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Estimation of potential nutrient fluxes from the Wadi Gaza catchment into the Mediterranean Sea with emphasis on flooding events

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ABSTRACT

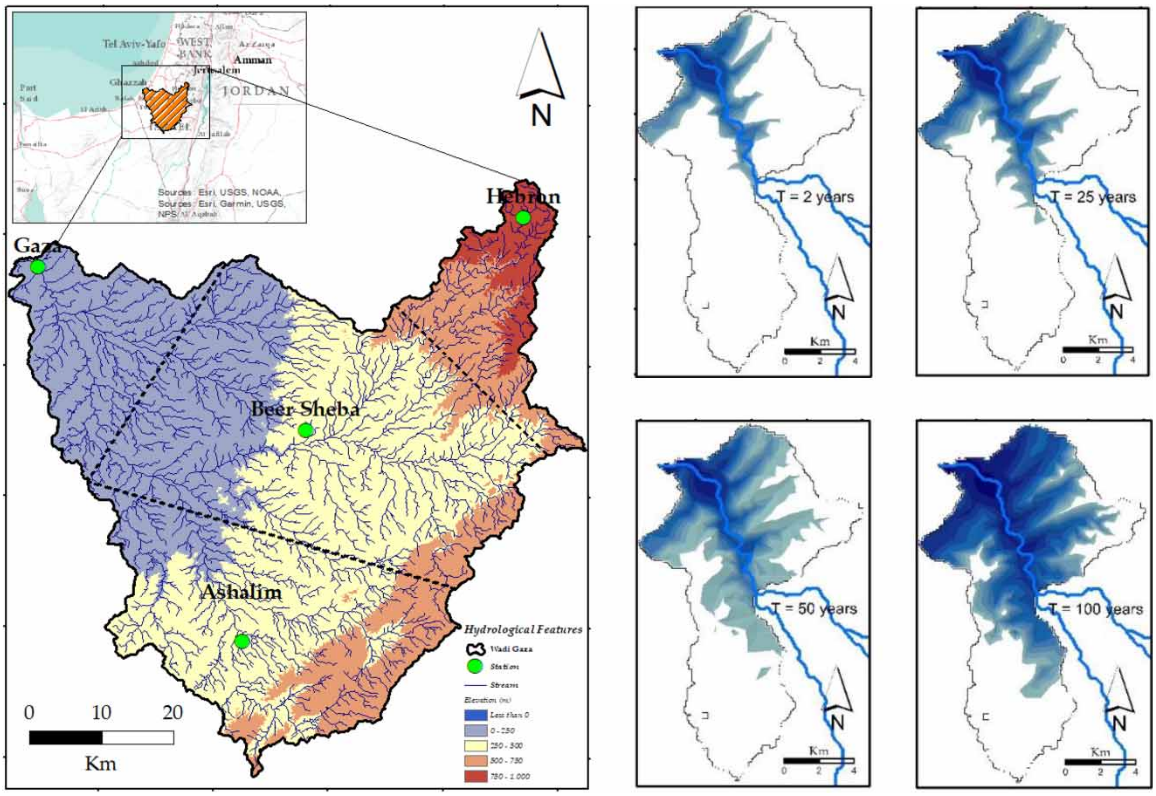
The coastal catchment of Wadi Gaza is the main surface water basin that flows downstream to Gaza's coastal plain zone and drains into the Mediterranean Sea. The model-based assessment of the Wadi Gaza hydrological system is an essential endeavor for more efficient management of water resources and ensuring water security in terms of climate changes and anthropogenic processes. The hydrological simulation of the basin was performed using the SWAT model between 1984 and 2020. The outputs of the simulation predicted an average discharge that varies between zero in the summer months and about 15 m^3/s in the winter with a maximum recorded discharge of about 130 m^3/s. The model predicted average sediment and nutrient discharge to the sea as 3673, 177, and 62 tons per month of sediments, total nitrogen (TN), and total phosphorus (TP), respectively. The average dissolved inorganic nitrogen discharges were predicted to be 4, 13, and 1 tons per month for Nitrate (NO_3), Ammonium (NH_4), and Nitrogen dioxide (NO_2), respectively during the rainy season. The constructed model is used to predict flood volumes and associated TN and TP for return periods (T) of 2, 25, 50, and 100 years. These return periods corresponded to total water discharges of 18, 91, 105, and 127 m^3/s, respectively, accounting for 1,142, 5,773, 6,915, and 8,059 tons of TN, and 414, 2,092, 2,505, and 2,919 tons, of TP respectively.

