Available online at https://sanad.iau.ir/journal/jrors
Publisher: Yazd Branch, Islamic Azad University
Journal of Radar and Optical Remote Sensing and GIS
ISSN: *2645-5161*

Semiotics and Comparative Analysis: Smart and Entropic Positioning in the North Direction of Stepped-Form Ancient Villages Case Study: (Masouleh, Abyaneh, Palangan), Iran

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A R T I C L E I N F O

Research Type:
Case study

Article history:
Received 25 September 2024
Accepted 30 December 2024
Published 19 January 2025

Keywords:
ARC GIS,
Box-counting,
Entropy,
Geomorphological Location,
Global MAP,
Underground Water Direction

A B S T R A C T

Objective: This study explores the role of geomorphology, astronomy, and underground water tables in determining the location and orientation of terraced villages in Iran, focusing on spring routing, underground spring height (MAD), and the sun's noon alignment with the village center. It also examines ridge line alignment, building orientations toward mountain fronts, and spatial connections within each settlement.
Methods: The research employs a box-counting method and a cubing algorithm to analyze topographical data, enabling the calculation of visible adjacent and non-adjacent zones. Ridge line alignments and building orientations in the four cardinal directions are studied in relation to the central core of each village. Comparative analyses of MAD, TIN, and river flow directions across the case study villages—MASOULEH, ABYANEH, and PALANGAN—provide insights into spatial patterns and proportional relationships.
Results: The findings indicate a significant correlation between the sun's rotational axis at noon, ridge line orientation, and village centers. The MAD and TIN analysis revealed comparable ratios in river paths across the villages. Specifically, MASOULEH and PALANGAN showed proportional similarities in their lower halves, while ABYANEH exhibited nearly double the values of the other two villages. Additionally, flow river direction patterns varied, with ABYANEH and MASOULEH showing a 3×3 structure, compared to PALANGAN's 2×2 configuration.
Conclusion: The study emphasizes the smart integration of environmental and astronomical factors in the spatial organization of terraced Iranian villages. The alignment of natural and built elements reflects advanced rural planning, highlighting the role of geomorphology and astronomy in shaping the settlement patterns of Masouleh, Abyaneh, and Palangan.

1. Introduction

A critical aspect of rural planning involves examining the influence of location and initial orientation on village design. In particular, villages characterized by "semi-contiguous rural areas with stepped

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Peer review under responsibility of Yazd Branch, Islamic Azad University

DOI: https://doi.org/10.30495/xxxxx.2023.1963135.xxxx

forms" provide a clear demonstration of this relationship. These stepped villages often emerge in response to the region's topography, climate, and socio-cultural practices, forming an intricate balance between human creativity and environmental constraints (Sarfo et al., 2024).

Among these, three notable terraced villages in Iran exemplify this archetype. They are celebrated as symbols of terraced rural settlements and showcase a harmonious interplay between human ingenuity and sacred geometry. This modularized positioning of architectural elements reflects a profound understanding of spatial organization influenced by both functional and symbolic considerations (Ghanbari et al., 2022). These patterns not only illustrate the villages' aesthetic and practical values but also emphasize their alignment with environmental and cultural contexts, making them timeless examples of sustainable rural design.

The routing of springs and the orientation of underground water tables play a critical role in shaping the spatial organization of villages. The medium height (MAD) of underground springs and their precise locations serve as foundational elements in determining the central axis of rural settlements. This natural framework not only influences the geographical layout but also reflects the harmonious integration of natural and cultural systems (Peach & Taylor, 2024).

The relationship between the four classical elements—water, earth, wind, and fire—has historically guided the placement and orientation of villages. These elements are intricately linked to the environmental and spiritual dimensions of settlement planning, with water being a particularly vital component in defining the central axis (Cao et al., 2024).

In this context, the ridge line and bottom line of the landscape act as guiding models for village design. Their orientation and alignment significantly impact the positioning of the central axis, serving as natural markers that define the core of rural settlements. This method highlights the profound connection between natural topography and human habitation, creating a sustainable and balanced approach to rural development (Cao et al., 2024).

The findings indicate that the development of village locations and their architectural principles in the region has been a dynamic and evolutionary process, yet strongly influenced by predetermined natural and cultural factors. The locational architecture of villages is deeply rooted in the principles of organic architecture, shaped by the interplay of topographical elements such as the central terrain and the surrounding mountain chains, including the Zagros and Alborz ranges. These natural features have historically provided a foundation for settlement planning, defining the orientation, structure, and functionality of rural areas (Reza, 2011).

According to the Comprehensive Encyclopedia of Vernacular Architecture by McColl (2014) topography can be classified based on distinct physical characteristics, encompassing eight primary types: subterranean, coastal, desert, forest, grassland, lacustrine, plain, marine, and littoral. Additionally, slope, elevation, and valley are included as crucial subcategories. Within this framework, this study narrows its focus to steep landscape areas, which present unique challenges and opportunities for rural design.

One notable feature of such landscapes is their "rippled" nature, which plays a significant role in shaping the spatial framework of villages. The interaction between this characteristic and other environmental factors has a profound influence on the morphology of traditional settlements, ultimately determining their sustainability, functionality, and aesthetic appeal (Liu et al., 2023).

The topography and location of land are profoundly influenced by natural factors such as rivers and mountains, which shape the environment and significantly impact human settlements. Historical evidence highlights how traditional villages like Masouleh have utilized an intelligent combination of natural and architectural strategies to achieve versatility and harmony with their surroundings (Daneshgar Nejad et al., 2022).

Masouleh exemplifies a sophisticated integration of the four classical elements—fire, water, earth, and wind—into its spatial and functional design. The alignment of solar noon (fire), the positioning of water springs, the ridgeline as a central axis (earth), and the southwest-northeast wind direction (wind) illustrate the village's effective adaptation to its environment. This modular and innovative approach has allowed Masouleh to create a sustainable and harmonious relationship with its natural surroundings (Daneshgar Nejad et al., 2022).

When compared to other traditional Iranian villages like Palangan and Abyaneh, Masouleh stands out for its unique ability to seamlessly blend environmental features into its architectural framework. The careful positioning of structures, the use of terraced designs, and the alignment with natural forces reveal an advanced understanding of how to maximize environmental benefits while preserving cultural integrity (Ghaderi et al., 2022).

The innovative use of the four elements in Masouleh's design demonstrates a sustainable and timeless architectural philosophy, which serves as a benchmark for rural planning and development. This comparison with Palangan and Abyaneh, as noted by Husain (2024), highlights the potential of integrating natural principles with architectural ingenuity to create enduring rural settlements.

The primary objectives of this study are twofold. First, it seeks to examine the impact of geographical orientation on the landmarking and spatial organization of ancient settlement textures and rural areas. This includes an analysis of the advantages and limitations posed by the presence of ridgeline angles in settlement layouts. Second, the study aims to uncover how traditional settlement morphology has been influenced by various environmental and topographical factors, including site selection criteria.

2. Material and Methods

2.1 Study Area and Case Selection

The study examines three notable Iranian villages: Masouleh, Palangan, and Abyaneh, each located in distinct geographical settings. Masouleh is situated in the lush, mountainous region of northern Iran, characterized by steep slopes and dense vegetation. Palangan lies in the rugged terrain of the Zagros Mountains in western Iran, marked by its stepped architecture and proximity to a river. Abyaneh, nestled on the slopes of the Karkas Mountains in central Iran, showcases a unique architectural style adapted to its arid and mountainous environment. These villages exemplify the interaction between natural geomorphology and human settlement patterns.

2.2 Research Objectives

The primary objectives of this study are:

- To analyze the impact of building orientation on urban routes and the central axis of villages.
- To investigate the alignment of ridgelines, direction of underground springs, and aquifer routing.
- To evaluate the role of natural elements, such as slope, elevation, and the Sinuosity Index (SIN), in determining the morphological patterns of these villages.
- To assess the relationship between entropy, geomorphological features, and spatial organization in these settlements.

2.3 Data Collection and Tools

The study employed a combination of geospatial analysis and computational modeling tools, including:

- AutoCAD and 3DMAX: For detailed architectural and spatial modeling.
- ArcGIS and Global Mapper: For topographical and geospatial data analysis.

- Box-Counting Method: For fractal dimension analysis and evaluation of spatial complexity.

Additionally, Digital Elevation Models (DEMs) were utilized to derive key metrics, such as slope gradients and SIN, which were critical for evaluating the topographical context of the villages.

2.4 Methodology

2.4.1 Topographical Analysis

The geomorphological framework was analyzed using trigonometric calculations to identify:

- Lowest and Highest Points: Determined using the slope and ridgeline orientation.
- Mean Average Deviation (MAD) of Elevation: Used to evaluate water table alignment and its relationship with settlement patterns.
- Contour and Curve Analysis: Identified using DEMs to understand the natural flow of the terrain.

2.4.2 Entropy and Fractal Analysis

The concept of entropy was applied to evaluate the spatial randomness and organization of the villages. Entropy was calculated using the formula:

$$P(X_i) \log P \sum - = H(X) \qquad \text{Equation (1)}$$

Where P (X_i) represents the probability of occurrence of a specific observation. High entropy indicated greater randomness in spatial distribution. The box-counting method was employed to calculate fractal dimensions, which provided insights into the complexity and modularity of the settlement patterns.

2.4.3 Spatial Orientation

The alignment of buildings and ridgelines was analyzed with respect to cardinal directions (north, south, east, and west). The proximity of alignment lines to the central core of each village was also assessed. Comparisons were drawn between the orientation of urban routes in the three villages, with a particular focus on Masouleh, which demonstrated innovative use of modularized patterns and natural elements.

2.4.4 Geoid and Level Surface Analysis

To evaluate the influence of geoid surfaces, the study considered their relationship with the Earth's physical features. The perpendicularity of geoid surfaces to the surrounding terrain was analyzed to understand its impact on settlement alignment and slope variation.

2.5 Key Parameters and Metrics

- Slope Gradients and SIN: Derived from DEMs to study mountain-front configurations.
- Fractal Dimensions: Evaluated using box-counting for visible zones on the terrain.
- MAD Height and Flow River Alignment: Investigated to understand the correlation between water flow and settlement axis.

2.6 Statistical and Comparative Analysis

The study incorporated comparative analyses to identify similarities and differences among the villages. Specific focus was placed on:

- The ratio of ridge angles to settlement alignment.

- The alignment of central landmarks in relation to topographical features.
- The use of modularity in settlement design.

2.7 Validation and Verification

The findings were validated using cross-referenced sources, such as the works of Talebnia et al. (2021). The study provided theoretical and practical frameworks for evaluating entropy, topography, and rural design.

2.8 Geoid and Topographical Features

2.8.1 Definition of Geoid

The geoid represents the Earth's surface when landmasses are excluded, focusing solely on oceans. It is a physical entity distinct from the mathematically defined reference ellipsoid. Unlike the ellipsoid, the geoid lacks a precise mathematical formulation and is characterized by being perpendicular to the surrounding surface at every point. This perpendicularity is a critical factor in understanding elevation and slope in geomorphological studies.

