleme sürecinde seçilen küme sayısına göre dokuz farklı bölgeye sahip olduğunu ve 2 numaralı kümenin yerleşim için en iyi aday olduğunu göstermektedir. Bu çalışmanın kapsamında eğim, bakı ve normalize edilmiş su indeksi ile bölge tahmini olması nedeniyle, çalışmanın sonucu ancak varsayımsal olabilir. Diğer yandan çalışma metodolojisi ile literatüre ve gelecek çalışmalara katkı sağlamaktadır.

Anahtar Kelimeler: Mars, Echus Chasma, Yerleşim Yeri, Kümelenme, Bölgeme.

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1. INTRODUCTION

Designing a habitable space on Mars has been a noteworthy research topic, alongside the research on accessing the red planet. Although creating such a big plan remotely without being there has many unpredictable variables, through science, distant planning for habitable space on Mars is possible and has already begun.

Rodrigue (2014) designated the "orders of relief" method to understand the variation on the Mars surface using the Mars Orbiter Laser Altimeter (MOLA) map. Rodrigue proposed five orders: large crustal rocks of Mars, prominent major features, unclear large areas, landscape scale areas, and small details. This classification facilitates the comprehension of the complex terrain of Mars from a systematic perspective. Another study by Rodrigue (2023) focuses on the topographic feature analysis via the software Gridview using MOLA data. In this study, Rodrigue reveals two important discoveries and fault lines in the Terra Cimmeria region on Mars and the geographical depression between the Terra Cimmeria and Terra Sirenum regions. Both studies on the classification and analysis of Mars's surface reveal significant clues of location selection for a possible settlement zone. Precedent examples of Mars settlements show the significance of an urban planning issue for other planets (Hohmann, 1972; Gaviraghi and Caminoa, 2013; Fross & Bielak-Zasadzka, 2019; Hollander, 2022). For lunar tasks, Dalton and Hohmann's (1972)' idea was to design a lunar city system, and they even proposed site plan drawings of the lunar colony. Selenia and SOM's Moon Village are the other examples of the off-world planning proposal in collaboration with the European Space Agency (ESA) (Hollander, 2022). ZA Architects proposes to send the robots to find the most proper location for colonization while designing the system of an underground colony; Foster and Partners propose robots to excavate the suitable region and create habitat modules using the inflatable structures (Fross & Bielak-Zasadzka, 2019, Hollander, 2022). BIG Architects recommends and represents the 3D printable habitat modules for Mars (Hollander, 2022). Besides these attempts, research on Mars colonization has also been growing. On the other hand, different design scales, from architecture to urban design, are necessary to answer the Mars habitat problem consistently. So, issues and solutions of the architectural scale must be combined with urban-scale solutions for the Mars habitation problem.

When considering the current circumstances of Mars habitation, it becomes clear that the problem is about more than just designing a habitable space. Gaviraghi and Caminoa (2013) point to a wider-scope problem in Mars settlement that necessitates a master plan before we can even think about accessing the planet. This problem definition of Mars settlement goes beyond just the architecture of habitable space. It also encompasses the design of the planet's infrastructure, the creation of standard space transportation, and the development of new economic opportunities on the planet. These are all part of the city planning requirements for Mars.

The research gap in the urban planning on Mars's surface is the motivation of this study. This paper first focuses on urban planning on Mars in the literature review, then explains location selection and zoning as the problem statement of the research. In the third chapter, the methodology of the paper is introduced, and finally, the findings and conclusion of the work are presented.

2. URBAN PLANING ON MARS

Urban planning on Mars presents unique challenges, making it a significant issue for scientists, urban planners, and architects. Donoghue (2016) criticizes the research on the Mars settlement problem for its focus on scientific, medical, and economic perspectives, neglecting human-related issues such as environmental psychology and urban planning. Donoghue (2016) proposes five phases of habitation of Mars: exploration, settlement, colonization, urbanization, and terraforming. Dezfouli et al. (2023) identify key physical and environmental components required to design habitable structures on Mars, emphasizing the importance of robust structural designs that can withstand the harsh conditions of Mars. Donoghue (2016) notes that on Earth, a building is a building; however, on Mars, a building must encapsulate all the necessary diverse requirements of a city. Urbanization must be thought of differently than on Earth in terms of its physicality. However, human-related issues, location decisions, and growth scenarios must still parallel Earth-like urbanization. Makanadar (2023) defines the Mars colonization problem as an interplanetary urban planning problem, emphasizing the crucial collaboration between different disciplines, including aerospace, biology, architecture, and urban planning. This interdisciplinary approach is key to addressing the complex challenges of urban planning on Mars. Despite the existing literature on the urbanization problem on Mars, it remains a significant research topic with many research gaps.