Key words: Mediterranean, nutrients, sediment, stream, Wadi-Gaza

HIGHLIGHTS

- The modeling-based assessment of the catchment is essential to characterize the hydrological system in the Mediterranean due to the lack of real field monitoring programs.
- The nutrient transport pattern depends on the discharges of stream flooding.
- The monthly amount of TN and TP that might be carried to the downstream zone of the Wadi Gaza during the wet seasons could be as high as 177 and 62 tons, respectively.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The lowland areas and coastal seas may receive massive volumes of water and associated nutrients loads during flood periods (Al-Najjar *et al.* 2022; Ziouch *et al.* 2020; De Girolamo *et al.* 2017). Even though the Mediterranean catchments are expected to experience severe droughts with climate change, flush floods might also increase in intensity and frequency resulting in significant episodic water and nutrient transports (Al-Najjar *et al.* 2020; Zettam *et al.* 2020). In the Mediterranean Sea, riverine flooding is particularly important for maintaining marine productivity, where the annual average nutrient loads discharged into the Mediterranean from the inland catchments were estimated as 1.87 million tons of TN, 1.22 million tons of N-NO_3, 0.11 million tons of TP and 0.03 million tons of P-PO_4 (Malagó *et al.* 2019). The catchment of Wadi Gaza is one of the major east Mediterranean catchments which provides the Gaza Strip in Palestine with a seasonal water stream from the Hebron Mountains. The hydrological analysis of the Wadi Gaza water resources is a significant challenge to evaluating the functioning of the land-sea interaction and understanding the water and nutrients fluxes into the Mediterranean coast (NAP 2016). The nutrients transported by the catchment of Wadi-Gaza to the downstream zone of the Mediterranean may reach approximately 2,000 tons of TN and N-NO_3, as well as 5 tons of TP and P-PO_4 per annum, according to a recent modeling of the terrestrial nutrient fluxes into the Mediterranean Sea (Malagó *et al.* (2019). Additionally, the Wadi Gaza basin, a transnational watershed governed by international water management guidelines, is experiencing pressures due to urbanization and climate change, which disrupt the basin's natural processes and have an impact on the habitats of about 154 faunal and 70 floral species (NAP 2016). The natural dynamics of Wadi Gaza, similar to those of many catchments in the eastern Mediterranean, are still uncertain and need to be investigated by conducting a simulation model for the entire basin. However, throughout the basin of the Mediterranean Sea, many researchers demonstrated the hydrological response of the Mediterranean catchments (Zettam *et al.* 2020; De Girolamo *et al.* 2017; Cooper *et al.* 2013; García-Pintado *et al.* 2007; Lillebø *et al.* 2007). A well-calibrated catchment model would be an essential tool for the water management authorities to better and more sustainably manage the water resources and to estimate the quantity and quality of flowing water in Wadi Gaza. The soil water assessment tool (SWAT) is a robust hydrological tool that is used to model the flows, sediment loading, and nutrient content of the water streams based on the setup of the functional units of land use, soil, and slope (Nguyen *et al.* 2019; Liu *et al.* 2017). In particular, this study provides an assessment and evaluation of the hydrological features of Wadi Gaza in Palestine by applying the SWAT model to predict the surge of water quantities and the loads of nutrients that are transported to the Mediterranean Sea.

2. MATERIAL AND METHODS

The Wadi Gaza catchment, as depicted in Figure 1, spans over an area of 3,594 km^2 with a topography elevation that varies from around 1,000 m above mean sea level upstream to 5 m below mean sea level downstream. Reliable field records for the daily data over the timespan of 1982–2020 for the parameter of