2.8.2 Level Surfaces and Contour Lines

- Level Surfaces: A horizontal surface is defined as a plane tangent to the geoid at a specific point (Fig.1).
- Curve Rate and Contour Lines:
- Curve rates refer to the lines that represent the height variation of points on a map.
- Contour lines connect points of equal elevation, forming measurement curves that illustrate terrain features (GORABI, 2016).

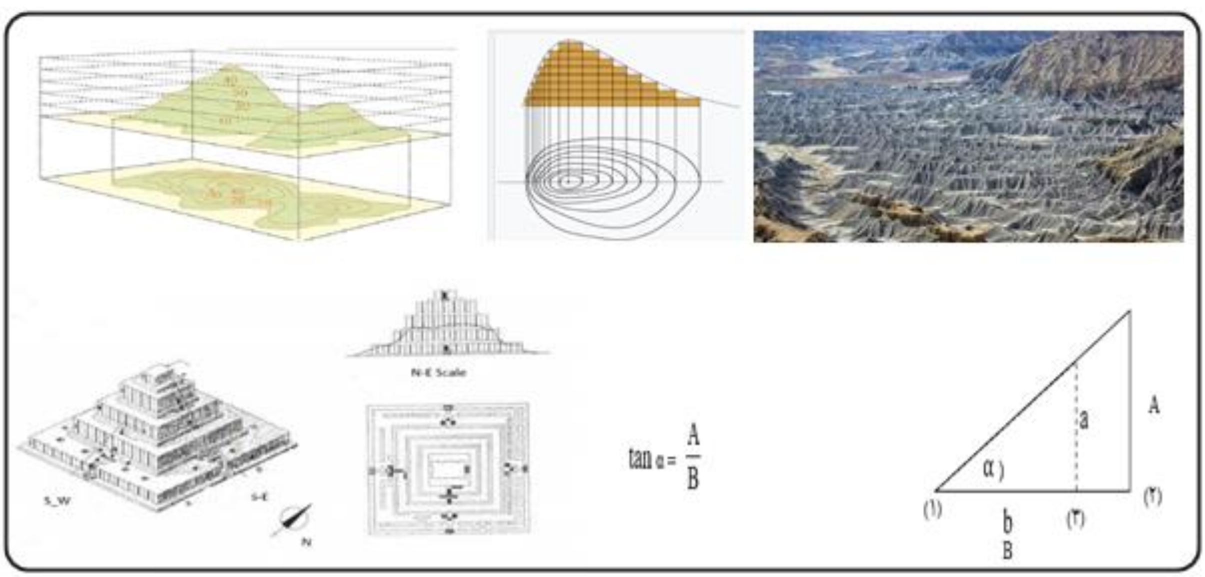

Fig. 1- Display of ten-meter height distances (contour lines) - The triangle method & MAD Hight

2.9 Entropy in Geomorphology and Topography

2.9.1 Concept of Entropy

Entropy, typically associated with disorder, randomness, or uncertainty, is a concept rooted in physics and chemistry. In the context of geomorphology and topography, entropy is used to study the spatial complexity and organization of natural systems, such as cities or villages. It is particularly valuable in understanding morphological evolution and the spatial patterns of settlements over time.

2.9.2 Characteristics of Entropy

Entropy is maximized when the available information is minimal.

A uniform distribution exhibits the highest entropy, as every event has an equal probability of occurrence.

The entropy formula is expressed as:

$$P(X_i) \log P(X_i) \sum - = H(X) \qquad \text{Equation (2)}$$

Where:

- X: Represents observations.
- $P(X_i)$: Probability of the i-th observation.

In a uniform distribution, where each event has equal probability ($P(X_i)=N/1$ entropy reaches its maximum value, equal to the logarithm of the number of observations. This relationship underscores the intrinsic connection between entropy and information theory (Rahmatabady & Amjadian 2020)

2.10 Triangle Method for Topographical Analysis

The triangle method was employed to analyze the topographical data, with a particular focus on the slope angles of the terrain. Three villages—Masouleh, Palangan, and Abyaneh—were selected as case studies for this analysis. The following key points were examined:

Point 1: The lowest point of the terrain, which served as a reference for comparison.

Point 2: The highest point of the terrain.

Slope of the Triangle: The slope between the lowest and highest points was measured but not analyzed in extensive detail.

Additionally, the Mean Absolute Deviation (MAD) was applied to calculate the medium height of each village, providing insight into the variation in elevation relative to the reference points. This metric is useful for understanding the overall topographical distribution and is especially relevant when studying rural settlements in mountainous regions.

2.11 Geographic Coordinates and Geomorphological Influences

2.11.1 Geographic Location of Iran

Iran is geographically situated between 25°3' and 39°47' north latitude, spanning approximately 14°44' in the northern hemisphere, which positions the country in the subtropical region. Longitudinally, Iran is located between 44°5' and 63°18' east, spanning approximately 19°13', placing it firmly in the eastern hemisphere. This unique geographic positioning significantly influences its topography and settlement patterns.

2.11.2 Geomorphological Context in Physical and Urban Development

Geomorphology plays a pivotal role in shaping the spatial distribution, physical development, and location of settlements, including villages and cities. The following aspects highlight its impact:

Impact on Development:

Geomorphic contexts influence the direction of urbanization and the initial siting of settlements (Mahmoudi, 1995)

- Physical Development:

Landforms determine the layout and configuration of residential areas, shaping future development trajectories.

- Spatial Distribution:

Geomorphological features influence settlement distribution, connectivity, and the sphere of influence within regions.

- Texture and Construction:

Built environments, such as villages and cities, are directly shaped by the geomorphic characteristics of their surroundings.

- Public Facilities and Services:

Infrastructure, transportation networks, and utilities are often planned based on geomorphological features (Tamadoni, 2014)

- Economic Activity:

Geomorphic contexts affect resource extraction, agricultural production, and other economic activities.

- Leisure and Recreation:

Landforms help identify areas suitable for parks, trails, and cultural centers, enhancing leisure opportunities.

2.11.3 Reciprocal Influences of Geomorphology

The primary objective of geomorphology is to elucidate the reciprocal relationships between settlements and their inhabitants, ultimately promoting the community's well-being. These influences include the physical transformation of land, zoning priorities, and topographical adaptation in urban and rural planning.

2.11.4 Comparative Analysis of Village Geographies

A comparative analysis was conducted for five villages situated in distinct geographic settings, considering the following parameters:

- Elevation
- Geographic coordinates
- Area
- Date of establishment

- Architectural styles

Fig. 2 provides a detailed summary of these comparisons, highlighting the interplay between geomorphic features and settlement characteristics.

The name of village /Coordinate	Picture	Geographic location Length & Width	Date and time of origin	Type of architecture
MASOULE 37°9′19″N–48°59′24″E		is located on a sharp slop and has two main slops including north-south and east-west. The height difference between its peak point and ground level is almost 100 meter	MASOULE has been named "the second cultural-historical region in the world after VENICE in Italy" by UNESCO organization. This mountainous and forested division has approximately 1000 years old	The buildings have been built into the mountain and are interconnected. Courtyards and roofs both serve as pedestrian areas similar to streets. MASOULEH does not allow any motor vehicles to enter, due to its unique layout.
PALANGAN 35°4′3″N–46°36′15″E		the length:46 degree & 36 min Width :35dgree &4 min Northern Slope and DEJAN Castle Among the mountains of SHAHU Slope in 2 direction N to S & vice versa . Slope 35-40 degree	Seljuk era, castle of SAMANIAN period	Complex – Semi –attachment architecture Mass The roof of each house is the yard of the next
ABYANEH 33°35′11″N–51°35′27″E		From the main road of NATANZE _KASHAN, there is a winding road that goes 22km deep into the mountains, passes several villages, and reaches to a valley with a historic village sitting in it The structural texture of "spiral" village houses corresponds to three periods Seljuk, Safavid, Qajar and there is no dead end in it	There is no evidence to indicate the exact date of the village but historians know that it has been around since Sassanid dynasty (700 AD) for sure. Seljuk period /dates back to 1500 years ago	ABIANEH village is the curious ochre red color that has painted the whole village. is constructed as on different levels on the slope, where one may notice some houses with their rooftops as the yard of the houses on the upper level.

Fig. 2- comparison of village locations, Impact on development, creation, and initial locating

2.12. Typology and Research Background

2.12.1. Impact of Groundwater Pumping on Earth's Rotation

The extensive extraction of groundwater by humans has influenced Earth's rotational dynamics. A study published in Geophysical Research Letters reveals that between 1993 and 2010, groundwater pumping shifted the Earth's axis by approximately 80 centimeters (31.5 inches) east. This shift is attributed to the redistribution of 2,150 gigatons of groundwater, causing a 6-millimeter (0.24-inch) rise in sea levels (Dzombak, 2023, June).

Water movement affects the Earth's mass distribution, altering its rotational pole through a process known as polar motion. Researchers modeled these changes by examining the combined effects of ice sheets, glaciers, and groundwater redistribution. The study found that the midlatitudes, particularly western North America and northwestern India, played a significant role in influencing polar drift due to the volume of water removed.

Although polar motion shifts do not currently pose risks to seasonal changes, they may have long-term implications for climate patterns over geological timescales. The findings underscore the substantial contribution of groundwater pumping to Earth's rotational behavior and global water dynamics.

2.13. Human Impact on Floods: A Case Study of Masouleh

2.13.1. Study Area

The study area, Masouleh, is located within the CHOCHOB natural geography and is characterized by glacial fine-grained sediments. Its latitude spans 37°47'10" to 37°51'46" north, and its longitude ranges from 48°53'56" to 49° east, with a mean elevation of 1,883 meters above sea level. The region exhibits a maximum elevation of 3,600 meters, a minimum of 850 meters, and a 48% terrain gradient.

The flood channel in this area measures 8.7 kilometers in length, with a calculated flood slope of approximately 17.5% and a time of concentration of 42 minutes (Gourabi, 2013)

2.13.2. Methods

The study employed geomorphological methods and utilized reference maps, including a 1:25,000 scale topographic map from the Natural Resources Organization and a 1:250,000 scale geological map produced by the Geological Organization. These data sources were complemented by field observations, GIS-based spatial analyses, and statistical tools such as Windsurfer and Minitab.

The study's findings emphasize the critical role of domain management in watershed flooding and highlight human contributions to flood initiation through land use practices and environmental changes.

