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Studying the Impact of Pollution from Wadi Gaza on the Mediterranean Sea Using GIS and Remote Sensing Techniques

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Abstract

Wadi Gaza is considered as one of the most important coastal wetlands located on the Eastern Mediterranean Basin. It is witnessing rapid degradation due to anthropogenic activities including but not limited to discharge of municipal sewage, dumping of solid wastes, rampant use of pesticides and illegal poaching. They form a river of untreated wastewater, more than 5 km long, before its discharge into the Mediterranean Sea. This study aims to perform an analytical study of Wadi Gaza and study its effects on the pollution of the seawater opposite to it using GIS and remote sensing techniques. The flow accumulation, the watershed and the stream orders inside and outside the Gaza Strip are determined based on a DEM which involves a radar terrestrial scanning of Palestine carried out by NASA's Endeavor Space Shuttle. The area of the watershed inside Gaza is estimated to be equal to 58.792 km^2. The Study also shows that the total amount of contaminated water that flows into the sea can be estimated to reach 146.5 mm^3/year. The total area of coastal sea contamination approximately reaches 38.8 km^2 and is oriented to the north direction along the coastal shore and its influence extends to Gaza seaport, 10 km apart from the Wadi.

Keywords

Wadi Gaza, GIS, Remote Sensing, Supervised Classification, Contamination

1. Introduction

Wadi Gaza is considered as one of the most important coastal wetlands located on the Eastern Mediterranean Basin. The Wadi is also a station point for the migratory routes from north to south and from south to north. In addition, it's the biggest in Gaza and having a special outstanding landscape and being one of the biggest in Palestine. Therefore, it has the potential for being a recreational area attracting people from different areas. In recognition of its importance as a natural area and as the only wetland in Palestine, Wadi Gaza was declared as a nature reserve in June 2000. The Ministry of Environmental Affairs (MEnA) requested that municipalities should revise their land use plans so that they ensured that the Wadi bed should be respected as a protected area [1]. Wadi Gaza springs from the Negev hills and the southern heights of Hebron. The length of the Wadi is about 105 km from its source and extends from the borderline in East Gaza to the coast where it discharges into the sea. It is located centrally along the Gaza Strip coast, and is bordered in the north-west by the sea, the south-east by the Bureij Camp, the south-west by the Nuseirat Camp, and the north by Al-Zahra City (**Figure 1**). The maximum elevation of the Wadi is 30 meters above sea level, dropping to sea level where it reaches the Mediterranean Sea. Its circuitous route through the Gaza Strip reaches 9 km. Its width varies from place to place, and gets wider near its mouth where it reaches about 100 m. The tributaries feeding Wadi Gaza have their sources in the central mountain areas, the low heights north of the Negev, and the west and southwest parts of the Hebron Mountains [2].

2. Problem Statement

Wadi Gaza is witnessing rapid degradation due to anthropogenic activities including but not limited to discharge of municipal sewage, dumping of solid wastes, rampant use of pesticides and illegal poaching. Wastewater comes as an effluent from two sources around Wadi Gaza; wastewater treatment plants and sewer systems from the middle area refugee camps. When those two effluents combine, they form a river of untreated wastewater, more than 5 km long, before its discharge into the Mediterranean Sea. Besides wastewater, Wadi Gaza is being used as a landfill for disposing huge amounts of solid waste and construction debris. The leachate generated from accumulated solid wastes has high contaminant concentrations which makes the situation more dangerous.

The worsening pollution in Wadi Gaza is having devastating impacts on the ecology, wildlife as well as the public health of the communities around the valley involving pollution of the coastal area on the Mediterranean Sea. As a result, the disease-causing bacteria and viruses that enter the water of the Sea can lead to serious consequences on human health in addition to inability of the population to repose and swim in the sea due to the severe pollution. Keeping in mind, Gaza coastal zone has multi functions and provides the area with different resources potential which could be classified into economic potential, social potential and scientific potential [3]. The Gaza Strip beaches are the only major source of recreation and tourism, a traditional zone for agricultural production as well as the main source of fishery sector.