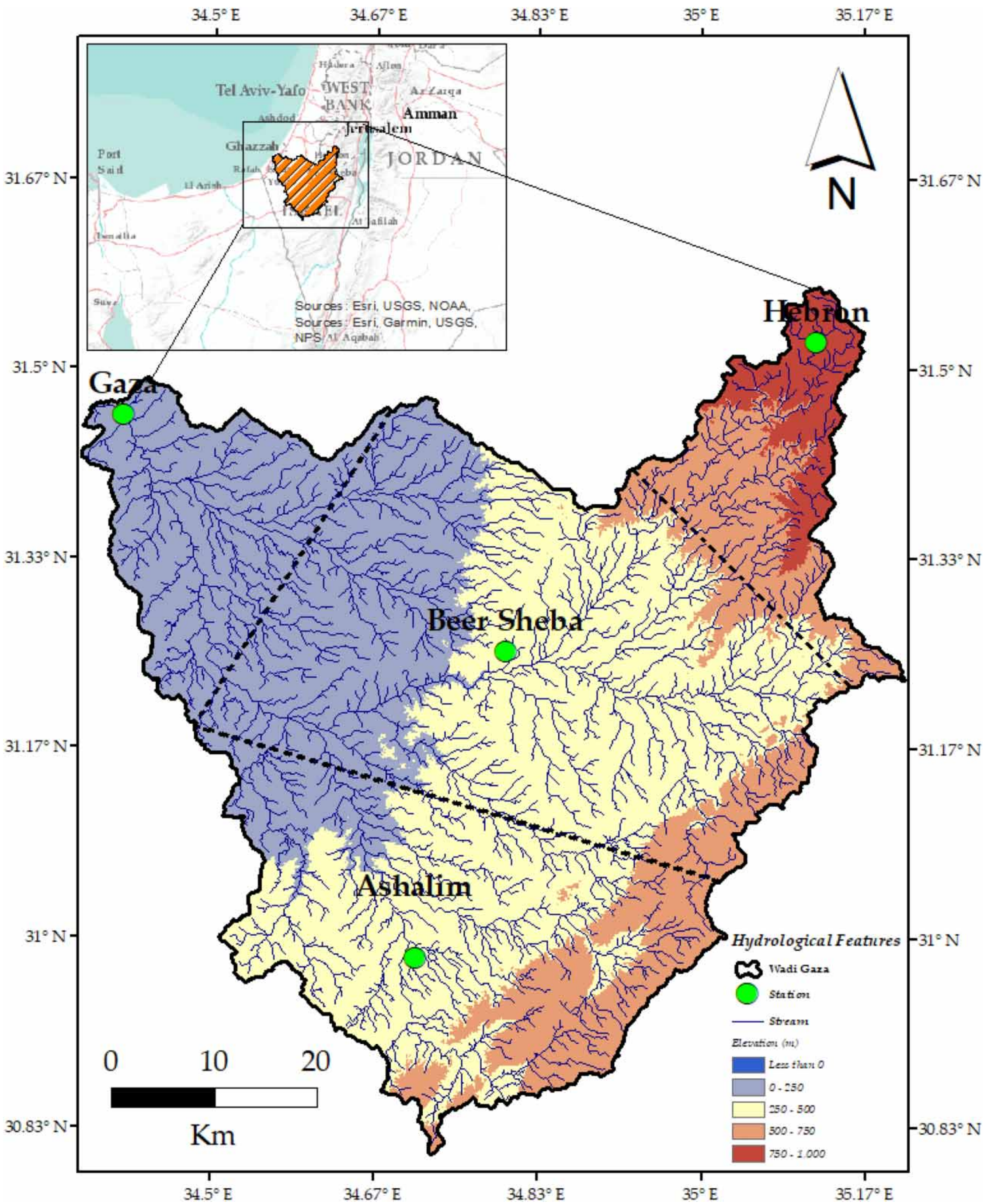


Figure 1 | Geographical location of the Wadi Gaza basin.

rainfall at four meteorological stations, shown in Figure 1 and Table 1, were obtained from the meteorological services of the Palestinian ministry of agriculture.

The monthly time scale of the rainfall dataset was analyzed using the innovative polygon trend analysis (IPTA) by dividing the dataset into two equal portions where the endpoint of the polygon created for each month is formed by plotting the first data set and the second data set on the coordinate x and y axes, respectively. Here, the 45° (1:1) line depicts the non-trend region and divides the area into an upper region with an increasing trend and a lower region with decreasing trend (Sen 2014, 2017). The scheme of Figure 2 introduces the systematic approaches of the methodology that was followed by this study to simulate the fluxes and nutrient transport through the Mediterranean catchment of Wadi Gaza.