3. Result

3.1 Geological and Hydrological Characteristics of the MASOULEH Basin

- The MASOULEH basin is comprised of four minor basins, with Khalil DASHT in the south serving as the primary region affected during the significant flood event of 1998. The geological structure of this minor basin reveals distinct altitudinal zonation (Fig. 3):
- Upper Elevations: Characterized by Permian-era limestone formations.
- Lower Elevations: These extend to the mainstem of the MASOULEH River and are marked by partially weathered white and grey limestones containing Cretaceous-era ammonites, along with Triassic quartzite, lime, and shale.
- Above an elevation of 1,100 meters, the geological composition is dominated by fine-grained glacial deposits. These deposits are relatively deep-seated, containing prominent glacial cirques and moraines, which extend approximately 5 km from the town and are visible up to an altitude of 850 meters. Along the valleys leading into the MASOULEH valley, such as GHALE ROUDKHAN and KARGANRIVER in TALESH, similar glacial sediments are present. These findings highlight the geomorphological complexity and the legacy of Quaternary glacial processes.

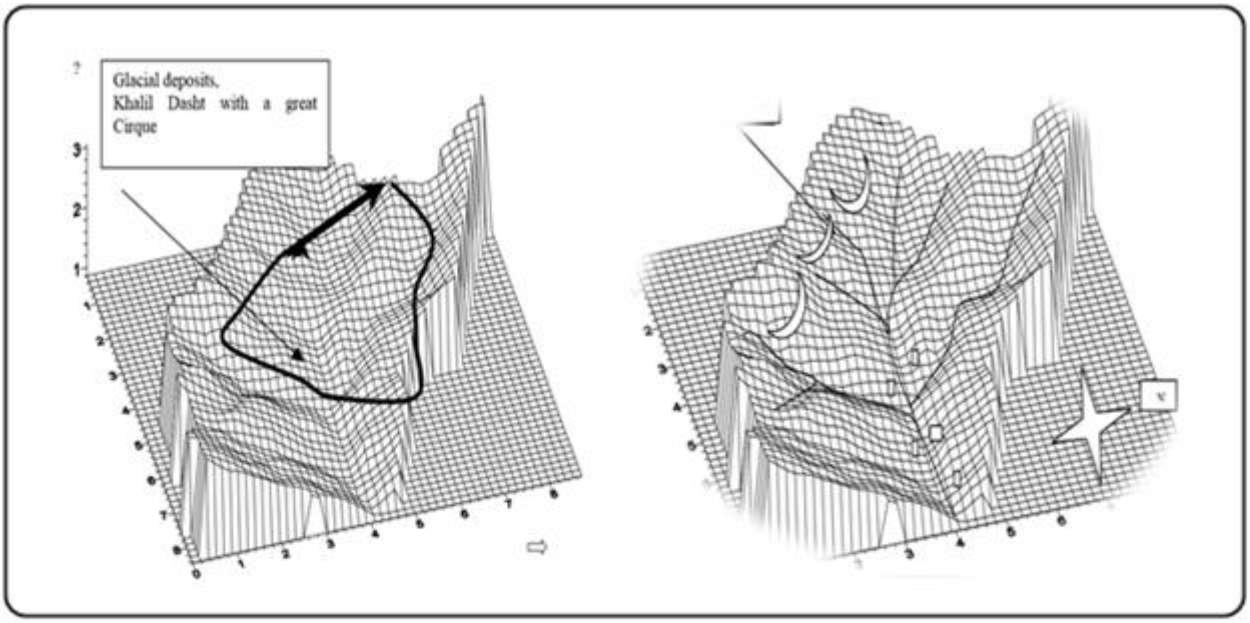

Fig. 3- Natural Geography and Geomorphological Context of Glacier Deposits in the MASOULEH Basin & Glacial Sediments of the Geomorphological Center

3.2 Rainfall Analysis and Its Inadequacy in Explaining the Flood Event

- An in-depth analysis of rainfall data from the MASOULEH basin and surrounding regions recorded on July 31, 1998, reveals a discrepancy between rainfall statistics and the observed water levels during the flood. The rainfall recorded that day was mild and statistically insufficient to justify the significant flood event.
- Rainfall Intensity: Based on statistical probability, such an event is expected to occur only once every five years. Notably, no similar flood event has occurred since.
- Runoff Coefficient: Despite a runoff water coefficient of 46%, only 5.4 mm of precipitation was directed into channel flow, indicating that the rainfall was not the primary driver of the flood.

3.3 Primary Causes of the 1998 Flood Event

The genesis of the flood can be attributed to a combination of geological, hydrological, and environmental factors:

- Glacial Sediments and Porosity:

  The upper elevations in the southwestern region of MASOULEH town are characterized by fine-grained, glacial sediments of Quaternary origin. These porous sediments in the MALARZAN DASHT area have facilitated precipitation infiltration, leading to the accumulation of large underground reservoirs over time.

- Groundwater Discharge:

Excess water from these reservoirs has been draining as natural springs at lower elevations. This gradual discharge mechanism created a latent hydrological vulnerability, contributing indirectly to the flood's intensity by altering the natural water balance and influencing the statistical restitution cycle.

3.4 Implications for Flood Risk Management

- The findings suggest that the 1998 flood was not merely a result of isolated meteorological phenomena but a complex interaction of geomorphological and hydrological factors. This highlights the need for integrated watershed management practices, including:
- Monitoring of Glacial Deposits: Regular assessment of glacial sediments and their water retention capacities.
- Groundwater Reservoir Management: Strategies to regulate discharge rates from underground reservoirs.
- Enhanced Rainfall Analysis: Incorporating geomorphological and hydrological data into flood prediction models.

3.5 Topography of MASOULEH and ABYANEH Villages

MASOULEH Village

The morphology of traditional settlements like MASOULEH is closely tied to environmental and topographical characteristics that influence the site selection and layout. Located on steep terrain, the village exemplifies the concept of "undulation" in its design, where the natural landscape is integrated into the architectural framework (Fig. 4).

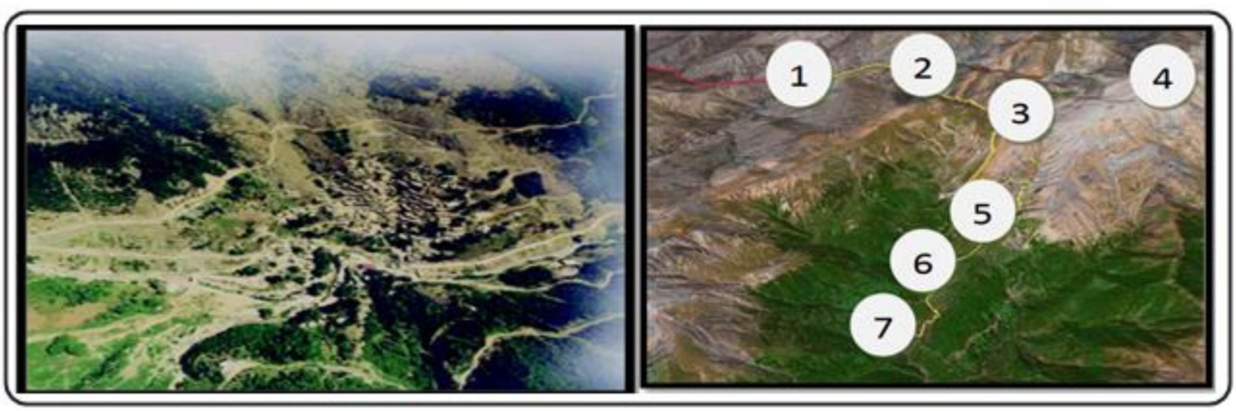

Fig. 4 -Topographical Map of MASOULEH: 1. Black River, 2. Tazekand, 3. Andareh, 4. Kooh Shah, 5. Olad Way, 6. Mirza, 7. MASOULEH.

- Classification of Topography:

  According to Paul Oliver's taxonomy in the *Encyclopedia of Vernacular Architecture*, the topography of MASOULEH aligns with the "slope" and "upland" categories. The steep topography forms the backbone of the village's cascading architecture.

- Natural Features:

  Rivers and mountains dominate the natural environment, influencing the settlement's arrangement and providing natural boundaries. Houses are constructed in terraces, where the roof of one unit often serves as a pathway for another at a higher elevation.

- Adaptation to Terrain:

MASOULEH demonstrates a deep integration with its environment, reflecting vernacular strategies to optimize space on challenging terrain while preserving the ecological and visual harmony of the site.

ABYANEH Village

ABYANEH is situated within the BAZROOD Valley, nestled between two foothills. The village benefits from natural protection against desert winds and exhibits unique spatial constraints that shape its growth and layout.

- Geographical Features:

The village is located on the northern slope of the valley, with the steep slopes of the KARKAS Mountain range to the north and agricultural lands to the south. The height difference between the highest and lowest points is approximately 70 meters, with an east-west orientation.

- Architectural Integration:

Similar to MASOULEH, ABYANEH demonstrates an unmanipulated approach to the natural environment. Residential units follow the contour lines of the terrain, and the rectangular-shaped houses are constructed parallel to the village's main pathway. The roofs of houses serve dual purposes, functioning as pedestrian pathways for higher-elevation buildings, reflecting a harmonious balance between architecture and topography.

3.6 Flood Risk Zoning Using GIS and RS Techniques

The MASOULEH watershed spans an area of 4,195 hectares in the west of FOMAN, approximately 60 kilometers from Rasht. Its geographic coordinates range from (Figs. 5 and 6):

- Longitude: 48°54'26" to 49°0'11" E (metric 314,164 to 322,680).
- Latitude: 37°06'24" to 37°11'31" N (metric 4,108,607 to 4,118,180).

Hydraulic Modeling and Flood Analysis

A hydraulic model of the MASOULEH River was developed using HEC-RAS software integrated with the HEC-GEO RAS extension. This model facilitated flood risk zoning and identified areas vulnerable to high discharge flows.

- Flood Characteristics:
- The study revealed that the large volume of water and the duration of flooding play significant roles in the impact on the MASOULEH watershed.
- Extreme Discharge Events:

  The high-intensity discharge flow poses significant risks to the surrounding settlements and infrastructure, emphasizing the need for effective flood management strategies.

- Implications for Regional Planning

The results of flood risk zoning underscore the importance of using GIS and remote sensing (RS) techniques for:

1. Identifying vulnerable zones within the watershed.
2. Enhancing the design of hydraulic infrastructure to mitigate flood impacts.
3. Informing urban and rural development strategies that prioritize resilience against natural disasters.