Smirnova (2020) proposes a cyborg city structure that can enhance the autonomous, self-sufficient system for underground urban organizations to protect the inhabitants of Mars from radiation. Łabowska et al. (2020) propose a Mars city organization with one million inhabitants containing social, industrial, residential, and municipality buildings. Detrell et al. (2021) represent a Martian city plan proposal ensuring the usage of local resources to obtain environmental sustainability. Curtò and Zarza (2024) analyze the transportation potentials for intersettlement connectivity.

This study particularly focuses on the zoning issue according to the terrain and water-related features of Mars to understand where to locate. Understanding the topography of Mars is crucial to building a physical habitat space, and understanding the water features is vital for a settlement. Łabowska et al. (2020) state that topography is one of the key components in Mars architecture, and location selection for colonization is a complex task. Fross and Zasadzka (2019) argue the necessity of landscape and terrain decisions for urban and spatial planning on other planets and the collaboration of architects, urban planners, and scientists. Suścicka et al. (2019) emphasize the importance of a plan for the entire infrastructure design on Mars according to the terrain-related inputs for cost-efficient urbanization. This paper proposes a methodology to decide the zones for spatial decisions for habitable surfaces.

3. METHODOLOGY

This study conducts clustering to understand the zones of possible settlement on Mars's surface according to topographic and water features. The study is divided into three phases: dataset preparation, clustering algorithm training, and visualization of the clusters to decide the zones in the selected region of Mars. Dataset preparation includes selecting Mars locations and extracting the topographic and water features from raster images in the planetary data system (PDS). Algorithm training involves choosing the best number of clusters, and visualization shows the clusters on their coordinates with color labels. **Figure 1** represents the flow of the work.

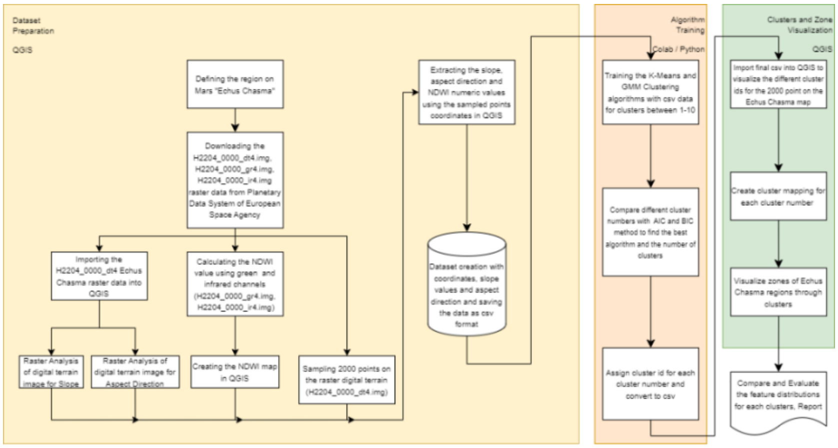

Figure 1: Workflow diagram illustrating the methodology steps

3.1 Region Selection, and Dataset

The Echus Chasma region is selected for the zoning task in this study. The selection criteria are related directly to the National Aeronautics and Space Administration (NASA) criteria and the European Space Agency (ESA) definition of the region. NASA (2021) listed four criteria for selecting the landing location. These are habitable environment evidence, geological analyses that include rock layers, supporting data for water, and secure and stable zones. European Space Agency (2008) defines the Echus Chasma region as 100 km long and 10 km wide, one of Mars's possible largest past water sources. Hollander (2022) represents the suitable locations on Mars for landing and planting and classifies "Valles Marineris" as one of these suitable locations, which Echus Chasma, namely "Grand Canyon of Mars," is located to the north of. Due to the above reasons, the Echus Chasma region is selected for zoning (**Figure 2**).