The dataset of the daily rainfall was accumulated into the form of the total monthly rainfall and analyzed in terms of trend using Mann–Kendall and Sen slope estimators. A digital elevation model (DEM) and satellite image covering the study area on a cell resolution of 30 m were obtained from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov) and the soil map was extracted from the soils portal of the Food and Agriculture Organization (FAO) (https://www.fao.org). The satellite images were processed on the platform of ArcGIS for producing the land use map of Wadi Gaza. The SWAT model (Arnold *et al.* 1995, 1998, 1999) was used in this study to process the hydrological assessment of Wadi Gaza to focus on the stream flows and the sediment and nutrient loads discharged to the downstream zone where the SWAT model depends on the stratification of the input layers and detecting the data from each of the layers based on the resolution of the layers, in parallel, the model delineates the study area according to the accumulation of the flow from the upstream to the downstream. The rainfall daily data and the surface runoff discharges were studied using the Gamble frequency analysis method to specify the extent of the inundation area downstream of Wadi Gaza. Admittedly, there are no measurements of the fluxes and transported nutrients downstream of Wadi Gaza, which makes it difficult to calibrate and verify the model. However, the need for catchment-specific analysis makes modeling processes valuable for illustrating the hydrological processes of the water basin. Hypothetically, considering that there is no monitoring program for flux gauging or sampling campaigns for nutrient estimations, particularly in the eastern Mediterranean catchment areas, and since the majority of studies that have been published for the entire Mediterranean catchments rely on metrological-based simulations, it is appropriate to introduce an assessment study by relating the fluxes of the streams with the potential sources of nutrients. This strategy is scientifically promising for the decision-makers to enable

Table 1 | Statistical analysis of the total monthly rainfall (mm)

Station	Maximum	Average	Minimum	St. Deviation	Mann–Kendall test	Sen's slope	Trend
Hebron	445	200	0.00	50	−0.97	0.002	No trend
Gaza	402	102	0.00	30	−2.27	−0.003	Decreasing
Beersheba	128	17	0.01	24	−1.48	0.140	No trend
Ashalim	107	13	0.04	18	−1.97	−0.005	Decreasing

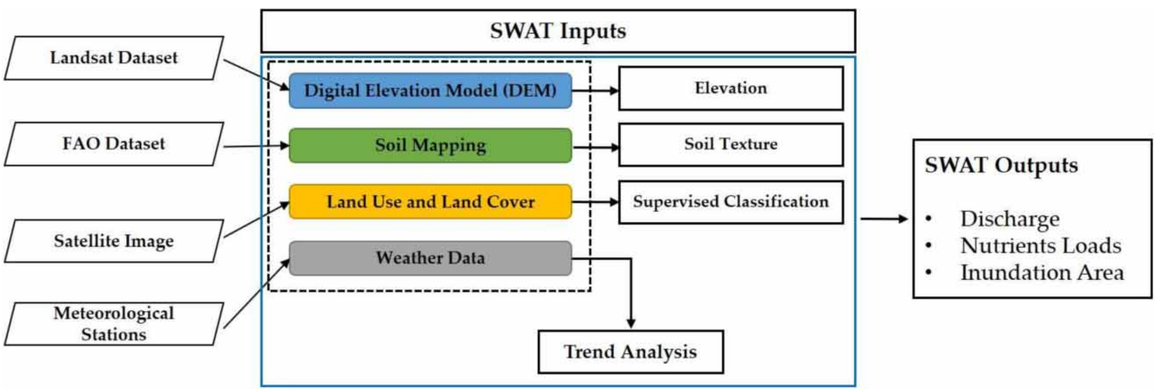


Figure 2 | Methodology approaches.

estimating the quantities of fluxes and nutrients which is crucial for the economic and agricultural growth as well as for understanding the behavior of flooding in the area for management and preparation of evacuation and flood alarming system based on the buffer zone of the flood.

3. RESULTS

The presentation of the total monthly rainfall data shown in Figure 3 indicates that the rainy months in the study area extend from October to March with a total monthly rainfall reaching a maximum value of about 445 mm in the northern parts of the basin. The dry months extend from May to September forming the summer season in the study area with no rainfall events. The meteorological stations at Hebron and Gaza refer to considerable amounts of rain while the stations at the Beersheba and Ashalim are located in the Negev desert which shows low rainfall patterns.

The statistical analysis of the meteorological data of rainfall, as depicted in Table 1, reveals that the total monthly rainfall ranges between a minimum and a maximum value of zero and 445 mm, respectively. Further, the mean total monthly rainfall over the basin of Wadi Gaza ranges between 13 and 200 mm. The trend analysis of the monthly rainfall in terms of the Mann–Kendall test and Sen's slope estimator refers to a non-trend or a decreasing trend in the pattern of the rainfall.

The frequency analysis was performed using the Gamble method over the return periods of 2, 25, 50, and 100 years for the rainfall and the surface runoff as shown in Table 2.