Wadi Gaza is now an open drain for sewage. Until 2011, it receives up to 11,000 cubic meters of raw sewage from the middle Gaza district and 40,000

Figure 1. Geographic location of Wadi Gaza.

cubic meters of partially treated sewage from Gaza city every day and discharge it to the Mediterranean Sea. However, now, due to the closure of the Gaza sewage outlet and the increase in population, the Wadi directly receives up to 14,000 cubic meters of sewage from the middle area every day. Most of the water feeds Wadi Gaza has stopped flowing into the Wadi because the Israeli authorities have built dams along the borders with Gaza, diverting all the water to Israel. Water samples taken from water wells and from the seawater opposite the Wadi showed high pollution levels of organic matter, faecal coliforms, faecal streptococci, and heavy metals [4] (**Figure 2**).

3. Aim and Objectives

This study aims to perform an analytical study of Wadi Gaza and measure its effect on the pollution of the seawater opposite it using GIS and remote sensing techniques. To achieve this aim, the following objectives should be considered:

- Estimation the watershed and stream orders of the Wadi.
- Estimation the amount of contaminated water flows into the sea.
- Estimation the area of the sea contaminated by Wadi Gaza.

4. Study Area Characteristics

Wadi Gaza region, as a part of the Gaza Strip, has a hot semi-arid climate, with warm winters and hot summers. Spring begins in March and extends to June. Despite the dryness, humidity is high throughout the year. The average temperature rise is 33˚C. January is the coldest month of the year, averaging the lowest temperatures of 7 Celsius. Rainfall is scarce and falls between November and March, with an average annual rainfall of about 116 mm. Winds are blowing

Figure 2. Wadi Gaza snapshots.

across the Wadi from the southwest. The highest average wind speed in Winter is about 7.3 knots/hour but the highest wind speed for the entire year is about 7.6 knots/hour in January. Wind speed is lowest in Summer, with a seasonal average of about 5 knots/hr. The average wind speed in spring is lower than in Winter to 6.7 knots/hr. The wind speed in Autumn is 5.6 knots/hour which is lower than its value in Winter and Spring. The terrain is flat or rolling, with dunes near the coast [5]. **Figure 3** illustrates some of the study area characteristics.

Table 1 illustrates the rainfall data on the study area during the interval between 1990 up to 2012 [6]. The average rainfall on the study area during the months of each year period is shown in **Figure 4**.

Evaporation is very important since it is a major factor that delineates the water budget and the general quantity of water in the study area. The calculations are based only on the rainy months. **Table 2** shows the daily evaporation rate of the study area along the months of a typical year [6].

5. Wadi Gaza Analysis

Analysis involves the estimation of the watershed area and the stream orders of Wadi Gaza. It also includes the estimation of the amount of contaminated water that flows into the sea via Wadi Gaza as well as the estimation of the area of the sea contaminated by this flow.

5.1. Watershed Area and Stream Orders

For this purpose, a Digital Elevation Model (DEM) of the area is downloaded from ASTER website. The DEM involves a radar terrestrial scanning of Palestine carried out by NASA's Endeavor Space Shuttle in 2016. The DEM is a grid of pixels where each pixel has a value equals its elevation above the mean sea level. To determine the direction of flow based on the height at the pixel level and not at the level of the tributaries, meaning that each pixel leads to the adjacent pixel holding a lower height value. The resulting raster file of this step is in the form of grid cells and each cell holds a value of one of these numbers (1, 2, 4, 8, 16, 32,

