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Geomorphic Hazards of Torrential Floods in Wadi Abu-Hasah El-Bahari and their Impact on the Royal Tomb of Akhenaten, Minia Governorate, Upper Egypt

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ABSTRACT:

Wadi Abu-Hasah El-Bahari is located in the Minia Governorate, Upper Egypt, around 60 km south of Minia city. Geomorphologists, archaeologists, and anyone concerned with preserving Egypt's pharaonic heritage are particularly interested in this valley because it exposes this beautiful Royal Tomb of Akhenaten to the hazards of frequent torrential floods. Given the design of the tomb's construction and the potential for subsequent flooding, weathering processes and soil erosion pose significant hazards for the tomb. The objective of this paper is to define the effects and causes of geomorphological hazards caused by floods on the Wadi Abu-Hasah El-Bahari basin and the royal tomb of Akhenaten. To do this, we will use satellite images, do a lot of fieldwork in the valley, and use runoff analysis, which includes a number of morphometric parameters and valley flood analysis models, to find possible dangers from heavy floods in the valley basin and around the royal tomb. The study shows that the tomb's location at the same level as the bottom of the valley stream makes it particularly vulnerable to damage from debris torrent processes stemming from flood events in the Wadi. The result is that past sediment accumulations in various channels along the Wadi have become mobilized during these periods of flooding and now pose a risk to Tomb Conservation through post-flooding debris deposition.

Keywords: The Royal Tomb of Akhenaten, geomorphic hazards, torrential floods, Wadi Abu-Hasah El-Bahari, Minia Governorate, Egypt

1. Introduction

Floods are a prevalent natural calamity that frequently transpires in the majority of semi-arid basins (Martelo and Wang 2024). The flash floods pose a significant hazard to infrastructure and human life. Additionally, they impact the country's business and economy and pose a threat to archaeological locations. The current study focuses on the flash flood effects that Wadi Abu-Hasah El-Bahari has had on ancient sites in Tell el-Amarna, particularly the Royal Tomb of Akhenaten, with the goal of mitigating the flash flood threats that these sites face. The article suggests a method to safeguard the tomb from the dangers of flash floods. This involves the use of a geographical information system (GIS) and remote sensing technologies to analyze the flow of water in the watershed during the torrential floods.

Over the past years, torrential floods have occurred primarily in the area of the Royal Tomb of Akhenaten, causing severe damage. One section of the compound wall collapsed, causing damage to the northern hall and the architraves above the burial chamber. Both the drawings and the actual tomb, specifically Akhenaten's royal tomb's northern wall, contained salt deposits. Here, we propose a new and faster method for the photographic and topographic documentation of archaeological sites (Redford 1987).

Akhenaten, the heretic pharaoh of the 18th dynasty, has intrigued many. Born Amenhotep IV (the son of the powerful pharaoh of Egypt, Amenhotep III, and the absolutely stunning Queen Tiy), he grew up inside Akhetaten, a city he built specifically to house his monotheistic cult of the god Aten, the physical manifestation of the sun. He ruled Egypt from 1352–1336 BCE and changed many aspects of Egyptian life. His revolutionary beliefs in his god and his humble status before him have left early scholars in a dilemma, which has made him a keen subject of debate for scholars up to the current day. Akhenaten, the heretic pharaoh of the 18th dynasty, has intrigued many. Born Amenhotep IV (the son of the powerful pharaoh of Egypt, Amenhotep III, and the absolutely stunning Queen Tiy), he grew up inside Akhetaten, a city he built specifically to house his monotheistic cult of the god Aten, the physical manifestation of the sun. He ruled Egypt from 1352–1336 BCE and changed many aspects of Egyptian life. His revolutionary beliefs in his god and his humble status before him have left early scholars in a dilemma, which has made him a keen subject of debate for scholars up to the current day (Stevens 2021).

1.2. Previous work

Several scholars, including (Labib 1981; El-Shamy 1992), Gheith and Sultan 2002; El-Zawahry et al. 2006; Abdel-Lattif 2012; Moawad et al. 2016), have studied the geomorphic hazards of torrential floods in some wadis in the Eastern Desert. Only one study (Zaid et al. 2013) researched the flash flood hazards of the Tell el Amarna area and Wadi Abu-Hasah El-Bahari, and they did not confidently utilize hydrological analysis models for streams.

1.3. Objective

This study's primary goal is to investigate how high-magnitude, low-frequency floods deplete the Wadi Abu-Hasah El-Bahari. We undertake this to enhance our comprehension, pinpoint, and safeguard the crucial cultural assets vulnerable to harm and devastation from these occurrences, particularly the Royal Tomb of Akhenaten. An understanding of the erosional and sediment transport processes is essential to assessing and predicting site instability and vulnerability to flood damage; however, work of this nature has rarely been attempted, and only a few studies have focused on protecting cultural resources from natural processes in Egypt.

1.4. Methods

This study employs geomorphological and geoarchaeological research methods, conducting a detailed geomorphological field survey of the valley to investigate the causes of its shape changes and the impact of floods, particularly in the vicinity of the royal tomb near the ancient city of Tell el-Amarna. To find out what risks might come from heavy flooding in the valley basin and around the royal tomb, it is necessary to look at and understand satellite images, do a lot of work in the valley itself, and use runoff analysis, which includes analysis of the hydrological characteristic's variables.

Wadi Abu Hassa's location at the valley's bottom, along with the tomb's excavation into living rock and abandonment in front of it, make it vulnerable to floods. Determining the impact of the flood on the tomb is essential because some Egyptian antiquities have suffered significant damage due to recent flooding in the Nile Valley, and there has been growing concern about the ultimate fate of ancient Egyptian antiquities among the global scholarly and heritage communities. As a result, a key consideration in this work is to create applied geomorphological knowledge that benefits local and national authorities responsible for managing and conserving Egyptian heritage sites. By providing an objective flood risk assessment, we can assist in developing protection strategies and, if necessary, mitigation measures to lessen the impact of flooding on the tomb.

2. Study area

2.1. Location

Wadi Abu-Hasah El-Bahari is located in the eastern desert in Minia Governorate. It originates from the Red Sea Mountain range at a level of 268 m above MSL and empties into the Nile River at the ancient city of Tell el-Amarna at a level of 45 m above MSL, with a basin length of about 21.4 km and a slope of about 10.2 m/1 km. The coordinates of the upper sources of the basin are 27° 3742 22 N and 31° 5 5' 53 59"N, while the coordinates of its mouth are 27°38'48 66"N and 30°53'28.20"E (Fig. 1).