The results trend analysis using the IPTA method, shown in Figure 4, indicates that there is a decreasing trend in the rainfall during February, March, April, and November at Hebron and Gaza stations. However, at Ashalim and Beersheba, the declining trend is recorded in March. By comparing the period of 2002–2020 to the period of 1983–2001, according to the IPTA, the rainfall might increase by about +27% in rainy seasons while the decrease might be assigned to −23% in the dry months at Hebron station. However, for the Gaza station, the increase in the amount of rainfall is depicted in October by about +81% while the decrease is recorded in the other months by about −50%. At the other two inland stations, the increase in the rainfall is limited to +21% while the deficit in the rainfall is about −63%.

The land use of the study area shows that the majority of the catchment is uncultivated or barren lands and the texture of the soil that covers the region is mostly clay or clay loam that is rich in the nutrient sources. The

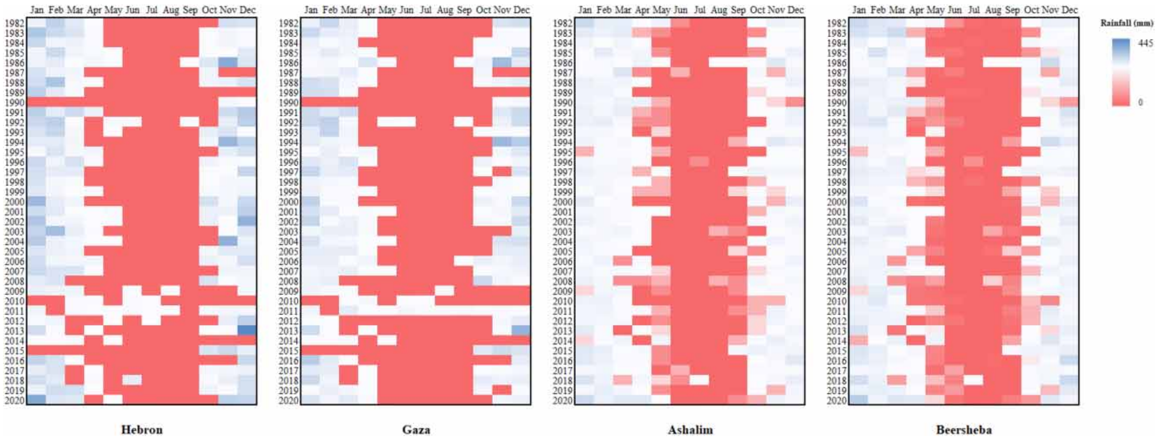


Figure 3 | Mapping of the total monthly rainfall.

Table 2 | Gamble frequency analysis for the rainfall and runoff

Frequency method	Return period (T)	Ashalim	Beersheba	Gaza	Hebron	Discharge (m^3/s)
Gamble	2	16	21	22	36	18
	25	35	41	45	64	91
	50	40	46	51	71	109
	100	44	51	56	78	127