Figure 2: Top View and 3D view of Echus Chasma Region

The raster image data of the Echus Chasma region is collected from the planetary data system (PDS) in the European Space Agency (2013). H2204_0000_dt4.img, H2204_0000_gr4.img, H2204_0000_ir4.img raster images are the data for extracting the topographic and water features. "dt" extension stands for digital terrain, "gr" is for the green channel, and "ir" is for the infrared channel of the raster data. All the raster images are in a resolution of 100m/pixel. Although the resolution of the raster images is not enough for a detailed analysis, which is one of the study's limitations, we can use this data for land zoning tasks.

After downloading the raster data, the digital terrain data is imported into QGIS software, and the slope and aspect direction features are extracted using the raster analysis tool for slope and aspect direction. Once the raster analysis was completed, two maps showing the slope and aspect directions were ready. The slope feature denotes the steepness factor of the terrain, while the aspect direction defines the orientation of the slope. Both features are necessary while deciding the location selection to understand the water drainage direction, erosion potentials of the region, the flatness of the area for landing, and solar illumination. These terrain characteristics can help to define the landing and colony positioning zones.

The NDWI method, a remote sensing technique proposed by McFeeters (1996), is a key tool in our research for understanding water features on the surface. According to McFeeters (1996), NDWI is the ratio between the difference and sum of the green and infrared channels (**Figure 3**). Using the h2204_0000_ir4.img and h2204_0000_gr4.img raster data, the NDWI value is calculated. These values are converted to a 2D raster image, an NDWI map. Mapping the NDWI value of a region is crucial in understanding the ecological features and deciding the urban planning strategies. Water, the most important factor in life, directly influences the habitability of a region for a colony.

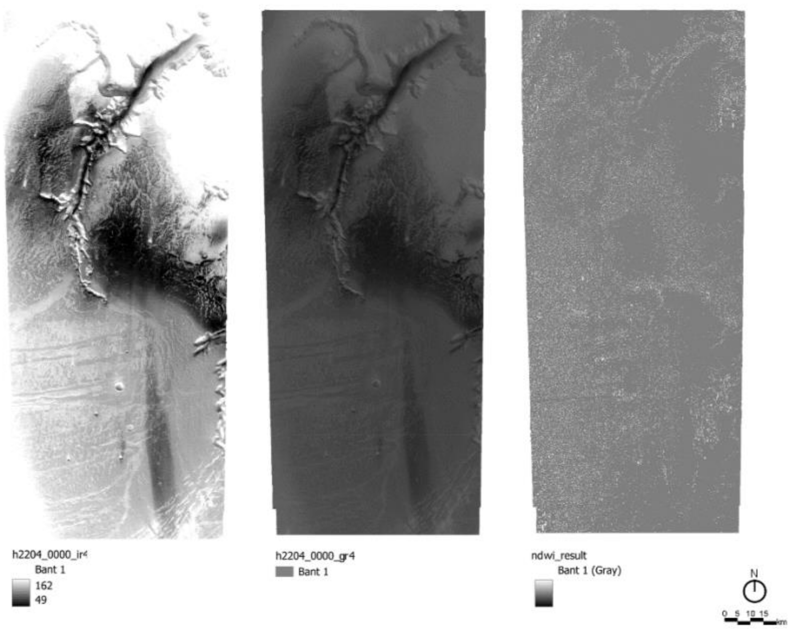

Figure 3: Infrared, green channels of Echus Chasma and NDWI map.

Figure 4 represents the Echus chasma digital terrain, slope, aspect direction, and NDWI maps. After creating the slope, aspect direction, and NDWI maps, 2000 points were sampled on a grid order in QGIS. These points are used to extract the numeric slope, aspect direction, and NDWI values from the sampled point coordinates. Following the assignment of slope, aspect direction, NDWI values to the point coordinates, a comma-separated value (.csv) file is created. This file, which contains the numeric feature values, serves as the dataset for the clustering task.