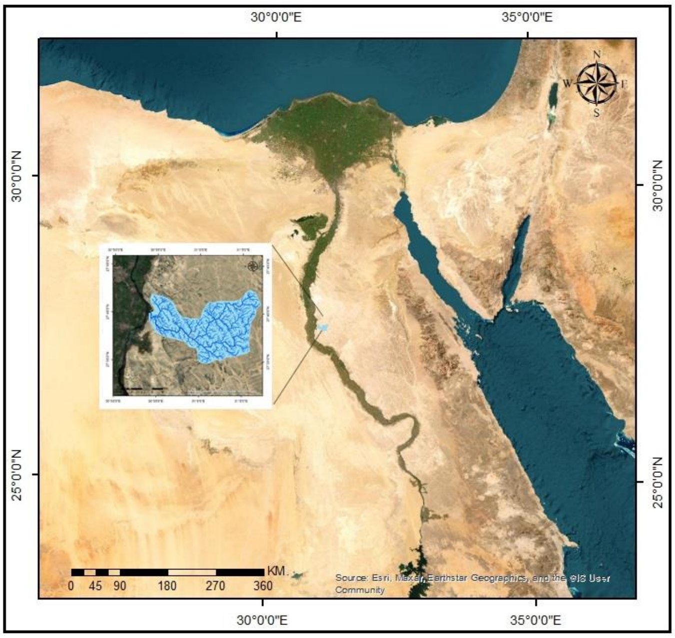


Fig.1: Location of the study area

The valley is one of the steepest in the area, with such steep sides that it looks V-shaped, deeply incised, and predominantly oval in shape. It has a narrow floor and flat-lying inner and side-stream terraces. The abandoned floodplain is laterally unstable, as indicated by numerous landslides and material creep. Channels are characterized by steep gradients and frequently changing bed gradients, and bedload dominates the valley floor. All of these are classic signs that a stream is adapting to tectonic uplift and has a lot of sediment available. Together, they make the beginning parts of the Abu-Hasah El-Bahari channels very susceptible to debris. These flood events are the most common in the Wadi, occurring at least once a year in certain parts of the catchment. The steep stream channels, where they most commonly occur, are ideal for transporting debris and sediment downstream. Eocene limestone and claystone make up the majority of the bedrock in Wadi Abu-Hasah El-Bahari. These rocks are rare in large, bare areas. Instead, these rocks are found in areas with boulders and pebbles, where the sediment is more resistant to flood-induced erosion. The channel frequently undercuts these boulder deposits to form small steps and ledges, causing the deposition to occur immediately downstream of the obstruction, which means that Wadi is a working system that is to some degree unstable. Akhenaten built the city of Tell el-Amarna on the alluvial fan of the Abu Al-Hasah El-Bahari basin (Figs. 2).

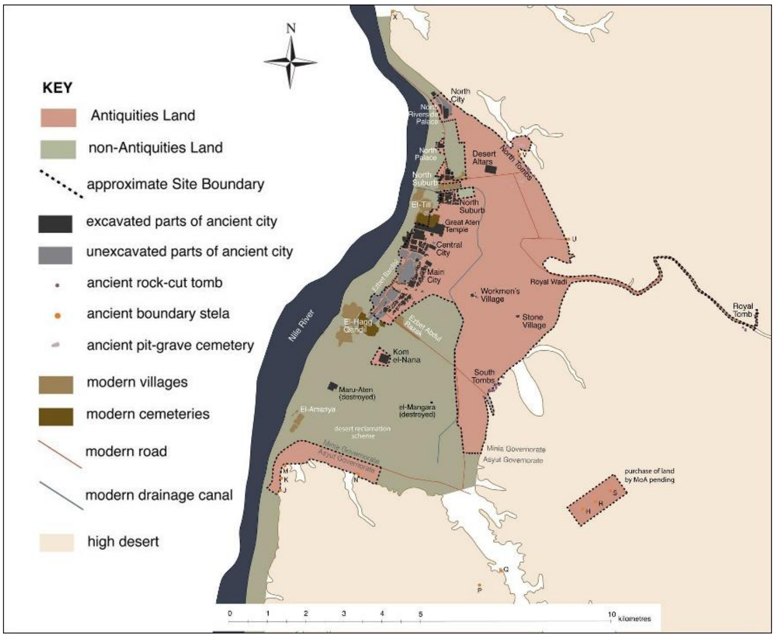


Fig.2: Location and structure of Tell El Amarna ancient city, the alluvial fan of Wadi Abu-Hasah El-Bahari and the Royal Tomb of Akhenaten (Stevens 2021)

2.2. Geological setting

The valley's drainage network cuts into the Eocene Plateau. There are numerous locations on the eastern cliff that feature exposed limestone areas. The site has multiple geological strata stacked on top of each other, originating from the Middle Eocene epoch. The Minia Formation (Fig. 3) is located above the Samallout Formation and, in certain areas, above the Maghagha Formation. The extensive coverage and substantial thickness of the limestone in the Samallout Formation make it economically significant (Youssef 2003). Furthermore, it contains a remarkably high proportion of top-grade calcium carbonate. There are layers of semi-homogenous chalk with tiny color grains that range from snow white to pale pink white, as well as dolomitic limestone. Nummulite, gizehensis, and other fossils make up the formation, which is very fossiliferous. The thickness of these layers varies, ranging from 5 to 50 meters. On the El-Battikh (Watermelon) Plain, big rocks and chert concretions make the contact surface between the Menya and Samallout Formations (Moftah et al. 2022) easy to spot (Figs. 3 and 4).