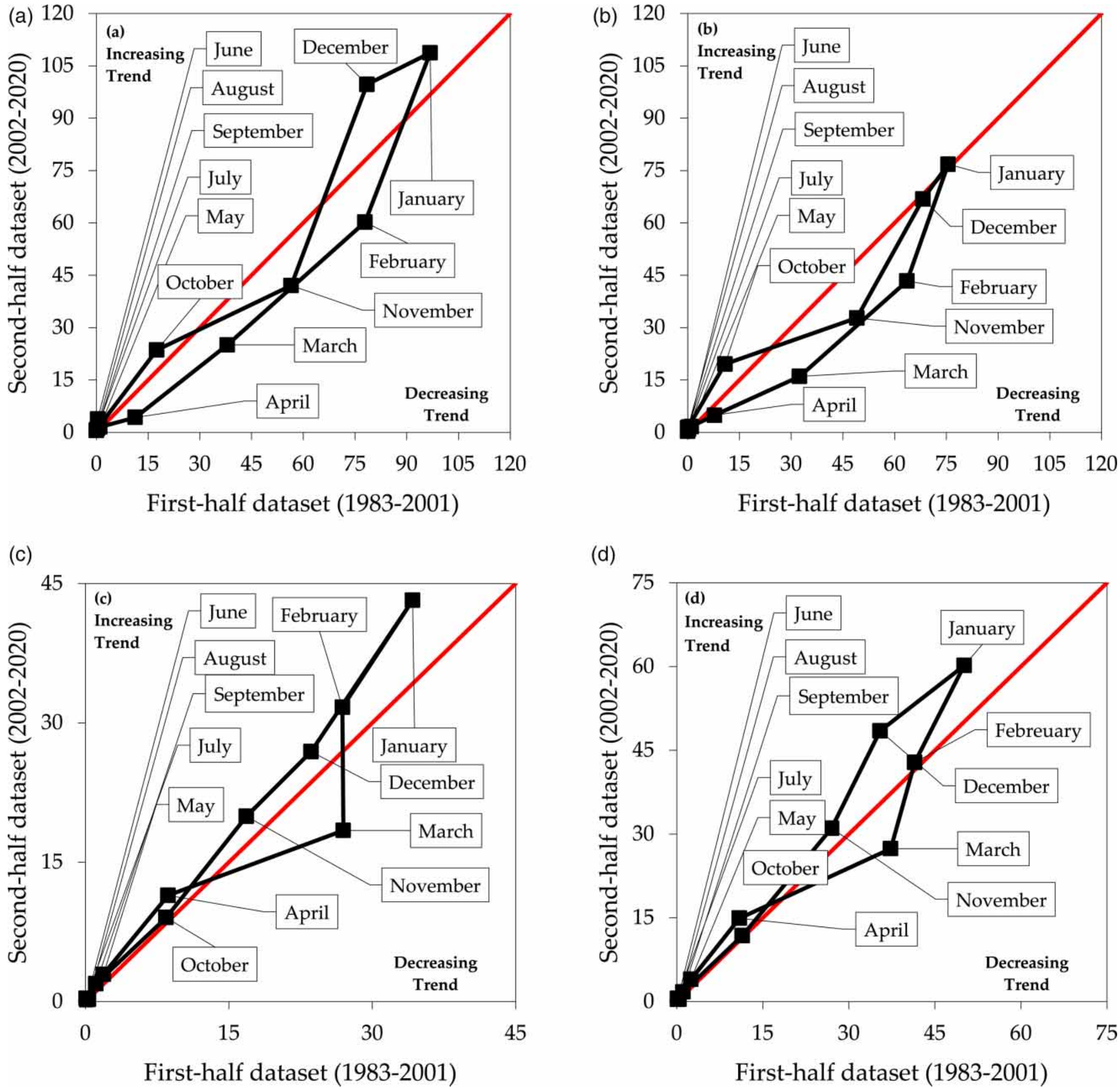


Figure 4 | IPTA method for total monthly rainfall for meteorological stations of (a) Hebron, (b) Gaza, (s) Ashalim, (d) Beersheba.

delineation of the catchment area shows that the catchment consists of 27 subbasins. Hence, at the downstream pour point, subbasin (1) receives all the discharges and nutrient loads coming from the upstream side as depicted in Figure 5. In particular, the main contributors' subbasins to the discharges come from the northern subbasins of the catchment.

The SWAT model outputs for the parameters of water discharge, sediment, and nutrient loading are shown in Figure 6. The average stream flows range between zero in the summer and about 15 m^3/s during the wet seasons with a maximum discharge reaching 130 m^3/s. In this regard, the sediment transport might reach the downstream areas of the Gaza Strip with a quantity of about 28,000 tons while the nutrient in terms of nitrogen (N) and phosphorus (P) is expected to be loaded about 1,052 and 392 tons on an average monthly basis, respectively.

The correlation between the stream flux and the transported nutrients through the catchment of Wadi Gaza is illustrated in Figure 7. Where a positive demonstrates the trend between the return period (T) fluxes and the TN and TP of nutrients. According to Figure 7(a), the designated flooding discharge of the $T = 500$ years is about 180 m^3/s that is assigned to 11,419 tons of TN and 4,138 tons of TP on an average month basis.

Based on the flooding analysis, shown in Figure 8, the produced discharges from the SWAT model were studied for the T of 2, 25, 50, and 100 years based on the Gamble frequency distribution method.

Potentially, an area of about 2.5 km^2 is under serious threats of flooding every 2 years while every 100 years, the inundation area is expected to be about 15 km^2 of land. In this context, the stream runoff flooding of 18, 91, 109,