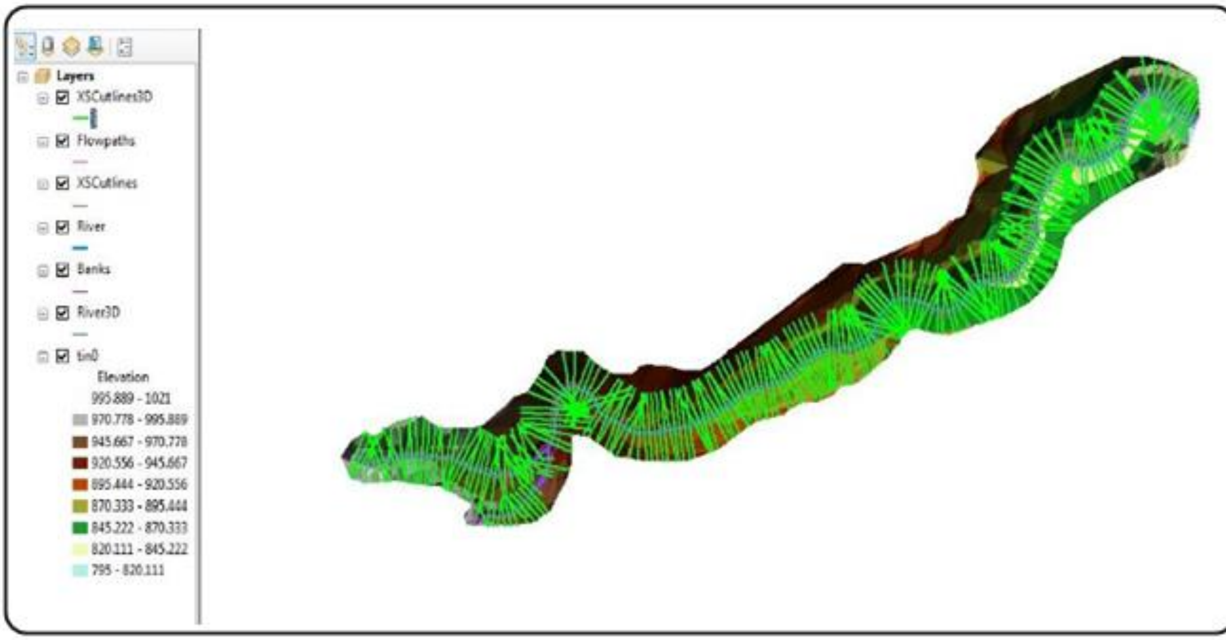

Fig. 5-Transverse Sections and Layer Preparation Using HEC GEO RAS Software

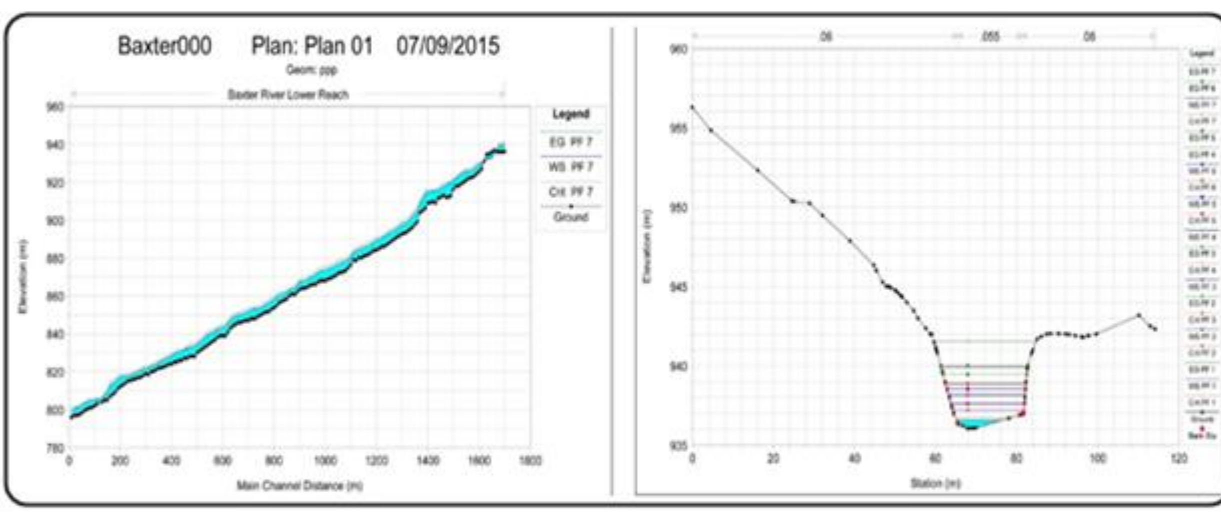

Fig. 6-Transverse and Longitudinal Profiles for 2-year and 200-year Periods.

3.7 Mapping Information for Analysis

This study employed comprehensive mapping techniques to analyze the region's topography and hydrology. Key features included cross-sectional profiles, channel geometry, and waterway slopes calculated using TIN (Triangulated Irregular Network) in HEC-RAS software.

The mapping process generated schematic plans of the river system, detailed profiles, and flood discharge data. Hydraulic calculations, such as flow dynamics and discharge rates, were performed to evaluate flood risks and identify high-risk zones.

The findings provide critical insights for flood risk zoning, water resource management, and infrastructure planning, enhancing resilience against natural hazards (Fig. 7).

Fig. 7- The flood zone in the return period of 2 and 200 years

3.8 Analysis and Outputs

3.8.1. Flood Zoning and Hydraulic Modeling

A detailed hydraulic analysis was conducted to simulate longitudinal, transverse, and three-dimensional sections of the river. This allowed for the generation of a table of hydraulic parameters and the creation of flood zoning maps for areas at risk. The results, spanning flood recurrence intervals of 2 and 200 years, were visualized using Google Earth and KML files. Historical records show that the most severe flood occurred in 1377, with most flooding events triggered during spring and summer due to the rapid basin response to heavy rainfall.

Geomorphological Influence on Village Architecture

This study compared the cube-shaped "ridge and bottom" architectural style of MASOULEH, ABYANEH, and PALANGAN, analyzing the impact of geomorphological entropy on settlement design. Geomorphological and architectural data were derived using satellite imagery, digital elevation models (DEM), and field evidence, analyzed with tools such as Global Mapper, AutoCAD, and 3DMax.

Key metrics calculated included:

- Mountain Front Sinusitis Index (SMF): SMF=LMF/Ls
- Cut Percentage (FD): FD=LMFD/Ls

3.8.2. Comparative Analysis of Village Elevations

MASOULEH:

- Lowest elevation: 840 m
- Highest elevation: 1120 m
- Main level curve interval: 20 m

PALANGAN:

- Lowest elevation: 975 m
- Highest elevation: 1200 m
- Main level curve interval: 50 m

ABYANEH:

- Lowest elevation: 2208 m
- Highest elevation: 2277 m
- Main level curve interval: 30 m

This analysis highlights the influence of geomorphological features on settlement layout, reflecting adaptations to slope, elevation, and topographical constraints (Figs. 8, 9, 10, 11).

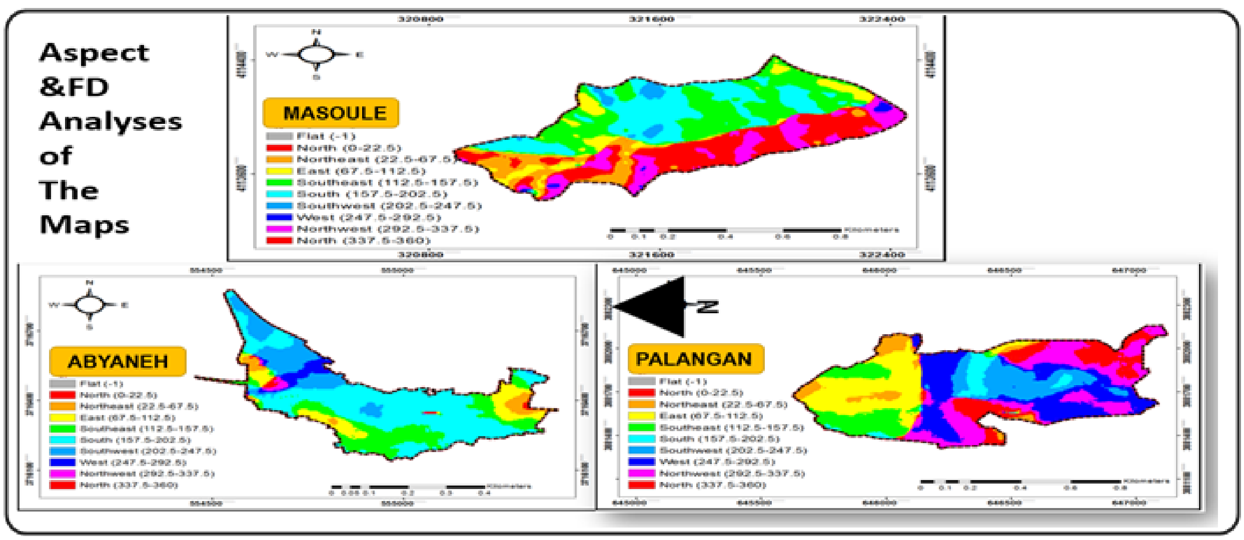

Fig. 8 - DEM (Digital Elevation Model) Height Calculated Based on Relative House Elevations