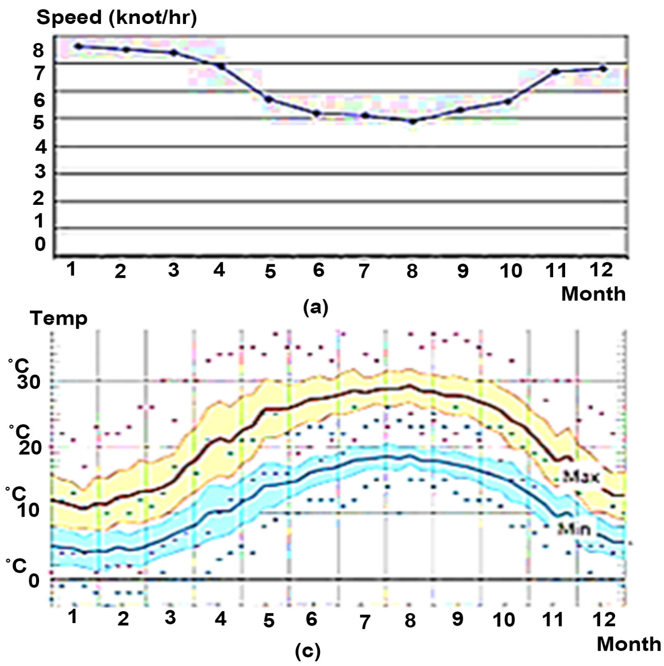


Figure 3. Study Area characteristics. (a) Speed in knot/hr; (b) Humidity %; (c) Temperature in ˚C.

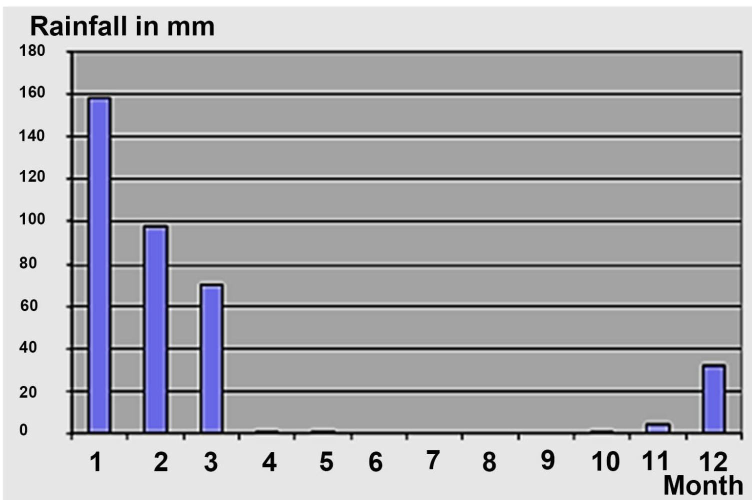


Figure 4. The average monthly rainfall on the study area in mm.

64, 128) (Figure 5). Value 1 indicates that the flow is to the East direction while 2 is to the Southeast, 4 is to the South, 8 is to the Southwest, 16 is to the West, 32 is to the Northwest, 64 is to the North and 128 is to the Northeast direction. Next, the flow accumulation, the watershed and the stream orders can be determined using the GIS tools (Figure 6). The area of the watershed is estimated to equal to 58.792 km^2.

5.2. Contaminated Water Flow via Wadi Gaza

The amount of contaminated water that flows into the sea can be calculated by adding the total amount of rainfall on the watershed area to the total quantity of

Table 1. Rainfall data on the study area for the interval 1990-2012.

Year	Average Rainfall (mm/year)	Qty (Mm^3)	Leaked Water (Mm^3)	Days of Rainfall	% Rainfall from Average
90-91	373.8	86.9	21.7	40	106.3
91-92	588.9	133.7	33.4	47	166.1
92-93	452.4	121.7	30.4	48	126.8
93-94	218.9	56.3	14.1	29	60.3
94-95	577.3	158.3	39.6	54	165.3
95-96	378.0	97.5	24.4	47	106.5
96-97	300.8	89.2	22.3	45	87.8
97-98	225.8	59.7	14.9	31	64.1
98-99	121.5	31.4	7.9	23	32.6
99-00	311.5	77.4	19.3	45	85.2
00-01	474.8	130.3	32.6	53	132.9
01-02	477.9	121.5	30.4	45	130.9
02-03	540.6	131.4	32.8	59	145.3
03-04	329.5	84.3	21.1	30	90.5
04-05	358.8	134.7	33.7	36	104.5
05-06	299.6	79.4	19.9	35	83.9
06-07	419.6	101.2	25.3	38	115.3
07-08	259	63.2	15.8	26	72.1
08-09	316.7	103.5	25.9	25	87.0
09-10	220.6	73.4	18.4	32	61.0
10-11	233.2	77.9	19.5	34	60.0
11-12	394.2	131.9	33	45	109.4