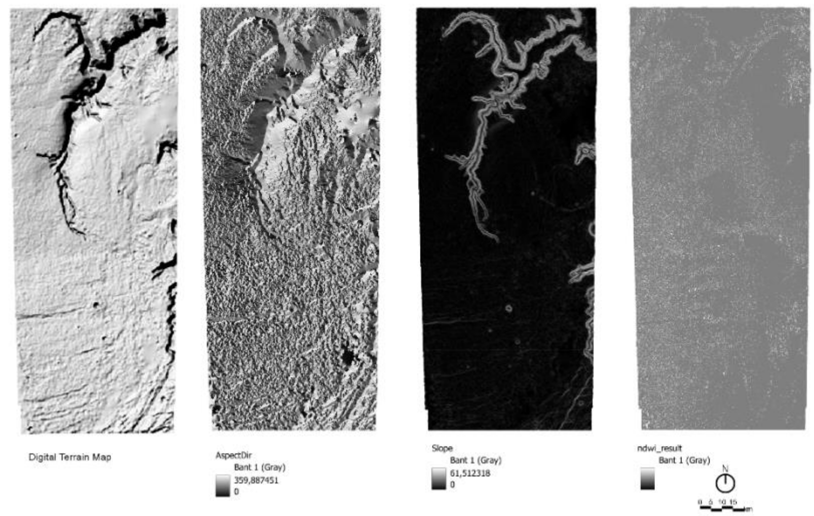

Figure 4: Echus Chasma region given with digital terrain, aspect direction, slope maps and NDVI values

3.2 Gaussian Mixture Model for Clustering

The task of zoning the Echus Chasma region is decided via the Gaussian mixture models (GMM) clustering method. Clustering is an unsupervised machine learning (ML) method for labeling hypotheses. The algorithm can only predict hypothetical cluster IDs as no label exists in the training sessions. On the other hand, the most important contribution of clustering algorithms is deciding the number of clusters within the dataset, which is previously unknown. So, variability in the dataset can be controlled and clustered according to the dataset's features.

GMM, a prominent clustering method in ML, is a density estimation method that falls under soft clustering methods (Hastie et al., 2009). It represents the feature density in each class and assigns cluster IDs accordingly. Unlike statistical clustering methods, GMM's approach is probabilistic, representing the probability distribution of different clusters rather than creating distinct clusters and efficiently used in complex data. GMM gives a probabilistic decision boundary for the cluster regions. Statistical clustering methods are deterministic and more robust in the simple data—statistical clustering results in discrete sets. Certain decisions on discrete sets can occlude the ambiguous, in-between samples in the dataset contrary to probabilistic models. Therefore, GMM is selected as the clustering method for precisely defining the ambiguous, in-between values of the selected features on the Echus Chasma region.

Before training the GMM algorithm, the slope aspect and NDWI features in the dataset are scaled between 0-1 to obtain scale compatibility between distinct features; moreover, with scaled data, the algorithm training efficiency can increase, and the interpretability of the results will be easier. After scaling the slope, aspect direction, and NDWI values, the GMM algorithm is trained for cluster numbers between 1 and 10. For each cluster numbers, AIC (Akaike Information Criterion), and BIC (Bayesian Information Criterion), the evaluation metrics for clustering, are calculated. Both metrics measures how well the clustering model fits the data. The better the model, the smaller the result of the AIC and BIC become. Min AIC and BIC scores indicate the optimal number of clusters for the slope and aspect direction datasets.

Figure 5 shows, AIC and BIC values have minimal variations and both showing the same pattern. 9 clusters takes the minimum value of AIC and BIC for the clustering. Hence we can decide the number of clusters as nine. After deciding the number of clusters, CSV file with the slope, aspect direction, NDWI value and coordinates of the points is appended with the related cluster IDs for the visualization task.