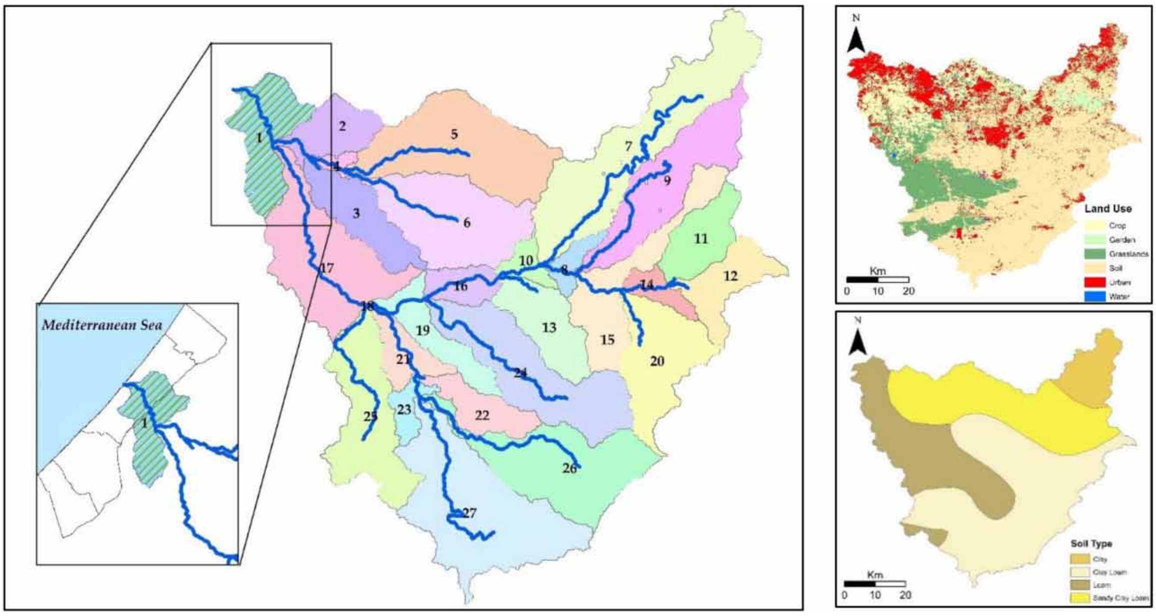


Figure 5 | Subbasins of the Wadi Gaza watershed area.

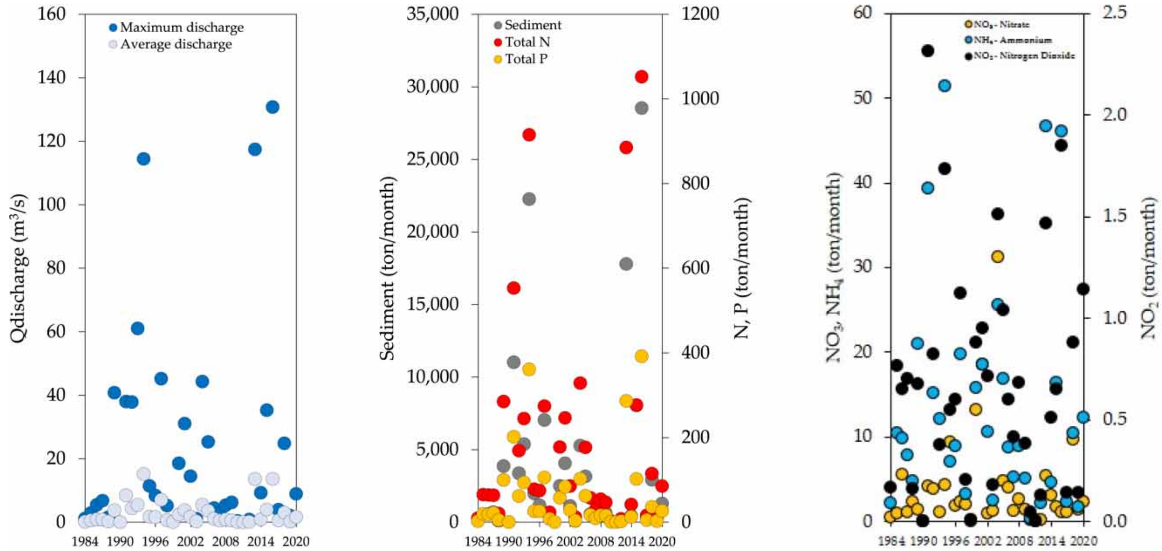


Figure 6 | Subbasins of the Wadi Gaza watershed area.