wastewater comes as an effluent from wastewater treatment plants and sewer systems from the middle area refugee camps, minus the sum of the vaporized and infiltrated water quantities. The quantities from outside Gaza are neglected because of building a dam at the Gaza Strip border which does not allow flow forward into Gaza. To estimate the average annual rainfall amount on the watershed region, the weighted mean from the nearby rainfall stations is considered (Figure 7), and is measured to be 364.513 mm. Thus, the total amount of rainfall on the watershed can be estimated to be 21.431 mm^3/year by multiplying the average annual rate by the watershed area. The average daily evaporation in rainy months, referring to Table 2, equals 3.32 mm considering the average number of days of precipitation per year is 33 days. The total amount of evaporation can be calculated by multiplying the average daily by the average number of precipitation days and the watershed area where it is found to be 6.441 Mm^3. The amount of infiltrated water leaked to the groundwater reservoir is taken as

Table 2. Daily evaporation rate of the study area in mm.

Day	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	2	2.6	2.9	5	2.9	2.6	6.6	5.6	5.8	4.6	5.7	3.8
2	1.7	3.6	2.1	3.2	2.9	4.5	7	5.2	6.4	4.2	3.1	2.6
3	1.6	1.2	2.7	4.4	3.4	4.4	6.3	5.4	6	4.3	3	2.8
4	3.7	1.5	3.1	4.2	4	5.6	5.4	5.4	5.8	4.2	3.3	3
5	3.6	3.6	2.9	2.4	4.2	5.5	7.4	6.7	5.8	4.1	3.7	2.8
6	1	3.4	4.7	2.5	6.9	5.3	8.6	6.3	6.3	4.2	3.1	2.6
7	1.3	3.2	4.3	3.8	5.7	5.4	6.8	6.2	5.9	4.3	3	2.9
8	1.4	5.2	4.4	4.2	3.9	5	7.2	5.8	6	4.7	4.1	3.1
9	1.9	2.8	2.8	4	4.9	5.4	6	6.1	5.6	6	3.3	2.8
10	2.8	3.1	2.5	3.3	5.1	5.6	6.3	5	5.3	4.8	2.4	4
11	2.7	2	4.6	4.1	5.5	5.2	6.9	5.6	6	4	4.5	2.4
12	3.1	3.4	3.8	5.3	4.2	5.7	7.2	6.5	5.8	4.8	3.3	3
13	1.6	4.3	2.3	5.4	4.8	5.6	5.2	7.2	3.8	5.3	3.1	3
14	1.5	2.9	3	4.6	5	5.5	6	6.1	6.2	4.5	3	3
15	2	2.7	3.4	5.1	3.9	5.6	6.1	6.3	5.2	4.2	2.9	1.8
16	3.6	4.4	3.7	2.9	5.1	5.9	5.4	5.9	5.4	4.6	3.3	2.4
17	3	3.1	5	3.2	5.1	6.3	6.2	5	5	4.2	2.4	2.6
18	1.5	4.8	4.7	3.2	5	5.7	6.2	5.5	4.3	4.4	4.1	2.6
19	2.6	1.9	4.4	3.1	4.8	6.5	5.1	6.4	6	5.2	4	2.6
20	3.8	2.7	4	3.9	5.1	5.4	6.6	6.2	5.7	3.8	3	2.6
21	2.9	2	3.6	4.4	5.2	5.4	5.8	5.7	5.3	4.3	3.7	2.5
22	2.7	2.1	4.1	5.2	4.7	5	6.4	5.7	6.7	4.6	4.3	1.7
23	2.4	3.9	4.3	5.2	4.2	6.1	6.1	5.9	7.3	3	4.6	1.9
24	3.1	3.9	4	4	3.7	5.9	6.2	6	6.2	4	5.7	2.8
25	4.1	1.3	3.2	4.4	5.7	6.6	6.8	6.2	5.9	4.9	5.2	2.6
26	3.4	2.7	2.8	4.1	5.4	6.4	6.2	6.9	5.5	4.2	3.2	2.5
27	3.3	3.8	3	4.1	5.5	5.9	6.1	6.7	5.8	5.9	3.7	2.4
28	2.8	3.4	3.5	6.9	5	6.2	7.1	5.4	6.2	4.3	3.8	2.8
29	3.4		5.3	6	7	5.7	6.4	5.9	6	3.8	2.2	2.1
30	2		4.7	4.8	5	5.3	5.8	5.5	4.4	3.7	2.8	1.8
31	3		4.9		4.8		6.4	6.8		5		1.5
Av.	2.6	3.1	3.7	4.2	4.8	5.5	6.4	6	5.7	4.5	3.6	2.6