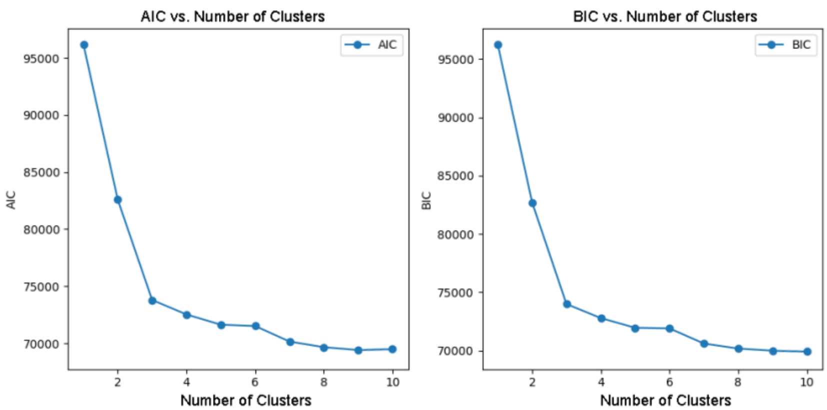

Figure 5: AIC and BIC Scores According to the Number of Clusters in GMM

3.3 Zoning Visualization in QGIS

The visualization process involves assigning cluster IDs to each coordinate in QGIS. After clustering and obtaining the CSV file with cluster IDs, the file is imported into the QGIS software. The imported points initially appear in a single color. The points are classified based on their cluster IDs to create a cluster representation, and different colors are assigned to each cluster. Once the cluster IDs and colors are assigned to each point, Voronoi diagrams are generated based on the cluster IDs. These diagrams are significant as they help us create clustered surfaces crucial for zoning. Finally, the zoning of the Echus Chasma region is represented in a Voronoi diagram with the assigned cluster IDs (**Figure 6**). All the square cells of the Voronoi diagram have the same size, almost 4 km2.

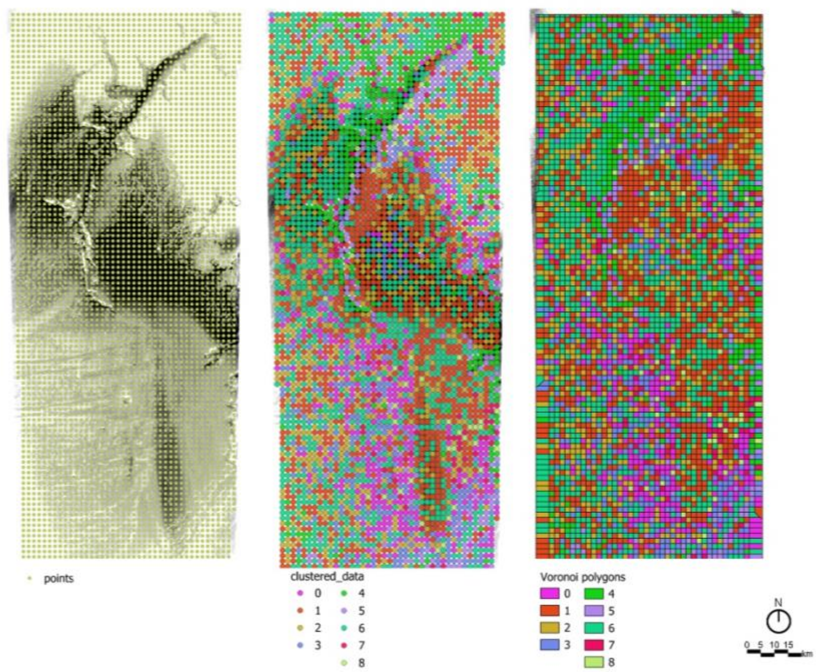

Figure 6: Steps of visualization of zoning decision according to clusters

4. FINDINGS

After deciding the number of clusters as 9, each cluster's feature distributions are represented in **Figure 7** and summarized in **Table 1**. **Figure 7** respectively represents the feature distributions for each cluster.

In slope distribution, cluster 2 is obvious for having mostly the minimum steepness value among all the clusters. Interestingly, two different patterns are obvious: 0, 1, 2, 3, 6, and 7 id clusters create a stack around the slope value 0, and their variance is too small. So, both the steepness value is low, and the terrain is almost flat. On the other hand, clusters 4,5,8 have the biggest variance, having terrain variations that are too different. The terrain in zones 4, 5, and 8 is rugged and difficult to settle or move.

Aspect direction distribution shows the values between 0-360. The interval between -45°/+45° demonstrates the Northwest-North-Northeast directions interval. 90° stands for the East, 180° for South, 270° for West cardinal directions. The north direction may help prevent solar radiation while taking the sunlight longer and indirectly, which can benefit site selection and colonization. When we control the densities of the directions, the north direction density is the highest in cluster 2, which makes this region the best candidate for a settlement location according to the aspect direction (**Figure 7**). This can be an advantage in preventing solar radiation and benefit from the longer duration of indirect sunlight. Clusters 4 and 6 have the highest South directional distribution, which can be a crucial problem in terms of solar radiations.

NDWI distribution takes values between -1/+1. Between -1 and 0 values show the surfaces without any water features. Values between 0 and +1 illustrate the water-related features. Distribution plots show that most values take negative or zero values; however, interpreting the NDWI values directly on the distribution plot is difficult. **Table 1** is descritable for NDWI distribution. In the NDWI column of **Table 1**, values show the number of points with values greater than 0. Cluster 6 shows the highest number of points having values greater than 0. Cluster 6, 1, 2, and 4 are the first four clusters listed in descending order of the number of points with values greater than 0.