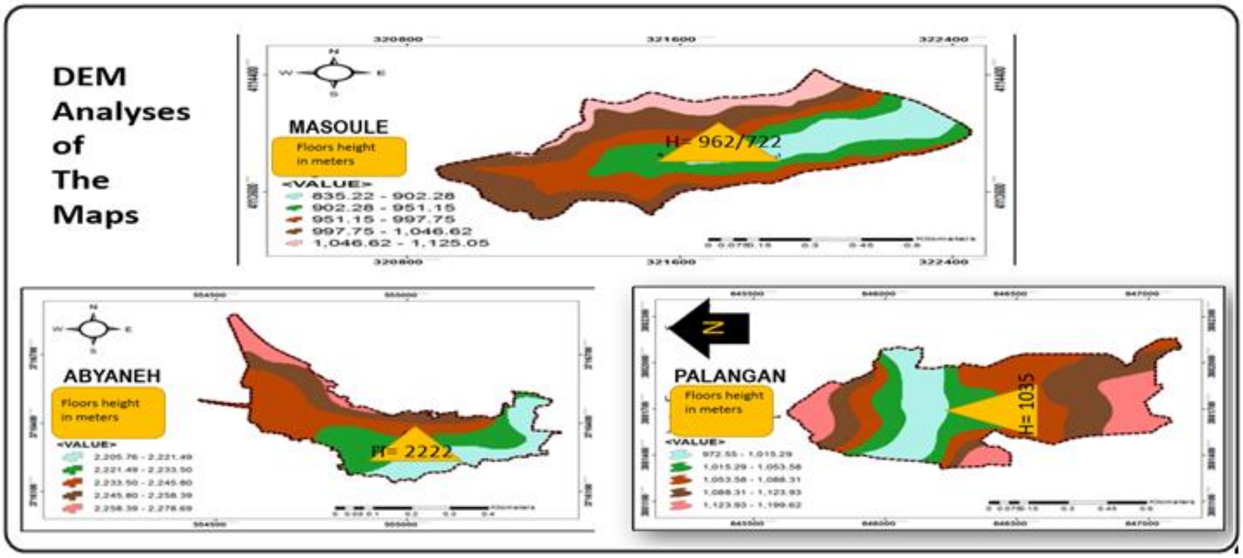

Fig. 9- Aspect (Mountain Front) Calculated Based on Relative House Elevations

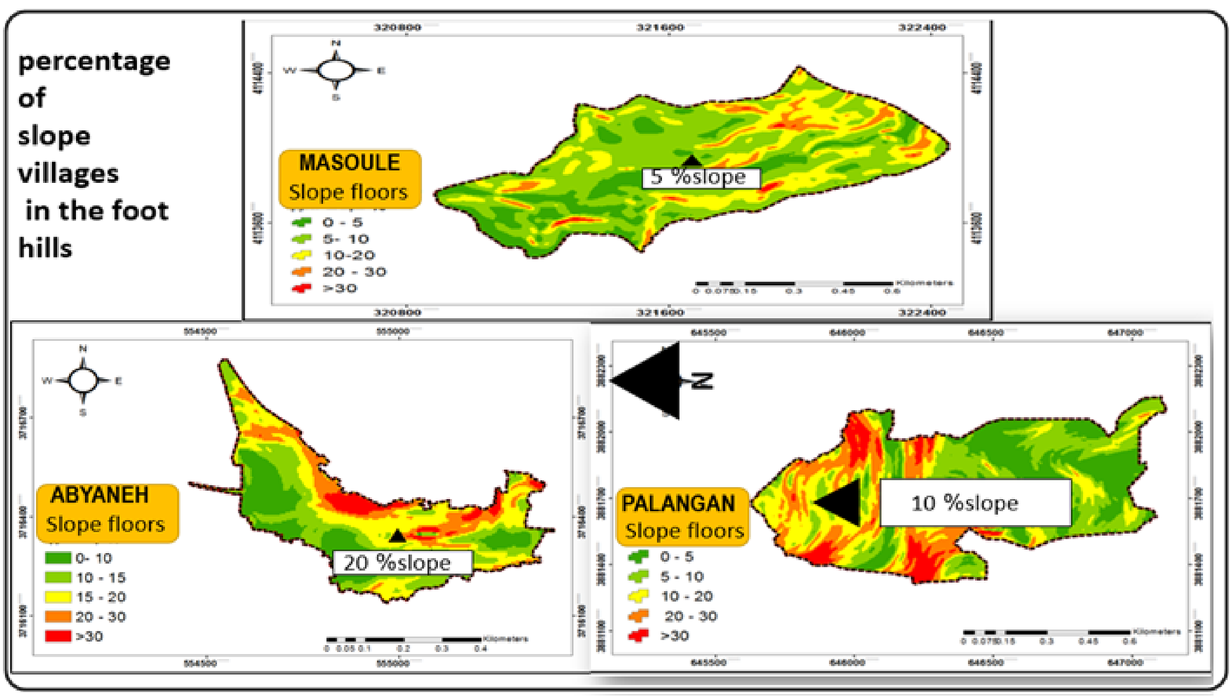

Fig. 10- Percentage of Slope in Villages Located in the Foothills

It is evident that the three villages—MASOULEH, ABYANEH, and PALANGAN—display notable differences in their elevations along the alignment curve. The highest elevation of ABYANEH, which is roughly twice that of MASOULEH and PALANGAN, highlights the variation in topographical characteristics. The distance between the main levels of the curves is relatively consistent at 20 meters for MASOULEH and 50 meters for PALANGAN. Similarly, the sub-curve intervals, which follow a 1:4 ratio (20 meters in MASOULEH and 5 meters in PALANGAN), also exhibit consistency.

Interestingly, while the lowest and highest elevations along the level curve vary, there is no clear correlation between the distance between the main and sub-level curves and entropy or natural location factors in the villages. These differences point to a more complex set of influences at play. It appears that the initial siting of these settlements was not determined solely by geomorphological factors. Instead, the orientation and alignment of each village's architecture, characterized by a "cube shape" with ridges and bottom lines following foothill axes, were crucial in determining their spatial distribution. Thus, these villages' topographical settings, although significant, were likely secondary to architectural and functional considerations shaped by their environment (Fig.11).

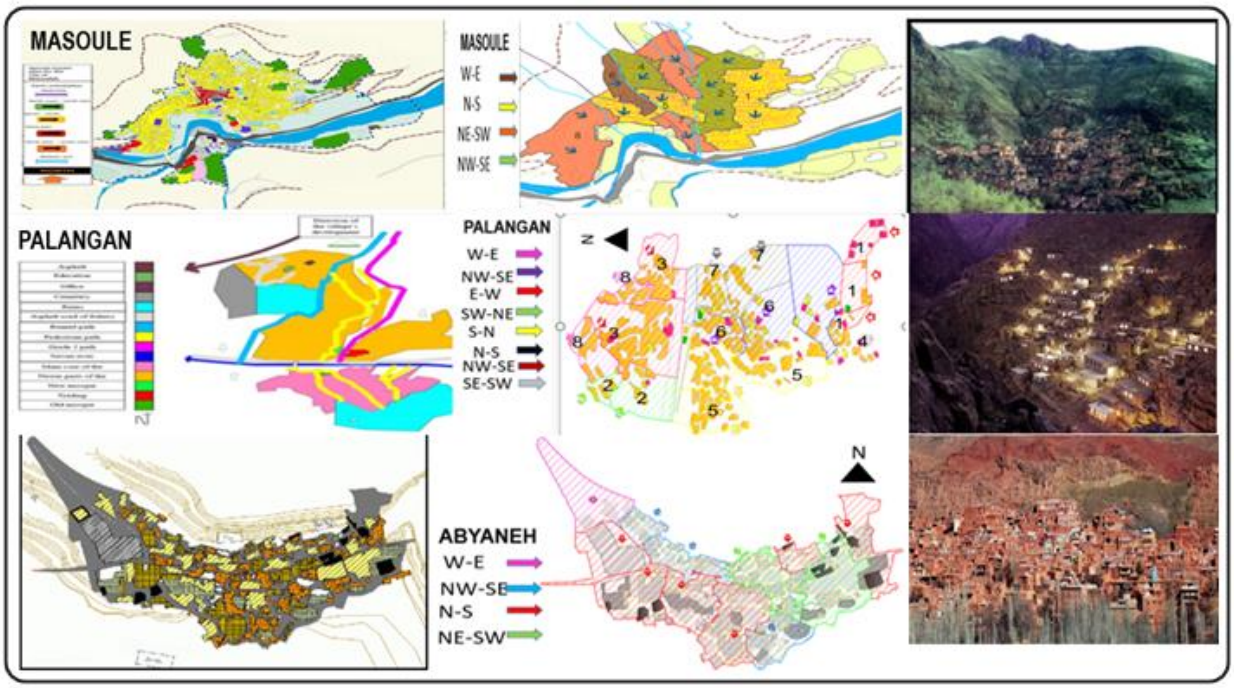

Fig. 11 - Orientation of Buildings Towards the Four Main Directions of the Mountain Front

4. Discussion

Geomorphological Factors and Village Locating in Relation to Flood Risk and Natural Geography

- Natural Locating and Physiographic Features

The natural placement of the three studied villages—MASOULEH, ABYANEH, and PALANGAN—shows a clear relationship between geomorphological features and settlement formation. As noted by Ismaili Aba Zar and Abdullahi Khodiar (2010) and supported by Najar pour Siyahkal et al. (2023), the physiographic characteristics of each village significantly influence its spatial orientation, elevation, and susceptibility to natural disasters such as floods.

The physiographic analysis included parameters such as maximum and minimum heights, height differences, and median heights. The median height, a critical metric for understanding the hydrological and geomorphological distribution, was classified and superimposed on AutoCAD land use and building plans. This provided insights into the interaction between natural geography and settlement planning, showing that the villages are located in areas where water availability and flood risks are balanced by strategic elevation placement.

- Rainfall and Flood Risk Analysis (31st July 1998 Event)

The flood event of July 31, 1998, demonstrated that mild rainfall alone could not account for the observed flood magnitude. A coefficient of runoff water at 46% with only 5.4 mm channeled highlights indirect geomorphological factors. Groundwater flow, slope gradient, and sediment retention likely played pivotal roles in amplifying the flood's impact.

Researchers investigating this event suggest that indirect factors, such as geomorphological characteristics and land-use changes, have a substantial influence on flood dynamics. This aligns with the findings of Wells (1988), who emphasized the importance of geomorphological processes in altering flood frequency and intensity.

- Comparative Analysis of Three Villages

The comparative physiographic analysis revealed distinct differences among the villages:

MASOULEH: Exhibits moderate elevation gradients with a focus on strategic placement along ridges and valleys to optimize water retention and minimize flood risk.

ABYANEH: Positioned at higher elevations, with a median height nearly double that of MASOULEH and PALANGAN, highlighting its unique adaptation to steep slopes and minimal flood vulnerability.

PALANGAN: Displays a ridge-based settlement pattern with frequent interaction with water flow paths, indicating an adaptive strategy for water accessibility and flood mitigation.

These distinctions underscore how geomorphological diversity influences settlement patterns, as seen in the calculated average slope percentages, length-to-width ratios, and ridge orientations.

- Influence of Water Flow and Settlement Centralization

The reclassification of height maps and analysis of water flow paths reveal a significant correlation between village center orientation and hydrological parameters. Villages appear to be centralized around focal points where water flow and elevation meet optimal conditions for settlement sustainability.

This aligns with traditional rural planning principles, where settlements are intentionally positioned to balance access to water resources with flood risk minimization. Such strategic planning demonstrates a "smart attitude" in selecting locations that consider long-term geomorphological and hydrological stability.

- Findings from Slope and Elevation Analysis

Analysis of ridge, bottom, and slope angles further elucidated the geomorphological dynamics at play. The variations in elevation and slope across the villages point to unique adaptive strategies:

MASOULEH and PALANGAN exhibit more frequent sub-level curves, indicating a finer adaptation to local micro-topography.

ABYANEH, with its steep terrain and higher elevation, demonstrates a focus on minimizing erosion and optimizing solar exposure.

Visual Evidence

Figs 12–16 provide critical visual support for these findings, illustrating the relationships between slope gradients, elevation distributions, and settlement layouts. These diagrams reinforce the argument that geomorphological entropy and hydrological dynamics are central to understanding village formation.

This discussion establishes a comprehensive understanding of how natural geography and geomorphological factors shape rural settlements in Iran. To further strengthen these conclusions, comparisons with previous studies, such as those by Mokhtari (2006) and Wells (1988), can be integrated to validate the role of hydrological and geomorphological processes in rural architecture and flood risk management.