354,242.802 m^3, according to the average amount of previous years [7]. The total quantity of wastewater that flows into the Wadi is estimated to be 12,500 m^3 [4]. On conclusion, the total amount of contaminated water that flows into the sea can be estimated to reach 146.5 mm^3/year.

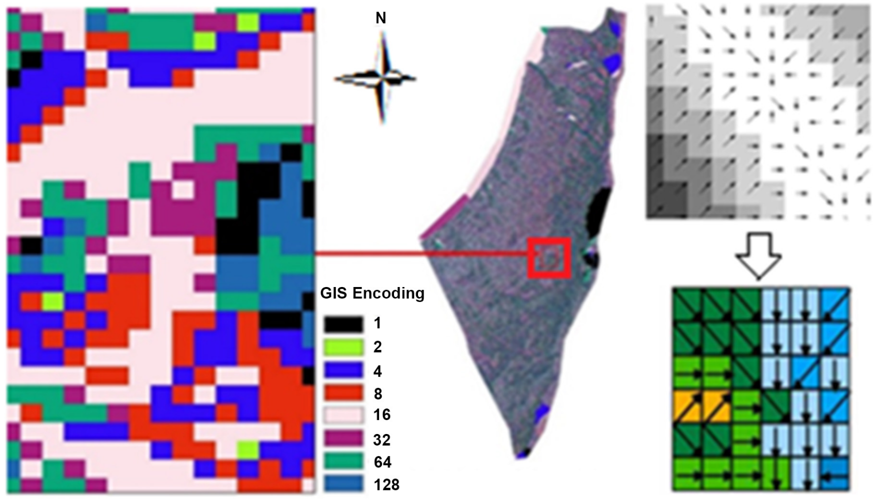


Figure 5. Estimation of flow direction.