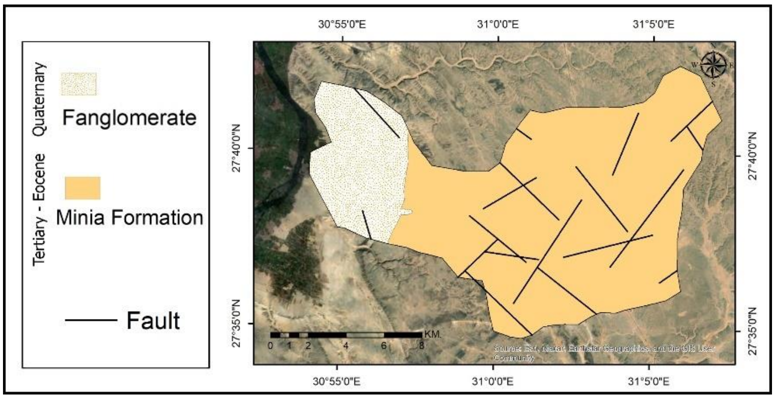


Fig.3: Geological map of Wado Abu-Hasah El-Bahari

Fig.4: The Minia Formation rocks in the wright side of the tributary of The Royal Tomb of Akhenaten

A network of valley streams intersects the Eocene limestone plateau, extending from east to west into the Nile Valley. Alluvial limestone materials partially stabilize a layer of gravel, rocks, and pebbles, primarily sedimentary rocks, that these streams cover the valley bottoms with.

2.3. Geomorphological and climate characteristics

The Wadi Abu-Hasah El-Bahari is a narrow, V-shaped valley with a narrow bed. It is the main stream for the six surrounding catchments. The catchments are characterized by steep and very steep slopes (above 25%) as a result of the DEM analysis of the basin. The classification of approximately 75% of the surrounding area as either steep or very sharp strongly favors the latter. The catchment area spans approximately 139.2 km2. The minimum and maximum rainfall records were 99.4 mm and 202.1 mm, respectively, from 2004–2018 (Zhang et al., 2022). Under the influence of gravity, the flash flood process involves moving water from high to low elevations in the terrain. The flow is unconfined and may display various characteristics. The unconfined flow may exhibit subcritical (i.e., lower than flow velocity) or supercritical (i.e., higher flow velocity) flow regimes, depending on the terrain's cross-sectional and longitudinal slopes, bed and bank materials, and the flow depth. Fig. 5 depicts the catchment, which consists of element-breaking bedrock and deep residual soil with a typical soil depth of 0.86 m. The uppermost earth material consists primarily of sand and silt, with a lower percentage of clay.

Fig. 5: Morphology of the upper sector of the Royal Wadi (one of the tributaries of the Wadi Abu-Hasah El-Bahari)

3. Results and discussion

3.1. The frequency and magnitude of flood events

Even today, flooding remains a rare occurrence in Egypt, with some suggesting that flood events during Akhenaton's reign served as a catastrophic catalyst for the onset of wadi erosion during Amarna's occupation. Data from Wadi Abu-Hasah El-Bahari demonstrating that a mere 3 mm of rain can generate a destructive flood is today's rarity, with the effect that Egyptian society as a whole is ill-equipped to cope with it. We can describe floods in contemporary and historic Egypt as events of great magnitude but low frequency. Floods, therefore, have been a powerful tool for landscape change. A study of modern flood incidence offers a greater understanding of the probability, risk, and magnitude of the event. In Wadi Abu-Hasah, flood data was effectively a by-product of channel measurement (Negm 2020).

3.2. Analysis of the variables associated with hydrological characteristics

The analysis of the hydrological characteristics' variables focuses on the quantity of runoff that a watershed produces for a specific rainfall pattern. This impacts the volume of runoff that falls during a storm. The correlation between meteorological factors and the morphological characteristics of the basin allows for the identification of high-risk locations within the basin. These areas pose a potential threat to the national industrial project area's economic stability. The synthetic unit hydrograph is a crucial tool for assessing the level of flooding danger in ungauged basins. The area under the unit hydrograph indicates the runoff volume across the entire watershed, which is equivalent to one inch of rainfall per hour. We use the average peak discharge to quantify the risk associated with the hydrographic basin (Wanielista 1990). We measured and calculated the hydrological characteristics of the 70 Abu-Hasah El-Bahari sub-basins using a variety of hydrological methods (Fig. 6a and Appendix 1).

3.2.1. The drainage density (D)

The drainage density is the measure of the length of stream channels per unit area of a drainage basin, which is defined as the ratio of the total length of channels within a drainage basin to the basin's entire area. The following equation (Fig. 6b) mathematically represents the drainage density.

D: L/A basin (Horton 2032)

Where:

D stands for drainage density, L for total stream length, and A for basin area.

As you can see in Tab. 1, Fig. 6b, and Appendix 1, the drainage density in the sub-basins is between 2.15 and 5.02 km/k2, and in the Royal Wadi it is about 3.53 km/km2. These low percentages demonstrate how hard the rocks are when rivers carve them, as well as how long the drainage network takes.

3.2.2. Volume flow (QT)

Stream flow, also known as discharge, refers to the amount of water that passes through a specific location within a given timeframe. Researchers often express it in cubic feet per second (m^3/sec). The stream's flow is directly dependent on the amount of water that the watershed discharges into the stream channel. Weather conditions have an impact, causing an increase during rainstorms and a decrease during dry periods (Owens 1974).

Volume flow is defined as the amount of water that enters the basin drainage network. Flooding happens when the amount of rainfall exceeds the losses and leakage, resulting in a concentration of large amounts of water in basins or parts of them. Furthermore, the absence of evaporation losses causes a high rate of water flow during a rainstorm, contributing to flooding. In order to quantify the rate of fluid movement inside the study area's basins, we utilize the following equation (Fig. 6c):

$QT\ (m3\ /\ s)$: $\sum L\ (KM)$ 0,85 (Shuster et al. 2005)

Where:

QT (m3/s): volume of flow (thousand m3). L(km)∑: the sum of the lengths of the basin's ducts (km). 0.85 is a constant exponent. When we apply the equation to the basins in the study area, we notice that their values vary.

The **volume flow** in the sub-basins ranges between 1330 and 16360 m^3/sec, with an average of 5520 m^3/sec, while in the Royal Wadi it is about 1.39 m^3/sec. In the Royal Wadi, the coefficient's low value indicates the average amount of water discharge in the sub-basins (Tab. 1, Fig. 6c, and Appendix 1).

3.2.3. The basin maximum flow rates (Qp)

The following equation extracts this value, which represents the strongest torrential activity that creates torrents, from the maximum flow of torrential water that reaches the valley streams.

Qp (m^3/s): (cp*a)/(tp(hr) • Qp (m^3/s) (Alley et al. 1999).