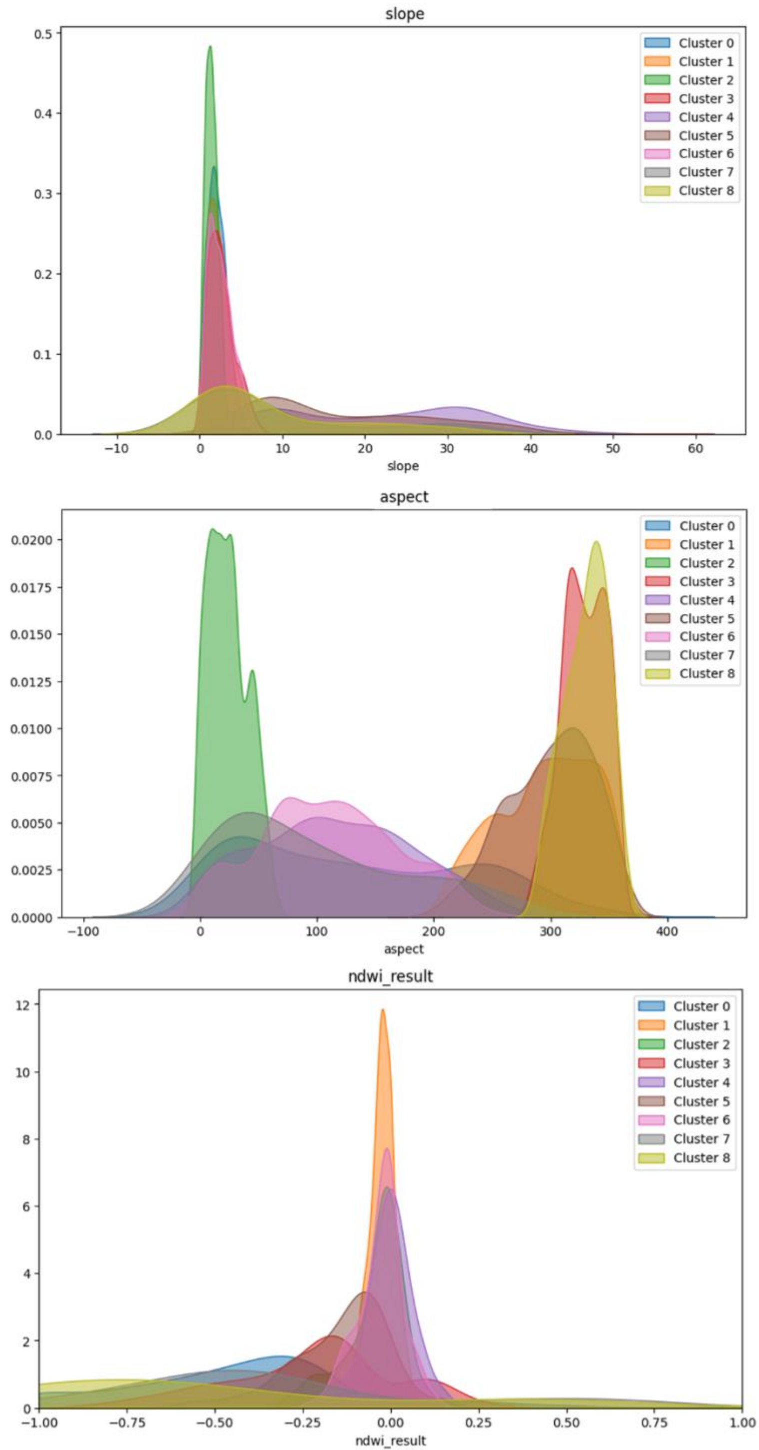

Figure 7: Distribution plots of features for each cluster.

Table 1 represents the best and the worst feature values to undestand the best and the worst zones among the clusters. In descending order, northDirection columns list the number of North-directed samples within the related clusters. Zone 2 has the highest number of points oriented in the North direction. Cluster 7 has the smallest number of points oriented in the north direction; hence, this cluster is evaluated as the worst zone with its orientation.

The slope mean column shows the mean values of the slopes within each cluster. The smallest slope mean represents the flattest surface zone. According to this, cluster 2 shows the flattest zone, and cluster 4 is the most rugged zone.