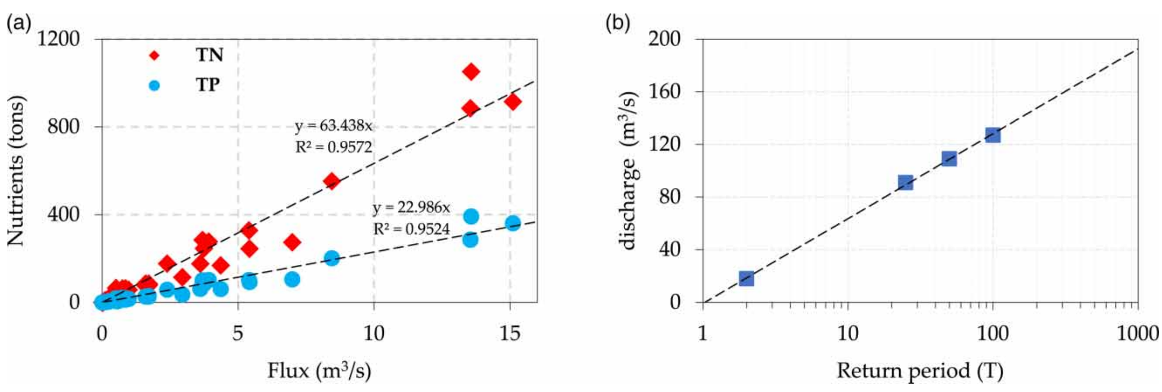


Figure 7 | Correlation of stream flux with the nutrient load for (a) nutrients and (b) fluxes and return periods.

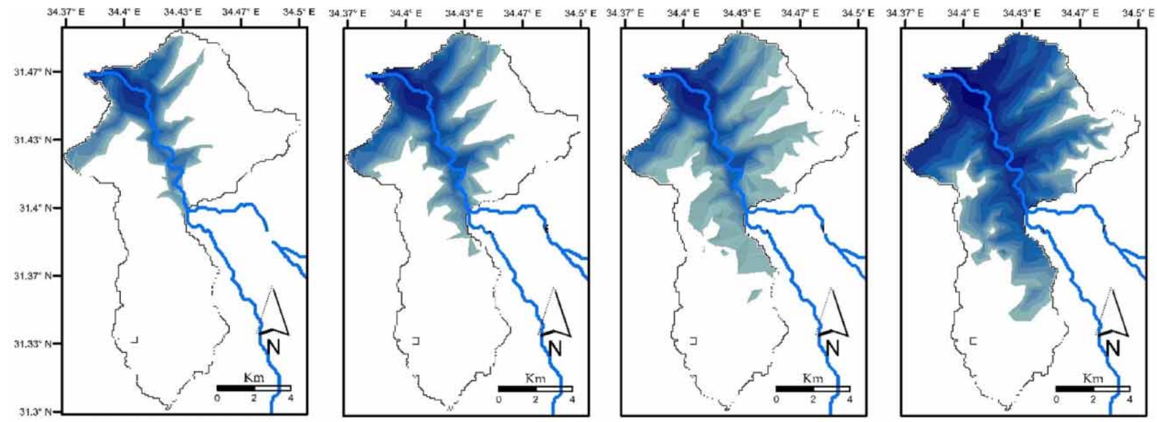


Figure 8 | Prospective flooding of Wadi Gaza.

and 127 m^3/s might provide the Mediterranean ecosystem with nitrogen inputs, respectively, of about 1,142, 5,773, 6,915, and 8,057 tons of TN. In addition, these discharges are expected to transport a phosphorus source of about 414, 2,092, 2,505, and 2,919, respectively.

4. CONCLUSION

The hydrological catchments of the southeastern Mediterranean are vital sources of water and nutrient supplies for the marine ecosystem. However, the lack of studies about the hydrological response of these catchments is an alarming matter in light of climate change implications, anthropogenic processes, and the recorded events of flooding. Therefore, the simulation-based assessment of the southern Mediterranean catchments is an effective trend to demonstrate the conditions of the hydrological features in terms of many affecting factors. The SWAT model is an efficient tool to study the hydrology of the Wadi Gaza catchment to define the potential resources of this area as well as to evaluate the flooding incidents. According to the simulation study for the catchment of the Wadi Gaza, the following could be concluded:

- On average, the stream downstream discharges vary between zero in the dry months and 15 m^3/s in the wet season.
- During the rainy seasons, there may be as much as 3,673, 177, and 62 tons of sediment, TN, and TP, respectively, that could be transported to the Wadi Gaza stream's downstream region.
- Every 2 years, there is a major risk of flooding in an area of about 2.5 km^2, and in 100 years there will likely be an area of around 15 km^2 under water.
- Efficient flood management and alarm systems for the downstream part of the Wadi Gaza basin should be designated to prevent sudden surges of flooding leading to disasters.

In particular, the runoffs of the surface water from the flooding of the Wadi Gaza basin are rich in the nutrient that might be used for enhancing the agricultural irrigation system in the Gaza Strip beyond using synthetic fertilizers that might negatively impact the environmental system. Furthermore, the runoffs comprise a considerable amount of water that might be used for closing the gap in the groundwater deficit and the water sector.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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