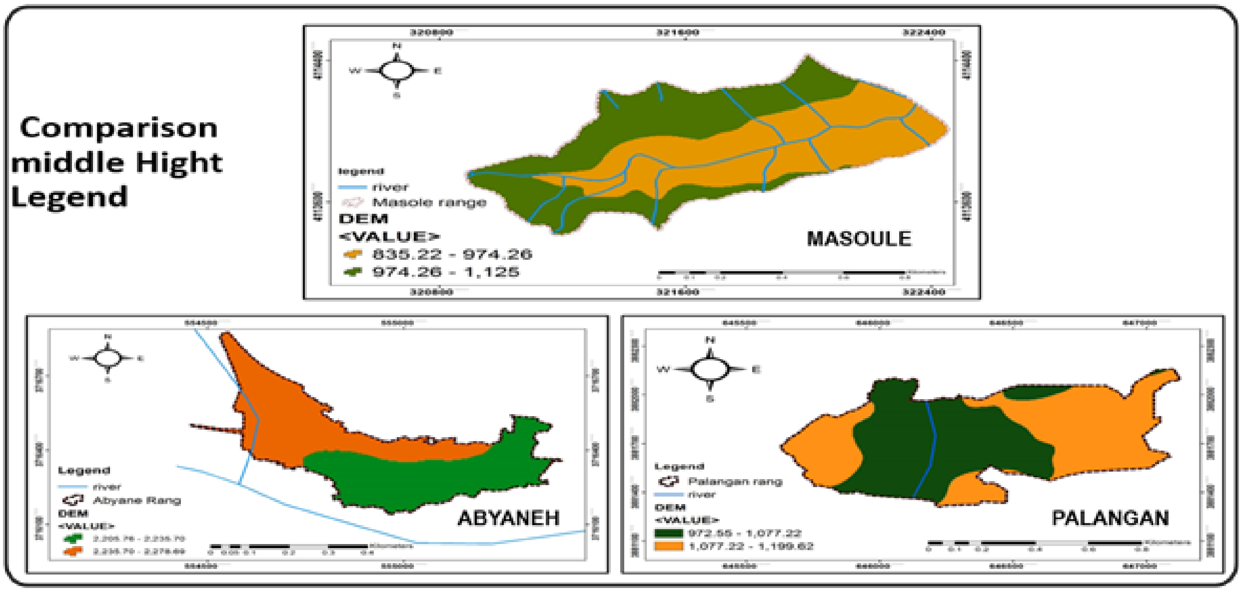

Fig.12- Comparison of Middle Hight Legend

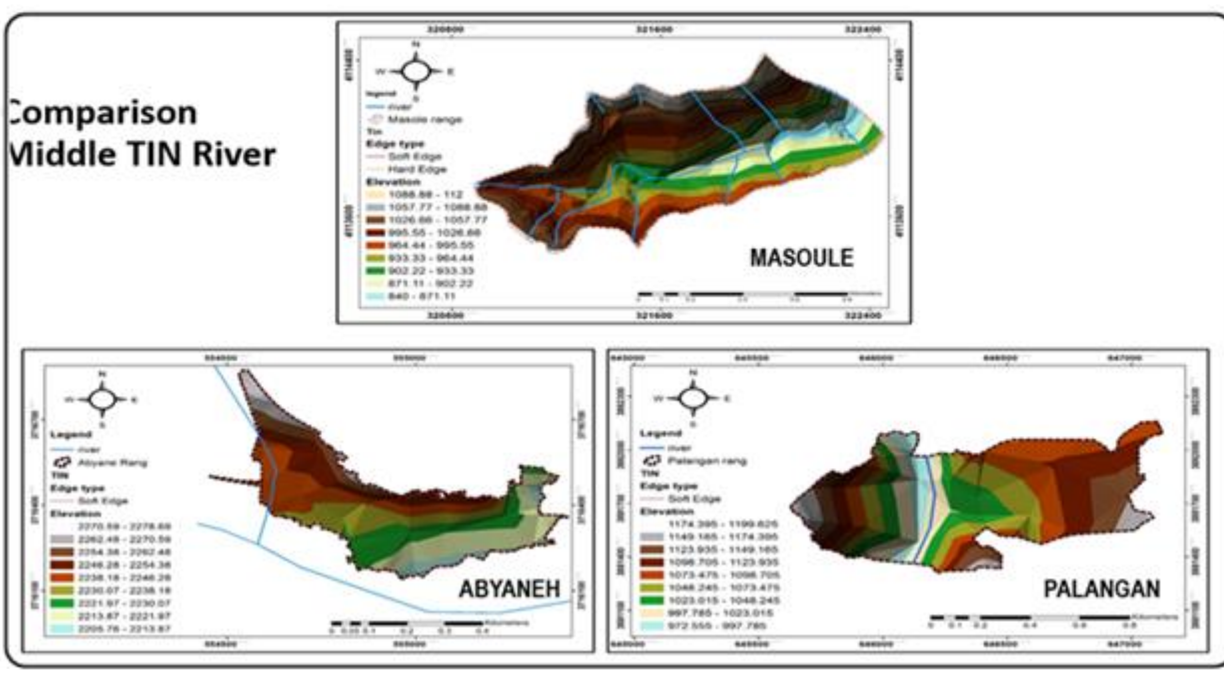

Fig.13 - Comparison of Middle TIN River

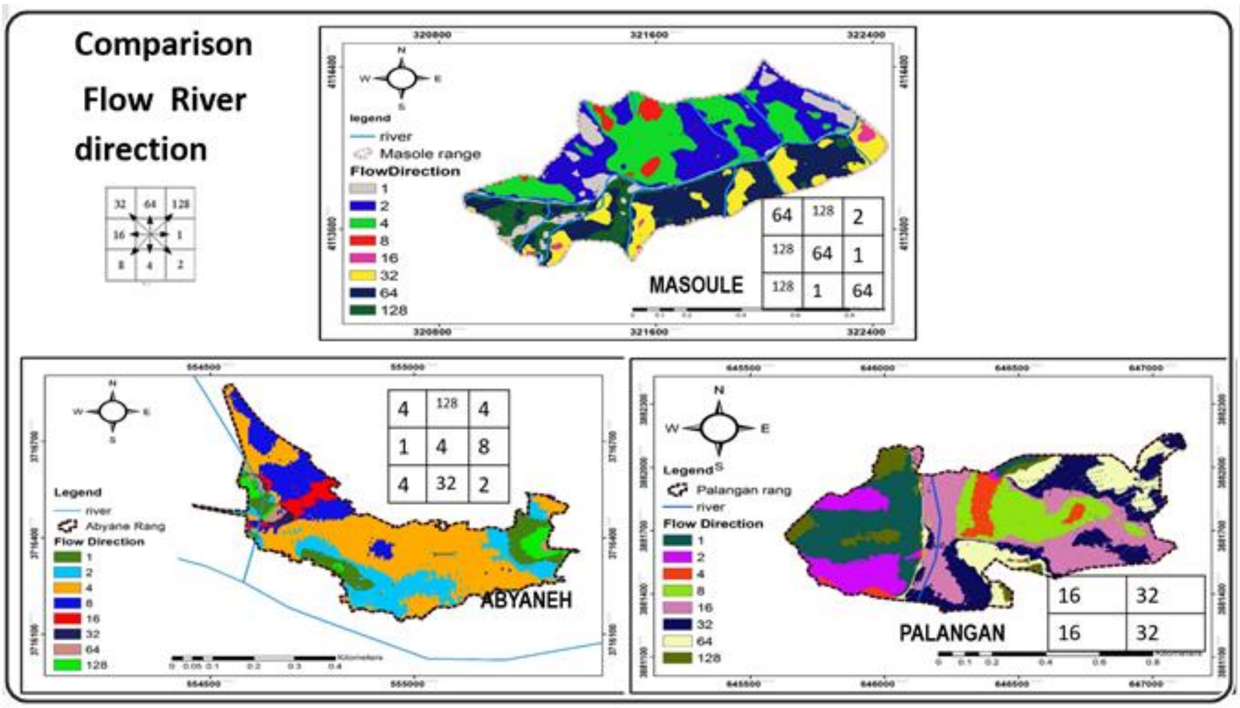

Fig. 14 - Comparison of Flow River direction

MAD high	Hectare area	Height floors
	11.798	902.28 - 835.22
	16.458	902.28 - 835.22
	19.982	951.15 - 902.28
*	21.721	997.75 - 951.15
	7.968	1,046.62 - 997.75

The middle height of MASOULEH 974/26 Meter

MAD high	Hectare area	Height floors
	4.74	2,221.49 - 2,205.76
	5.90	2,233.50 - 2,221.49
*	6.53	2,245.80 - 2,233.50
	3.47	2,258.39 - 2,245.80
	1.85	2,278.69 - 2,258.39

The middle height of ABIYANEH 2235/70 Meter

MAD high	Hectare area	Height floors
	11.54	1,015.29 - 972.55
	14.70	1,053.58 - 1,015.29
*	19.65	1,088.31 - 1,053.58
	17.46	1,123.93 - 1,088.31
	13.11	1,199.62 - 1,123.93

The middle height of PALANGAN 1077/ 22Meter

Fig. 15 - Comparison Middle height & MAD is mainly direction It corresponds to the middle height by hectare meter

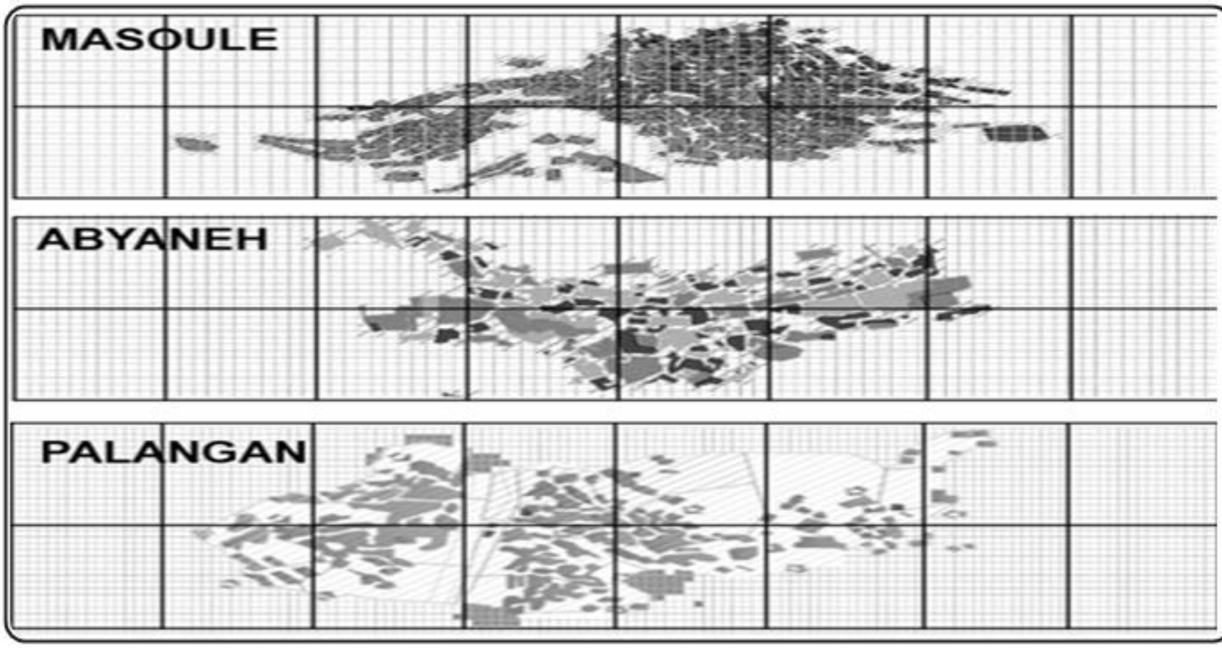

Fig. 16- Box-Counting Analysis of Urban Patterns in MASOULEH, ABYANEH, and PALANGAN