When applying the equation to the basins in the study area, variations in their values are revealed, such as the maximum flow rate of torrents in the drainage basin (m^3/s). Cp is a coefficient that relates to the capacity of a drainage basin to store water; its value is between 4.5 and A: basin area km^2; tp (hr): duration of drainage basin response to rainfall (hour).

The maximum flow rates in the sub-basins range between 0.75 and 11.75 m^3/sec, with an average of 3.56 m^3/sec, while in the Royal Wadi it is about 0.59 m^3/sec. In the Royal Wadi, the coefficient's low value indicates the average amount of water discharge in the sub-basins (Tab. 1, Fig. 6d, and Appendix 1).

3.2.4. Estimating the duration of stream flow (Tm)

We've determined the discharge estimates and can now compute the stream flow. We can calculate the duration of a torrential flow's progressive increase in intensity. Tm (hr) refers to the duration from the start of water flow at the base of watercourses to its peak period. As the intense flow's gradual ascent in the area grows shorter, the period of water scarcity increases. We collect data from the lower parts of sewers and valleys during periods of precipitation until the start of run-off, using the provided equation. The research area's sub-basins show variations in the recorded values.

Tm (hr): (1)/3 Tb (hr). (Mohideen and Rahaman 2021)

Where:

The time period from the start of the torrent to the peak period on the curve, TP (hr), represents the base time of the torrent in hours. We calculate the duration of the gradual decrease in the torrent flow (Td).

The estimated duration of stream flow in the sub-basins ranges between 0.04 and 6.44 hours, with an average of 0.64 hours, while in the Royal Wadi it is about 0.10 hours. In the Royal Wadi, the coefficient's low value indicates the average amount of water discharge in the sub-basins (Tab. 1, Fig. 6e, and Appendix 1).

3.2.5. The flow velocity (V)

The flow velocity is one of the hydrological variables that measures the velocity of the flow, and it is an important indicator in knowing the danger of the drainage basins during the surface run-off. We can calculate the speed of the flow by dividing the distance by time, but note that the values vary between the sub-basins of the study area (Tsanakas *et al.*, 2016).

V(M/S): 〖(L(M))/ (3.6 TC (S)

Where:

V is the velocity of the basin's surface runoff. L (M): the length of the basin (m). Tc (S): time of concentration (hour, minute, second).

The flow velocity in the sub-basins ranges between 1.37 and 146.69 km/h, with an average of 18.99 km/h, while in the Royal Wadi it is about 4.38 km/h. In the Royal Wadi, the coefficient's very low value indicates the average amount of water discharge in the sub-basins, which means slow water speed in this tributary (Tab. 1, Fig. 6f, and Appendix 1).

3.2.6. Lag time (TP)

The time interval between the midpoint of the surplus rainfall mass and the middle of the runoff hydrograph's peak is known as lag time. We calculated its value using the following equation (Granato, 2012):

Tp (hr) = ct (Lb Lca) 0.3 (Raghunath 2006).

Where:

TP (hr): deceleration time. The peak flow time coefficient, which is specific to the basin's nature and slope, has a value of (1,2). Lb refers to the length of the stream (km). Lca: the distance between the basin's mouth and its gravity center (km).

The **lag time** in the sub-basins ranges between 1.44 and 128.86 hours, with an average of 12.76 hours, whereas in the Royal Wadi it is about 2.03 hours. This coefficient's very low value in the Royal Wadi shows the average amount of water that flows through the sub-basins. This means that there isn't much time between the middle of the extra rainfall mass and the middle of the peak runoff hydrograph (Tab. 1, Fig. 6g, and Appendix 1).

3.2.7. The concentration time (Tc)

A watershed's time of concentration (Tc) refers to the maximum duration required for a drop of water to travel along the hydrological path from one location as far away from the outlet as possible before it reaches the outlet. Theoretically, Tc is defined as the time period between the cessation of net rainfall and the cessation of runoff. Field measurements or formulas, which are typically based on empirical data, can practically determine the concentration time.

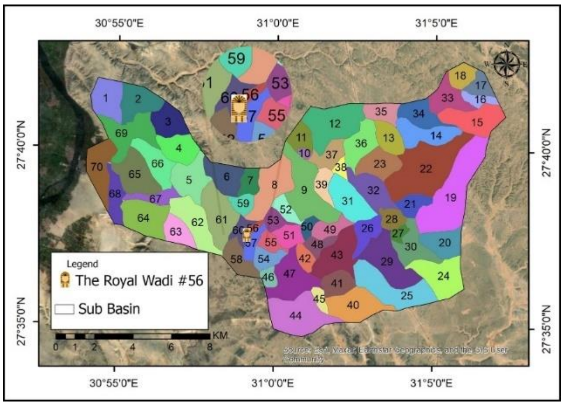
One of the hydrological variables is the duration of water coverage, reaching Wadi's mouth, where you may observe the water flow level, categorized as either high, medium, or weak. We can use various statistical methods to calculate the concentration time parameters, and the semi-arid condition of the study location holds significant importance.

Tc: 1.15* (L) / 0.38 7700(H) (Al-Fatlawy and Alzaili 2022)

Where:

TC: time of concentration (hours), L: length of stream (m), H: rate of height of the basin (m).

The concentration time in the sub-basins ranges between 1.02 and 19.56 hours, with an average of 4.72 hours, whereas in the Royal Wadi it is 5.31 hours. In the Royal Wadi, the coefficient's very low value indicates the average amount of water discharge in the sub-basins, which means a short period of time is required for water to move within the tributary (Tab. 1, Fig. 6f, and Appendix 1).