The NDWI column represents the number of points in the dataset with an NDWI value higher than zero. The highest number of NDWI values shows the prevalent presence of water features in the related zone. According to the NDWI column, cluster 6 has the highest number of NDWI values, which is higher than 0. The worst cluster for NDWI value is zone 8.

ClusterID	NorthDirection	SlopeMean	NDWI
2	625	1,425124	193
1	380	2,443336	207
3	242	2,646213	67
6	166	2,529766	341
0	119	2,086597	30
5	85	17,63663	16
4	61	22,595386	147
8	40	9,69854	3
7	34	9,883308	13

Table 1: Number of North Direction oriented points, Slope Means, Number of NDWI values which are greater than zero with their corresponding cluster IDs.

Figure 8 illustrates the best zone for settlement, zones with the best features, and zones with the worst features. The best zone is selected as cluster 2, as this cluster has the best value for both slope and aspect direction and takes a considerably high NDWI value, too. However, cluster 2 does not create a connected big region but rather has distributed parts of similar feature zones. Cluster 6 is the best cluster for NDWI but not the best one for both slope and the aspect direction and shows a similar distribution pattern as cluster 2 on the map without having a connected region. The worst slope zone, cluster 4 is obvious and this zone is located on the canyon part of the Echus Chasma region.

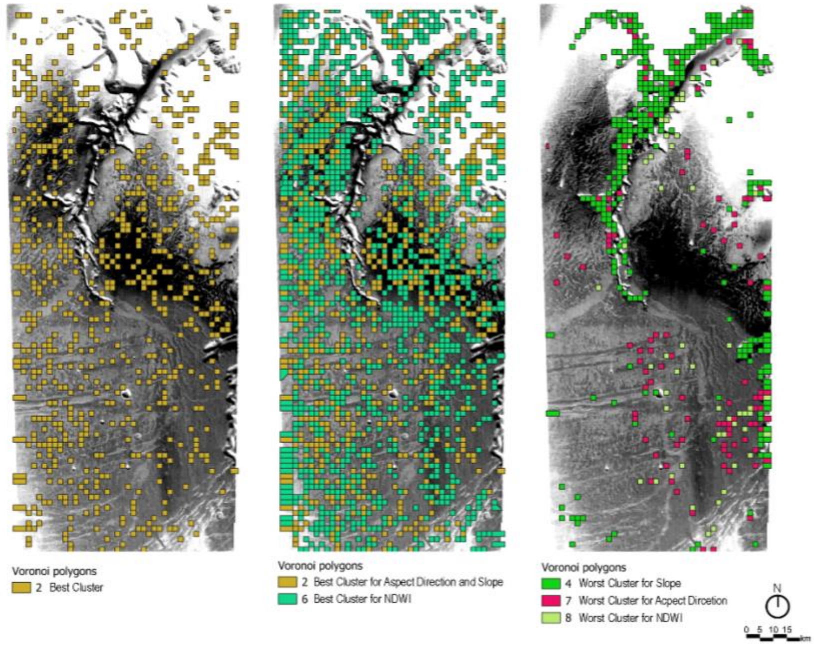

Figure 8: Mapping the best and worst zones on Echus Chasma according to slope, aspect direction and NDWI

4. CONCLUSION

This study proposes a method to decide the zone clusters on Mars according to topographical and water features. This study uses GMM clustering to define habitable zones. The region selected for the zoning task on Mars is the Echus Chasma region. After extracting the slope, aspect, and NDWI data from the Echus Chasma region, the clusters are determined through GMM, and then zones are created through visualization in QGIS. This study aims to subdivide Mars' surface distantly to create a template or starting point for an urban planning task.

Along with this motivation of the study, this research proposes a hypothetical best settlement zone for the selected region, Echus Chasma. The best settlement region in this study is located on the cluster 2.

This study can only propose hypothetical zones based on three features: slope, aspect direction, and NDWI of Echus Chasma, which creates the biggest limitation of the study. On the other hand, since the reliability of the NDWI value cannot be validated, it needs to be controlled carefully. However, the study has a guiding function in creating hypotheses. However, the validity of NDWI also has certain limitations. From a methodological perspective, this study contributes to the literature on Mars architecture and urban planning. It opens new discussion topics for future works about the selection criteria of the settlements on Mars.

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