The fractal dimensions of the urban patterns in MASOULEH, ABYANEH, and PALANGAN were analyzed using a cubing algorithm to calculate adjacent and non-adjacent zones visible to the facades (Fig. 17). The study applied an iterative box-counting method, dividing the area into 16 boxes (7.32 meters each) in the first step, then progressively increasing to 64, 256, 1024, and 4096 boxes. This approach revealed distinct fractal ratios for each village, reflecting their spatial complexity and interaction with natural topography. MASOULEH demonstrated the highest complexity due to its dense terraced layout, ABYANEH showed moderate complexity with balanced adaptation to steep terrain, and PALANGAN exhibited simpler patterns, aligned with its linear ridge-oriented development. These findings highlight the influence of geomorphological entropy and adaptive settlement strategies in shaping the villages' unique urban structures.

$$D_{\text{MASOULEH}} \ \frac{(\text{Box},0.9\text{-}0.4)=[(\text{Log}664)-(\log 206)]}{[(\log 128)-(\log 64)]} = \frac{2.822-2.313}{2.107-1.806} = \frac{0.509}{0.301} = 1.691$$

$$D_{\text{ABYANEH}} \ \frac{(\text{Box},0.9\text{-}0.4)=[(\text{Log}583)-(\log 192)]}{[(\log 128)-(\log 64)]} = \frac{2.765-2.283}{2.107-1.806} = \frac{0.482}{0.301} = 1.601$$

$$D_{\text{PALANGAN}} \ \frac{(\text{Box},0.9\text{-}0.4)=[(\text{Log}598)-(\log 204)]}{[(\log 128)-(\log 64)]} = \frac{2.\ 79-2.36}{2.107-1.806} = \frac{0.43}{0.301} = 1.\ 433$$

Fig. 17- Formulas Representing the First, Second, Third, Fourth, and Fifth Iterations of Urban Patterns in MASOULEH, ABYANEH, and PALANGAN, with the Last Iteration.

Fig 18 illustrates the results of the box-counting method applied to the urban patterns of MASOULEH, ABYANEH, and PALANGAN, highlighting their fractal dimensions across different grid sizes. The increasing box counts from 16 to 4096 grids demonstrate the spatial complexity of each village. MASOULEH consistently exhibits the highest values, reflecting its dense terraced structure, while ABYANEH shows moderate values, aligning with its balanced adaptation to terrain. PALANGAN, with slightly higher counts than ABYANEH, indicates a simpler linear organization. These differences underline the geomorphological and architectural adaptations specific to each settlement.

GRID size	Box Number	BOX –counting		
		MASOULEH	ABYANEH	PALANGAN
8	16	7	8	11
16	64	21	22	28
32	256	64	63	72
64	1024	206	192	204
128	4096	644	583	598

Fig. 18 - Number and Size of Boxes Used in Different Iterations.

The analysis reveals distinct variations in the fractal dimensions and geomorphological characteristics of the three villages. MASOULEH exhibits the highest fractal dimension range ($1.585 < D < 1.691$), indicating a higher degree of self-similarity in its urban pattern compared to ABYANEH ($1.458 < D < 1.607$) and PALANGAN ($0.966 < D < 1.433$). This suggests that the terraced layout and compact spatial structure of MASOULEH reflect greater geometric complexity.

When comparing river path elevations, MASOULEH and PALANGAN share relatively similar values, while ABYANEH's river path elevation is approximately double that of the other two villages, reflecting significant topographical distinctions. The Triangular Irregular Network (TIN) analysis shows overlap in the river path for MASOULEH and PALANGAN at lower elevations, whereas ABYANEH exhibits a higher elevation overlap, aligning with its elevated location.

In terms of river flow direction, MASOULEH and ABYANEH demonstrate vice-versa directional codes in a 3×3 table, contrasting with the mirrored 2×2 flow direction observed in PALANGAN. Additionally, the middle height and hectare-to-floor ratio differ significantly: MASOULEH's MAD direction area is triple that of ABYANEH, while ABYANEH's floor height is 2.5 times greater. PALANGAN, in turn, exhibits a hectare area half that of ABYANEH but with a floor height approximately half as high. This inverse relationship between MAD hectare area and floor height across the three villages emphasizes the interplay of geomorphological constraints and settlement design (Figs. 19–23).

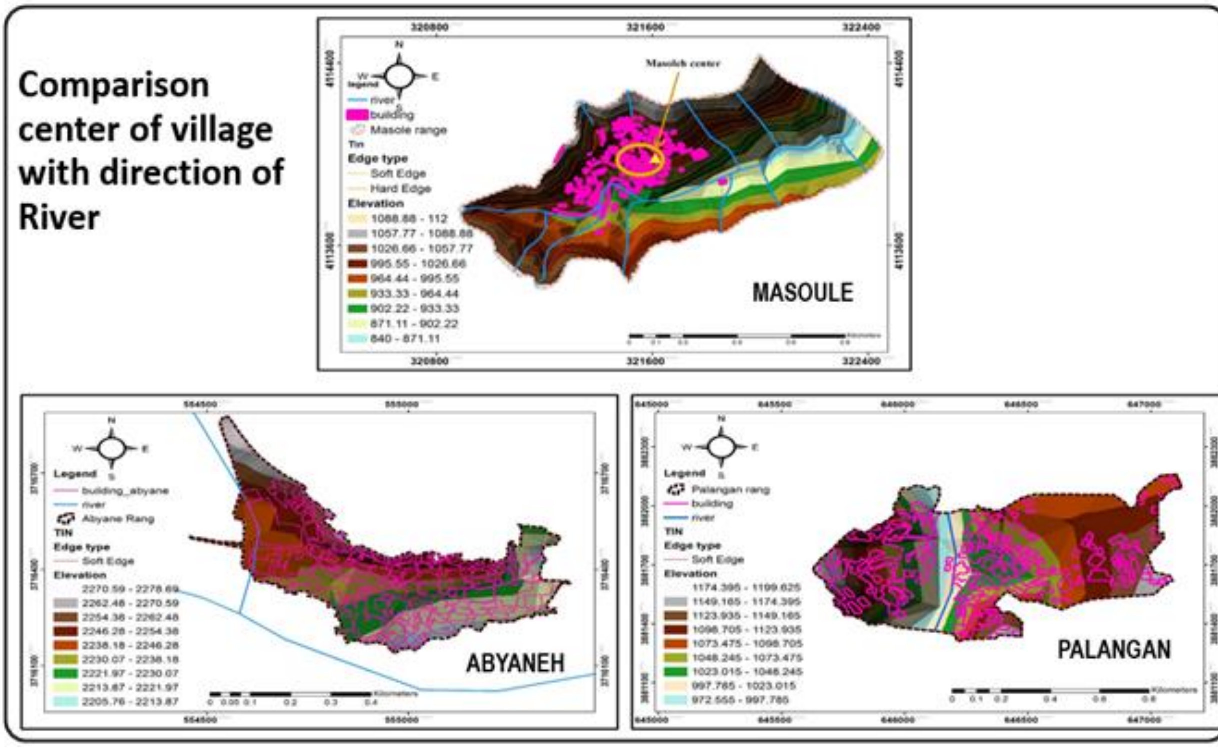

Fig. 19- Comparison of Village Center with River Direction and Altitude Based on MAD Overlaps

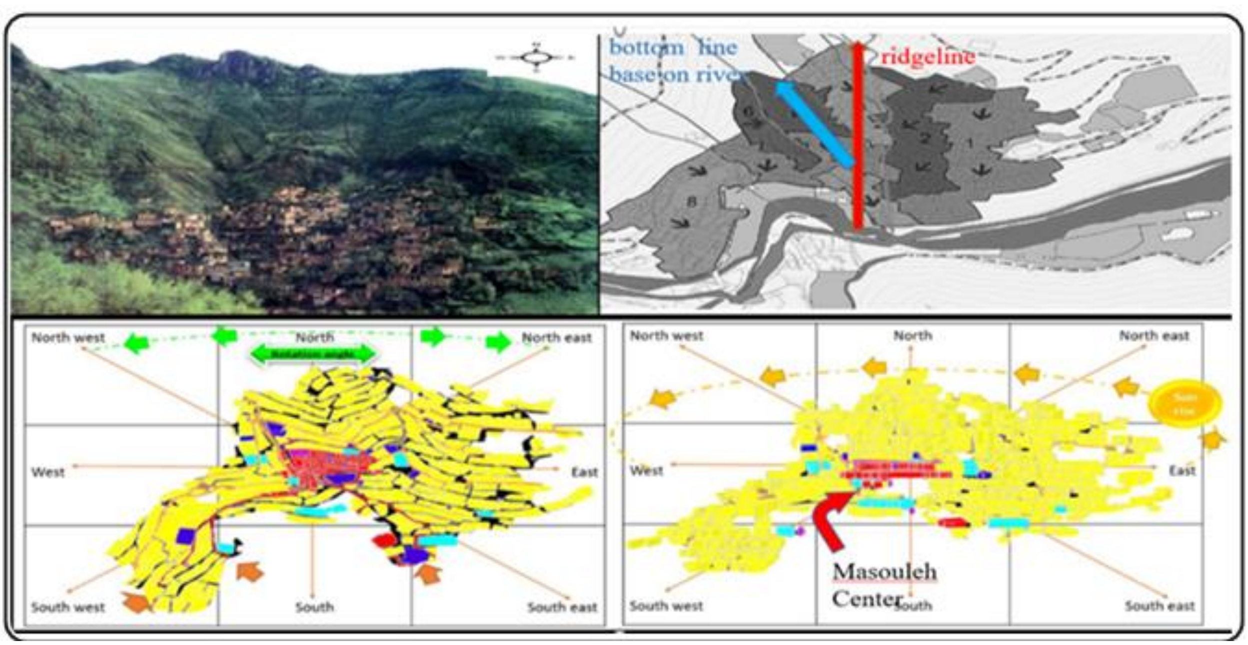

Fig. 20- Comparison of River Direction, Bottom Line of River, and Ridgeline with MASOULEH Center