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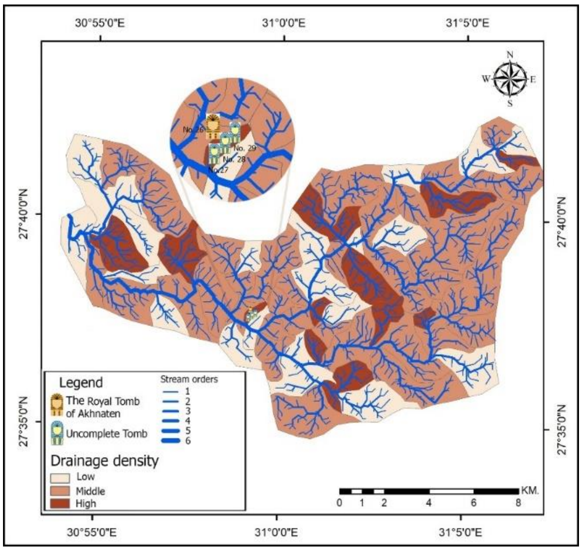

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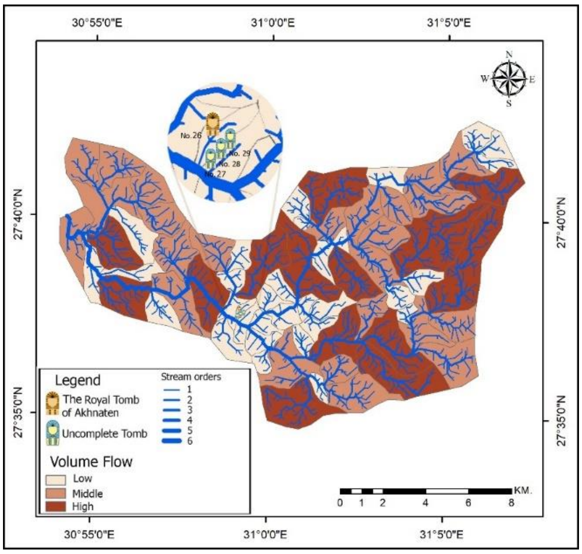

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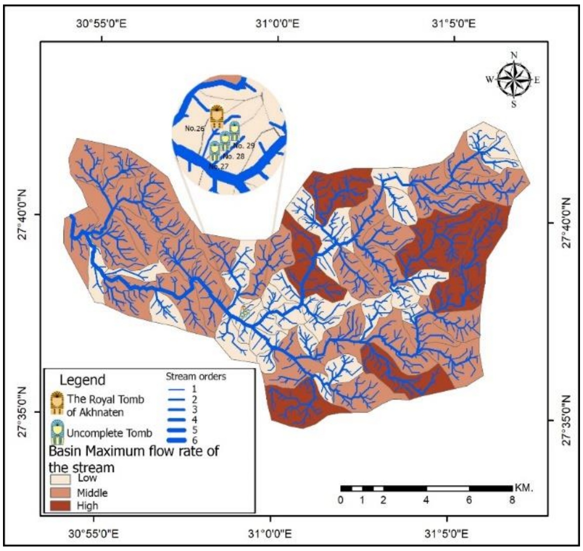

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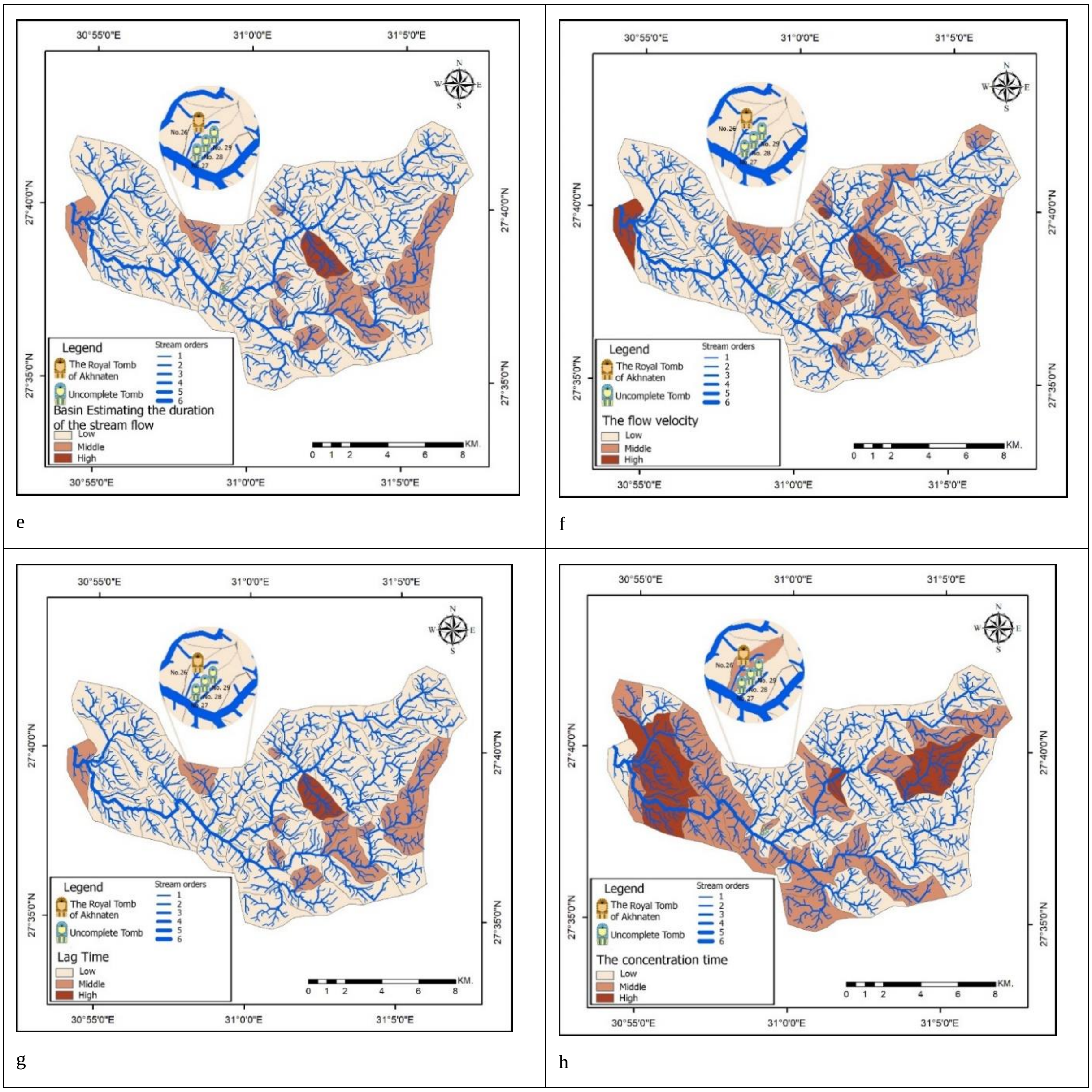

Fig. 6: Results of **Analysis of the variables associated with hydrological characteristics**

a: Numbering of the sub-basins included in the Wadi Abu-Hasah El-Bahari; b: Drainage density; c: Volume flow; d: Basin maximum flow rate of the stream; e: Basin estimating the duration of the stream flow; f: The flow velocity; g: Lage time; h: The concentration time

Tab.1: The results of the hydrological characteristic variables for the mean of Wadi Abu-Hasah El-Bahari and the Royal Wadi.