5.3. Sea Area Contaminated

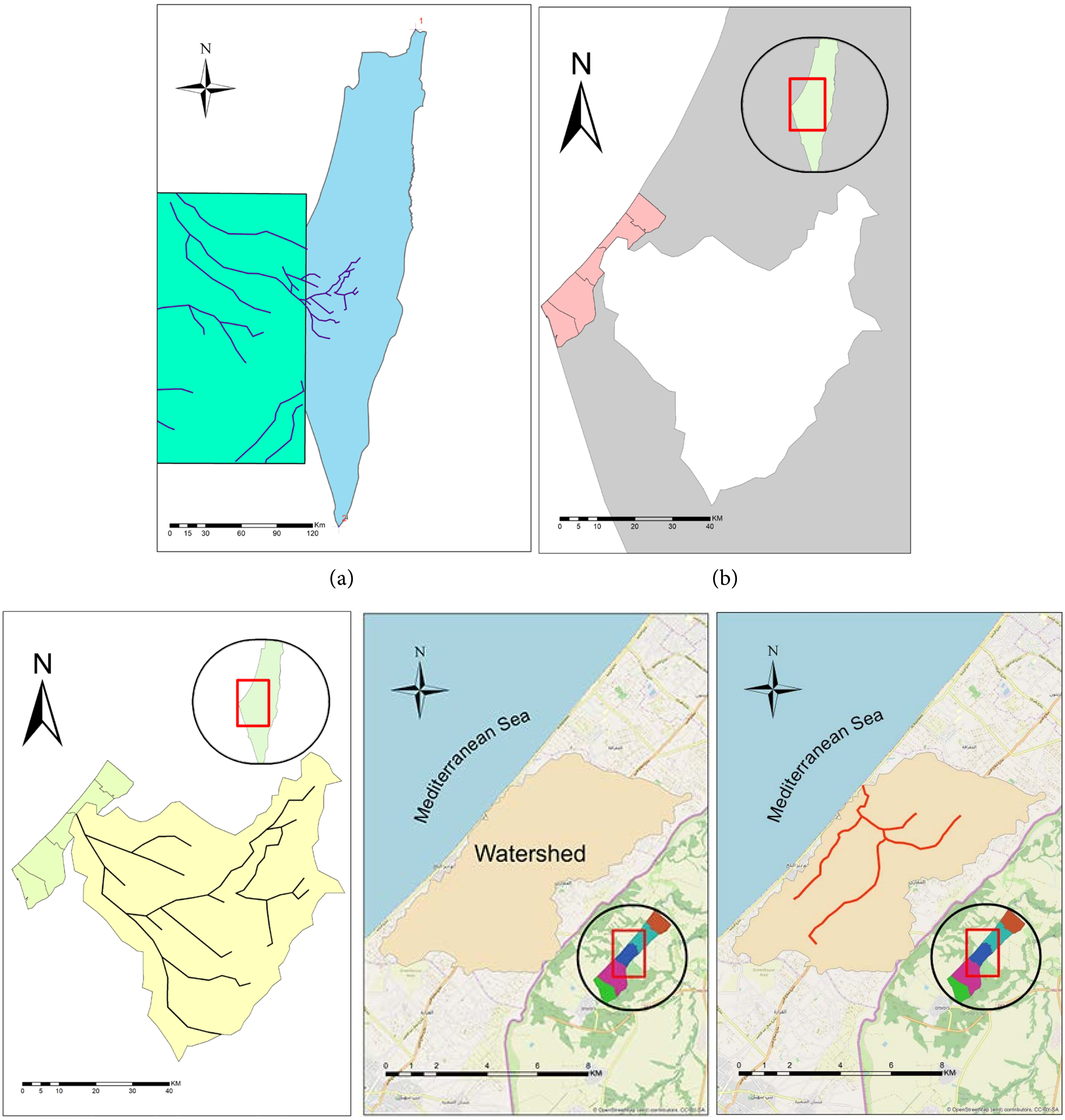
A Landsat remotely sensed imagery is downloaded from the U.S. Geological Survey (USGS) website, Landsat archive of December 2016. A full-band imagery in a Geostationary Earth Orbit Tagged Image File Format (GeoTIFF) is used. First, pre-processing of the obtained image which includes radiometric and geometric correction is performed using ERDAS Imagine 2016 software. Principal Component analysis of the main component of a multi-spectral image has been performed so that the convergence between the primary colors is separated so that each color is easily controlled, and the range is maximized between the smallest value and the largest value. Next, supervised classification is used since the Area of Interest (AOI) is known and clear to be distinguished. Thus, the spectral signatures are developed and then the software assigns each pixel in the image to the type to which its signature is most similar.

Figure 8 shows the satellite image enhancement and classification. GIS techniques are used to estimate quantities of seawater polluted as extracted from the classified image using ArcGIS 10.5 software.

Table 3 summarizes the amount of sea pollution divided into three levels based on the degree of contamination. The contamination, as shown in Figure 8(c), is classified into three greyscale areas where each area expresses the amount of pollution in it. The total area of contamination approximately reaches 38.8 Km^2 and is aligned to the north direction on the coastal shore and its influence can extend to further than Gaza seaport which is 10 km far from the Wadi, along the coastal shore.