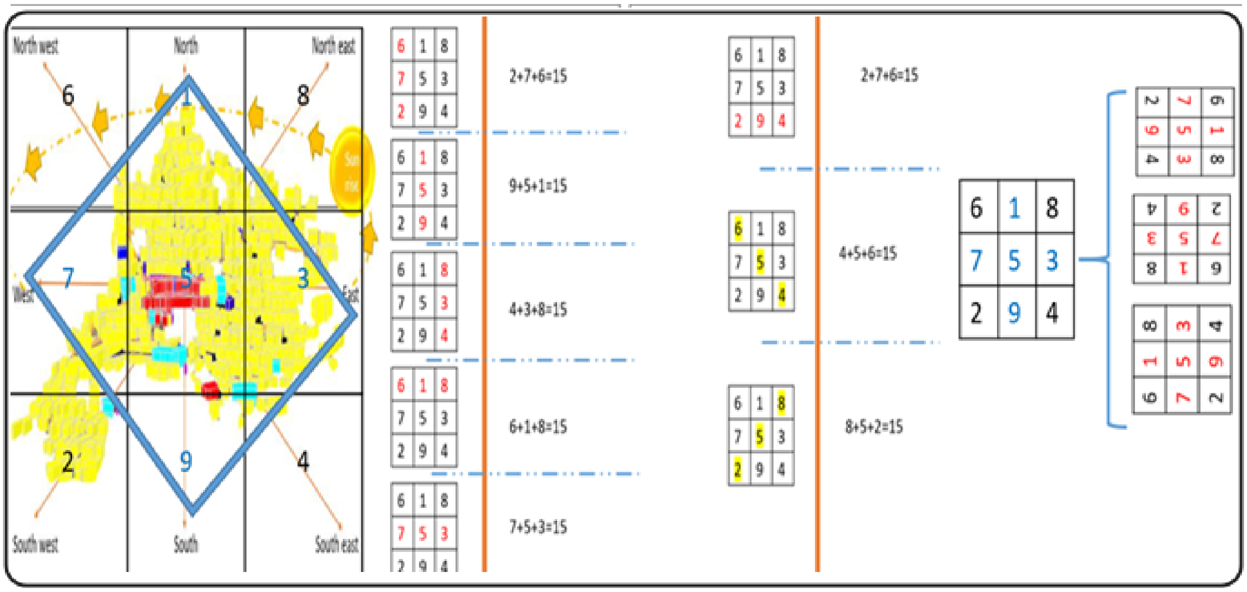

Fig. 21- Comparison of River Direction, Bottom Line of River, and Ridgeline with MASOULEH Center, Magic Square 3x3 (Cube), and the 4th Element

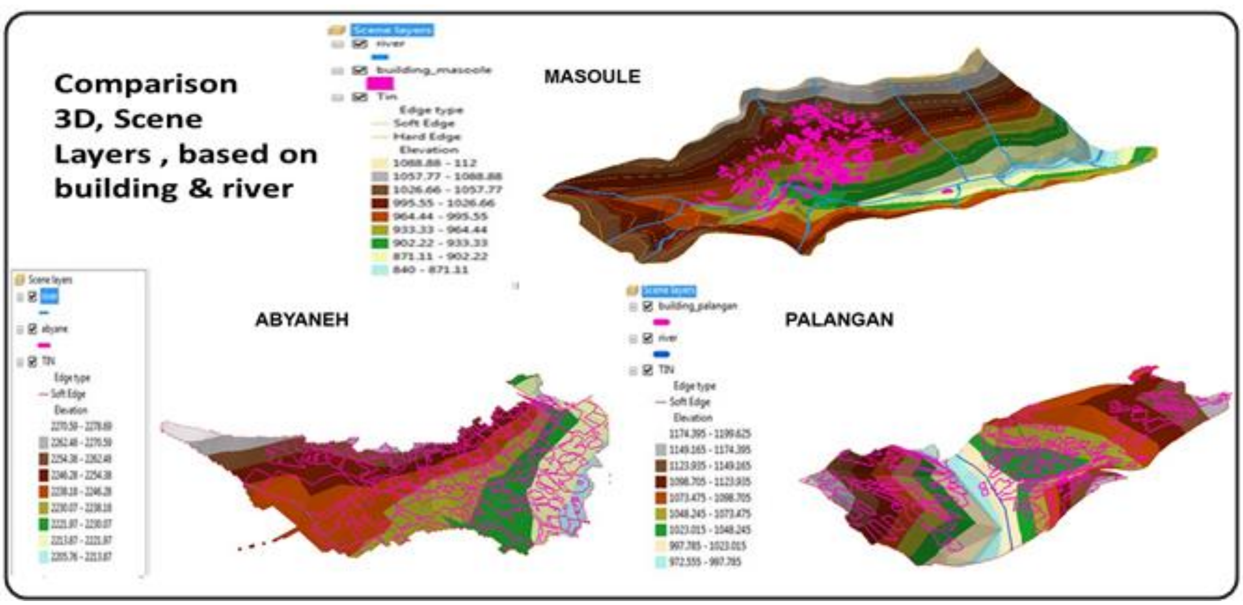

Fig. 22 - Three-Dimensional View Comparison of Scene Layers Based on River Direction, Bottom Line of River, and Ridgeline

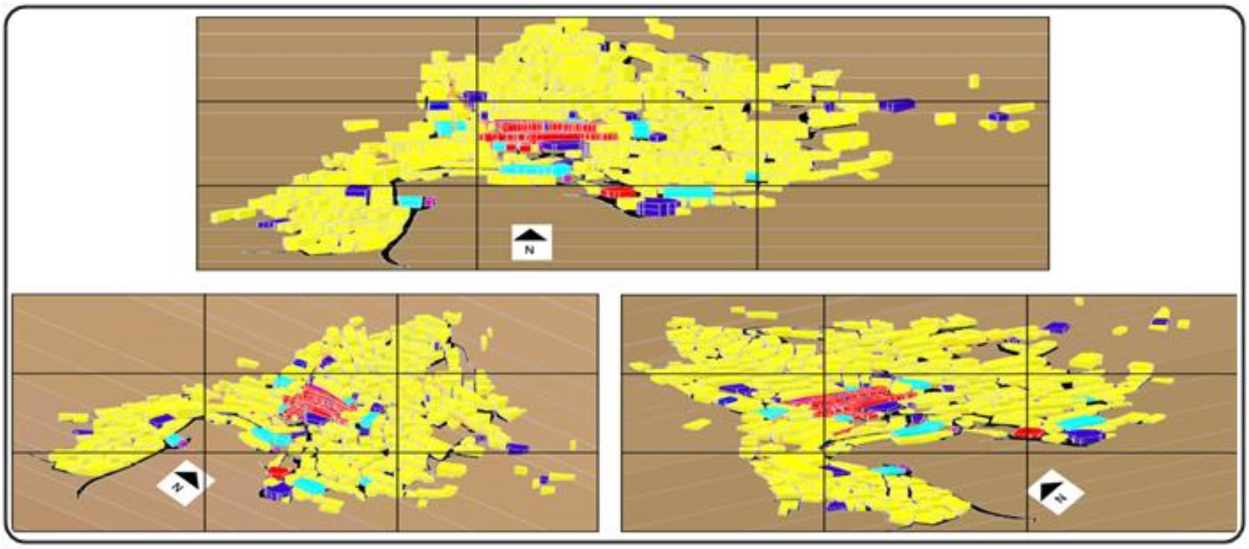

Fig. 23- Three-Dimensional View of Bottom Line of River and Ridgeline Compared with MASOULEH Center (Bazaar)

The orientation and spatial organization of MASOULEH's urban center highlight the ingenuity of ancient Iranian architects in integrating natural geography with settlement planning. The alignment of the village center, influenced by the direction of river flow and MAD height, underscores the profound relationship between geomorphology and urban design. The overlap between ridgeline and bottom-line directions further reflects a harmonious adaptation of the village structure to its natural environment.

This study revealed variations in the ridgeline angles and their indirect effects on underground springs and aquifers, which are influenced by rotational direction and altitude. The relationship between MAD height and hectare area illustrates a proportional balance, reflecting the village's sustainable integration of spatial and natural elements.

Additionally, the comparison across the three villages identified consistent mathematical and numerical ratios tied to specific heights, indicating shared geomorphological patterns and sacred geometric principles. These ratios, unique to each village, suggest a deliberate application of universal design codes, allowing for sustainable and enduring settlement systems. Such findings highlight the enduring legacy of our ancestors' architectural wisdom, rooted in an understanding of mystical and mathematical archetypes.

5. Conclusion

The spatial organization and architectural patterns of the three villages—MASOULEH, ABYANEH, and PALANGAN—reflect the intelligent integration of natural geography, topography, and traditional planning principles. The bazaar in MASOULEH is strategically located at the center, influenced by the middle height of the area, overlapping with the Magnetic Anomaly Detection (MAD) point. This centrality, tied to underground water and magnetic fields, highlights the alignment between the village's layout and its geological features.

In MASOULEH, underground water plays a pivotal role in determining the village center and bazaar location, emphasizing an innovative understanding of hydrology and geography. Similarly, the spatial patterns in ABYANEH and PALANGAN demonstrate thoughtful adaptation to environmental constraints, such as steep slopes and river paths. The alignment of architectural forms with ridgelines, bottom lines, and contour lines indicates deliberate planning based on topographic and hydrological factors.

The study reveals that the villages share consistent numerical ratios and height modules, pointing to an inherent geometric and proportional system. MASOULEH exhibits higher self-similarity and entropy, with a majority of houses oriented northeast, suggesting advanced planning principles. The northward orientation of ridgelines and the inverse relationship between MAD height and hectare area further underline the integration of natural and architectural elements.

Ancient Iranian settlements, as seen in these villages, reflect a "smart" or "intelligent" design approach, where natural features such as underground springs, solar positions, and mountain ridges were effectively utilized. The proportional alignment ratios (1:2, 1:4, 2:4) and geocentric evaluations highlight a profound understanding of sacred geometry and environmental adaptation.

Key insights for future research include:

- The significance of alignments based on geocentric and bottom-line factors.
- The role of approximate alignments in understanding changes over time.
- The importance of underground springs and their alignment with architectural features.
- The deliberate orientation of settlements, particularly the northward alignment of ridgelines and uniform northeast-facing structures.

Ultimately, the findings underscore the exceptional intelligence and ingenuity of ancient Iranian architects in designing sustainable rural settlements adapted to their environment, as exemplified by MASOULEH's central landmark aligning with the sun and water points. This study bridges traditional knowledge with modern spatial analysis, offering a framework for exploring sustainable design in similar contexts.

Acknowledgements

We would like to express our sincere gratitude to all those who contributed to this study.

Declarations

Funding Information (Private funding by authors)

Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (Not applicable)

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