B	**A**	**ML**	**TL**	**SBR**	**D**	**QT**	**QP**	**Tm**	**V**	**TP**	**Tc**
Unit	(Km^2)	(m)	(km)	(m)	(km/k^2)	(1000 m^3/s)	(m^3/s)	(h)	(km/h)	(h)	(h)
The Royal Wadi	0.41	1394	1.47	67	3.53	1.39	0.59	0.10	4.38	2.03	5.31
Mean of sub-basins	2.52	2293	7.69	36	3.13	5.52	3.56	0.64	18.99	12.76	4.73

Where:

B: Basin	SBR: Sub-basin relief	Tm: Estimate stream flow duration
A: Area	D: Drainage density	V: Flow velocity
ML: Main stream length	QT: Volume flow	TP: Lag time
TL: Total streams length	QP: Maximum flow rate	Tc: Concentration time

3.3. Causes of torrential floods in Wadi Abu-Hasah El-Bahari

The Royal Tomb of Akhenaten, number 26^{th} in the Amarna tombs series, is located approximately 6 km. from the entrance of the Royal Wadi in a right-side valley that diverges from it. Akhenaten, Princess Meketaten, Queen Tiy, and potentially Nefertiti were the intended individuals. There are additional, uncompleted burial chambers adjacent to the southern section of the primary royal wadi. Their dimensions and placement suggest that the Royal Family specifically designed them. The steep entrance staircase of one of the tombs (# 27) in the Royal Wadi bears a striking resemblance to the one in the Royal Tomb. This stairway leads to a corridor of remarkable size, but it does not extend very deep into the tomb. Located in a nearby side valley to the east, there are two further tombs (#. 28 and 29) that remain incomplete and without any decorations. Tomb 29 is particularly characterized by a lengthy, straight hallway that descends via four openings (Shaw 1990) (Figs. 7 and 8).

Fig. 7: The entrance of uncompleted tombs # 27 and 28 in the Royal Wadi

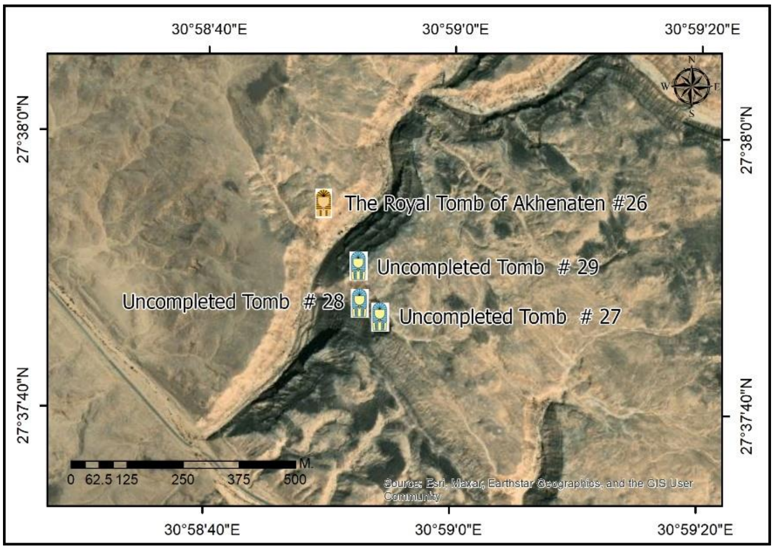

Fig. 8: The location of the tombs in the Royal Wadi (Source: Esri, Maxar, Earthstar Geographics 2024)

After conducting a field study of the valley and the location of the Royal Tomb and analyzing the hydrological characteristics, we have concluded that the valley load in the Royal Wadi has a limited volume and moves at a slow speed. We observe that the royal tomb's vulnerability to floods and the destruction of its contents is not due to hydrological factors but rather to errors in the tomb's design, such as its placement at the bottom of the stream and the absence of a well. The tomb's entrance serves as a safeguard against both thieves and flooding. For that reason, we suggest that the first reason for flood waters submerging the tomb was its excavation at the same level as the valley's bottom, rather than on one of its sides, which facilitated the entry of flood waters into the tomb and distorted its inscriptions.

The second reason is the tomb's design and the failure to dig a deep well at its entrance to protect it from thieves and floodwater, like the wells dug at the entrances to the main tombs in the Valley of the Kings on Luxor's western mainland (Figs. 9 and 10).

Fig. 9: The entrance to the Royal Tomb of Akhenaten at the same level as the valley bottom, taken in 1978 (Amarna trust 2017).

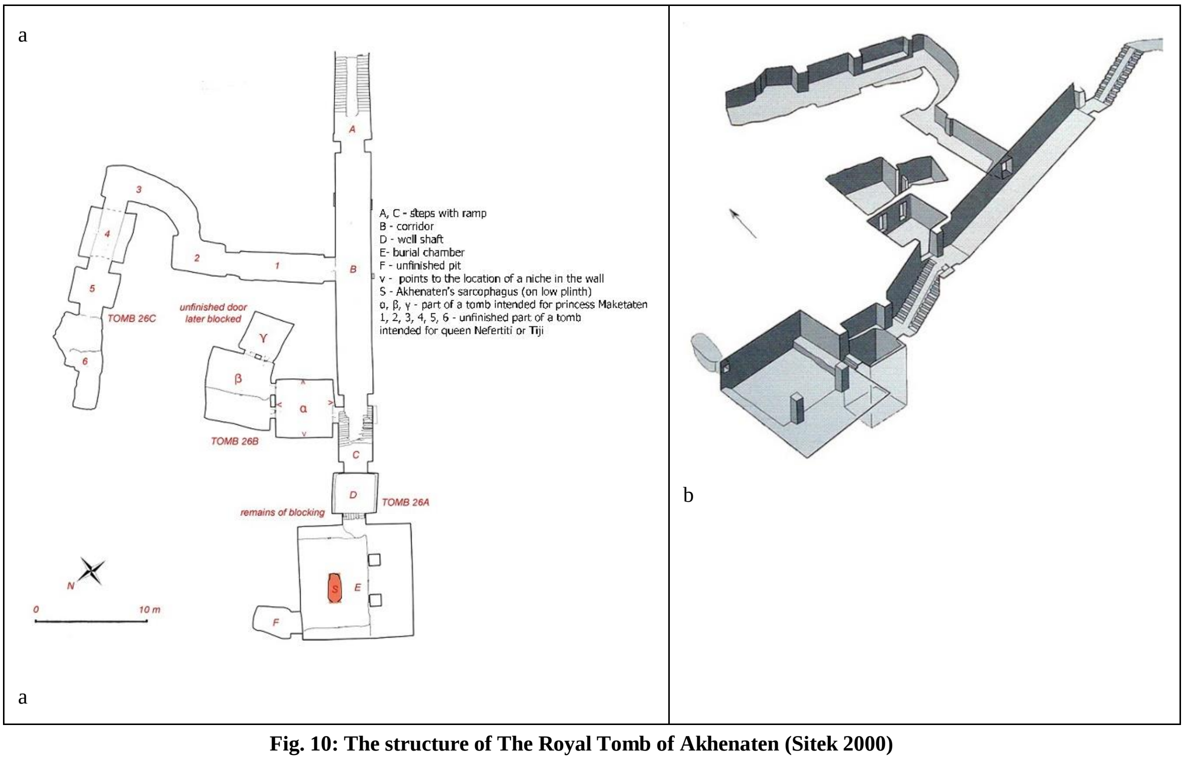

Fig. 10: The structure of The Royal Tomb of Akhenaten (Sitek 2000)

The construction of Akhenaten's tomb at the same level as the bottom of the Royal Valley is peculiar; also, there isn't a deep well at the entrance to the tomb, which would have kept thieves and floodwaters out. This makes it seem like the deliberate and systematic engineering mistakes in his tomb were a response to his religious revolution against polytheism and his call for the Atonian monotheistic religion (Stevens 2021). This religious revolution sparked Amun's priests in Thebes, who obliterated and destroyed his paintings and statues in an attempt to erase his reign from history. We know that Akhenaten's tomb witnessed widespread defacement of inscriptions and obliteration of paintings of his wife Nefertiti, leading us to believe that these engineering errors were deliberate and systematic attempts to take revenge on Akhenaten (Zhdanov 2022).

4. Conclusion

According to the research, floods in Wadi Abu-Hasah El-Bahari pose a significant threat to the royal tomb of Akhenaten. We point out that the exposure of the Royal Tomb to floods and the destruction of its contents is not due to hydrological factors, but rather to errors in the tomb's design. We believe that the engineering errors were intentional during the construction of Akhenaten's tomb as a form of revenge against him, and the evidence for this is the widespread destruction of statues and paintings of Akhenaten and his wife Nefertiti, the obliteration of all his works, and the attempt to erase him from history because of his religious revolution. This research has demonstrated the importance of geohazards in archaeology, and we hope it will open the door to further interdisciplinary studies to help preserve cultural heritage in Egypt.

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Author contributions

Magdy Torab conceived the article's ideas and conducted the data processing and interpretations; he also wrote and prepared the manuscript and conducted fieldwork in the study area.

Emad El-Bardan contributed to the analysis of the variables associated with hydrological characteristics, remote sensing, GIS data processing, and design and drew all the maps in the article.

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Availability of data and materials

Additional hydrological data is provided in Appendix #1.

Declarations of competing interests

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.

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Appendix #1

The results of the hydrological characteristic variables for the sub-basins of Wadi Abu-Hasah El-Bahari

SB#	**A**	**ML**	**TL**	**SBR**	**D**	**QT**	**QP**	**Tm**	**V**	**TP**	**Tc**
Unit	**(Km2)**	**(m)**	**(km)**	**(m)**	**(km/k2)**	**(1000 m3/s)**	**(m3/s)**	**(h)**	**(km/h)**	**(h)**	**(h)**
1	2.98	2687.00	6.74	62.00	2.26	5.07	4.22	0.13	4.73	2.53	9.46
2	3.02	2137.00	10.08	26.00	3.34	7.13	4.26	0.45	11.28	8.94	3.16
3	2.47	1720.00	7.37	63.00	2.98	5.46	3.50	0.16	4.66	3.10	6.16
4	2.56	2355.00	8.52	59.00	3.32	6.18	3.62	0.19	4.97	3.74	7.89
5	3.30	2934.00	11.82	35.00	3.58	8.16	4.66	0.37	8.38	7.32	5.83
6	2.63	2887.00	7.69	7.00	2.93	5.66	3.68	1.40	41.91	27.93	1.15
7	1.25	1938.00	3.37	8.00	2.69	2.81	1.76	0.90	36.67	17.99	0.88
8	4.22	3916.00	13.27	19.00	3.14	9.00	5.95	0.64	15.44	12.74	4.23
9	5.53	4309.00	15.30	33.00	2.77	10.16	7.81	0.35	8.89	7.00	8.08
10	0.33	789.00	1.45	4.00	4.47	1.37	0.45	2.00	73.34	39.91	0.18
11	1.45	1393.00	5.35	12.00	3.68	4.16	2.04	0.86	24.45	17.17	0.95
12	5.28	2653.00	16.60	22.00	3.15	10.89	7.44	0.59	13.34	11.78	3.32
13	1.99	2219.00	6.07	18.00	3.05	4.63	2.80	0.52	16.30	10.43	2.27
14	3.03	3410.00	11.14	36.00	3.67	7.76	4.28	0.36	8.15	7.11	6.97
15	3.76	3567.00	12.43	24.00	3.30	8.52	5.31	0.51	12.22	10.24	4.86

16	0.94	1866.00	3.60	20.00	3.85	2.97	1.32	0.47	14.67	9.44	2.12
17	1.27	1478.00	2.99	17.00	2.36	2.54	1.79	0.37	17.26	7.45	1.43
18	1.46	1448.00	4.70	13.00	3.23	3.73	2.05	0.70	22.57	13.90	1.07
19	8.17	6134.00	26.79	9.00	3.28	16.36	11.41	1.71	32.60	34.21	3.14
20	2.56	1991.00	8.70	11.00	3.40	6.29	3.59	1.02	26.67	20.49	1.24
21	1.47	2150.00	4.85	14.00	3.29	3.83	2.08	0.66	20.96	13.21	1.71
22	8.31	5298.00	25.74	65.00	3.10	15.81	11.75	0.22	4.51	4.50	19.56
23	2.64	2250.00	7.26	41.00	2.75	5.39	3.73	0.22	7.16	4.49	5.24
24	4.01	2755.00	11.24	23.00	2.81	7.82	5.65	0.46	12.76	9.25	3.60
25	5.12	3800.00	16.69	48.00	3.26	10.94	7.24	0.28	6.11	5.54	10.36
26	1.80	2681.00	6.74	7.00	3.75	5.06	2.51	1.60	41.91	31.93	1.07
27	0.59	829.00	2.96	10.00	5.02	2.52	0.83	1.07	29.34	21.44	0.47
28	1.24	1298.00	4.30	26.00	3.48	3.45	1.75	0.36	11.28	7.13	1.92
29	4.57	3784.00	13.21	10.00	2.89	8.97	6.41	1.14	29.34	22.81	2.15
30	2.74	2481.00	7.90	25.00	2.88	5.80	3.87	0.39	11.74	7.80	3.52
31	3.47	3036.00	12.32	2.00	3.55	8.45	4.67	6.44	146.69	128.86	0.34
32	2.97	3316.00	9.88	14.00	3.33	7.01	4.18	0.82	20.96	16.47	2.64
33	2.52	1722.00	6.52	21.00	2.59	4.92	3.56	0.41	13.97	8.13	2.05
34	2.40	1918.00	7.14	21.00	2.97	5.31	3.39	0.46	13.97	9.21	2.29
35	1.64	1661.00	3.54	11.00	2.15	2.93	2.32	0.57	26.67	11.36	1.04
36	2.80	3115.00	8.61	13.00	3.08	6.24	3.94	0.81	22.57	16.11	2.30
37	1.77	1638.00	6.30	16.00	3.56	4.78	2.49	0.66	18.34	13.20	1.49
38	0.53	867.00	1.40	9.00	2.62	1.33	0.75	0.60	32.60	12.05	0.44
39	1.30	1277.00	4.38	214.00	3.38	3.51	1.84	0.04	1.37	0.85	15.52
40	3.98	3772.00	10.78	16.00	2.71	7.55	5.60	0.64	18.34	12.82	3.43
41	1.84	1639.00	6.86	11.00	3.73	5.14	2.58	1.02	26.67	20.36	1.02
42	0.96	1694.00	4.22	5.00	4.38	3.40	1.34	2.16	58.68	43.30	0.48
43	3.93	3264.00	13.23	34.00	3.36	8.98	5.56	0.37	8.63	7.46	6.30
44	5.29	4027.00	15.08	31.00	2.85	10.04	7.47	0.38	9.46	7.58	7.09
45	0.72	1590.00	2.92	12.00	4.04	2.49	1.02	0.76	24.45	15.28	1.08
46	0.75	1175.00	2.45	33.00	3.25	2.14	1.06	0.23	8.89	4.52	2.20
47	4.11	2224.00	11.33	44.00	2.76	7.87	5.81	0.24	6.67	4.79	5.56
48	1.05	1298.00	3.04	12.00	2.91	2.58	1.47	0.61	24.45	12.29	0.88
49	1.44	2273.00	3.77	31.00	2.61	3.09	2.04	0.24	9.46	4.70	4.00
50	0.68	803.00	2.56	6.00	3.74	2.22	0.96	1.39	48.90	27.80	0.27
51	1.44	1686.00	4.22	46.00	2.94	3.40	2.03	0.18	6.38	3.56	4.41
52	1.16	1793.00	3.54	10.00	3.06	2.93	1.63	0.80	29.34	15.99	1.02

53	1.06	1023.00	3.37	29.00	3.18	2.81	1.49	0.28	10.12	5.58	1.69
54	1.38	1475.00	4.60	62.00	3.34	3.66	1.95	0.15	4.73	2.96	5.20
55	1.00	1092.00	2.93	22.00	2.93	2.49	1.41	0.33	13.34	6.66	1.36
Royal W.56	0.42	1394.00	1.47	67.00	3.53	1.39	0.59	0.10	4.38	2.03	5.31
57	1.02	566.00	2.65	61.00	2.59	2.29	1.45	0.11	4.81	2.14	1.96
58	2.07	2002.00	4.27	71.00	2.06	3.43	2.93	0.09	4.13	1.81	8.08
59	1.08	1067.00	3.74	15.00	3.48	3.07	1.52	0.59	19.56	11.84	0.91
60	0.97	872.00	3.34	44.00	3.46	2.79	1.37	0.19	6.67	3.90	2.18
61	4.07	2092.00	12.53	79.00	3.08	8.58	5.75	0.15	3.71	2.97	9.39
62	3.66	1685.00	10.33	91.00	2.83	7.28	5.17	0.11	3.22	2.29	8.71
63	1.86	2106.00	4.88	89.00	2.63	3.85	2.63	0.09	3.30	1.78	10.65
64	3.86	2668.00	13.15	95.00	3.40	8.93	5.47	0.13	3.09	2.69	14.40
65	3.71	2911.00	13.60	97.00	3.66	9.19	5.25	0.14	3.02	2.80	16.04
66	2.66	3017.00	5.37	81.00	2.02	4.17	3.77	0.08	3.62	1.67	13.88
67	1.35	3044.00	3.57	88.00	2.65	2.95	1.91	0.08	3.33	1.65	15.22
68	1.93	3385.00	5.72	26.00	2.96	4.41	2.73	0.35	11.28	6.94	5.00
69	3.96	3388.00	7.98	106.00	2.02	5.85	5.61	0.07	2.77	1.44	20.40
70	3.25	1793.00	6.19	4.00	1.91	4.71	4.54	1.70	73.34	33.92	0.41
Mean basin	2.52	2293.21	7.70	35.80	3.13	5.52	3.56	0.64	18.99	12.76	4.72

Where:

SB#: Sub-basin number	SBR: Sub-basin relief	Tm: Estimate stream flow duration
A: Area	D: Drainage density	V: Flow velocity
ML: Main stream length	QT: Volume flow	TP: Lag time
TL: Total streams length	QP: Maximum flow rate	Tc: Concentration time