5.4. Discussion

Although Wadi Gaza was declared as a nature reserve, it still continues to be a source of complain to inhabitants live around the Wadi as well as being one of the major sources of pollution to the Gaza Strip environment. The annual amount of 146.5 Mm^3 of contaminated water that runs via the Wadi and



(c) (d) (e)

Figure 6. (a) Flow accumulation; (b) watershed; (c) stream orders; (d) Gaza watershed; (e) Gaza stream orders.

discharges into the sea and which results to pollute an area of 38.8 Km^2 from the coastal zone is very impressive. The area around Wadi Gaza suffers from a foul smell and health problems. The coastal area is important from an economical point of view. It is rich sources of food, energy and minerals and considered a primary source of livelihood for a large part of the Palestinians. It has also sustained functions for the marine life and the biodiversity, which has important to the local, regional and global environment as will. The beach is the only continues

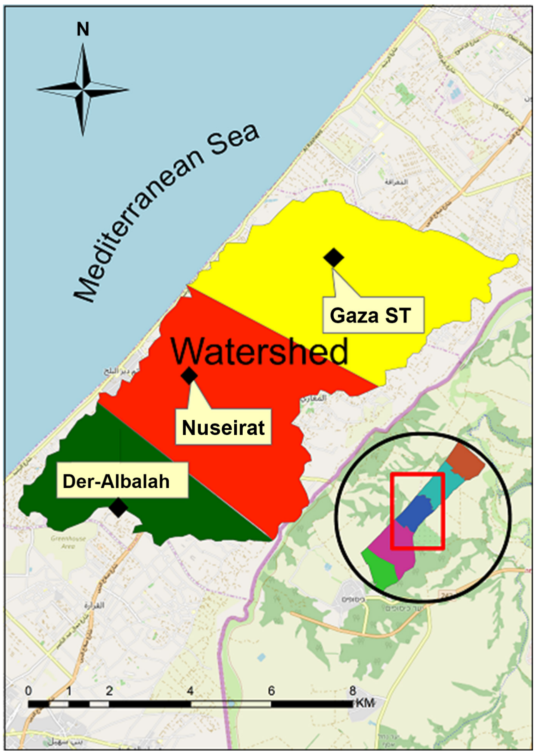


Figure 7. Watershed division by rainfall stations.

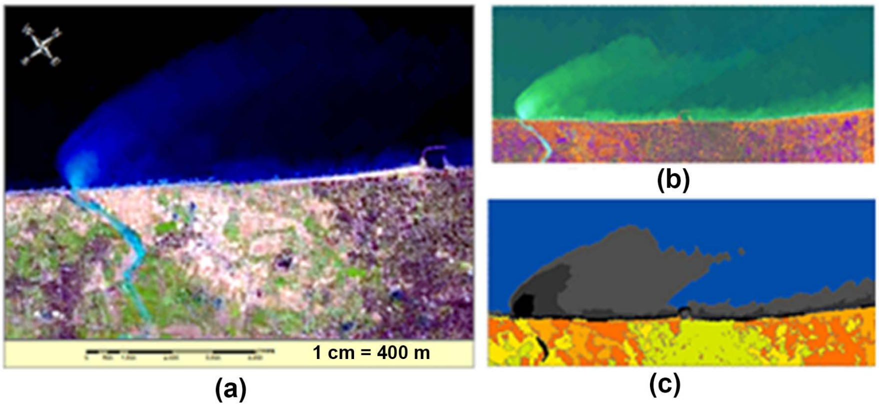


Figure 8. Satellite imagery analysis. (a) Landsat image; (b) Principal Component analysis; (c) Supervised classification result.

Table 3. Amount of seashore contamination.

ID	Level of Contamination	Contamination Area (Km^2)
1	High Degree	2.9
2	Medium Degree	8.3
3	Low Degree	27.6
	Total	**38.8**

accessible recreational area for the population of Gaza. In the same time, sand dunes in the coastal zone hold the best ground water resources in Gaza.

The study results highlight an environmental alert to the local authorities to face the resulting risk through activating the natural area of the Wadi and find a proper solution to the wastewater problem. A wastewater treatment plant is very essential to serve the middle area and households should be connected to a pumping station in order to pump the sewage to this plant. The donor organizations should devote more funds to treat the harmful impact of this problem. In addition to, several future studies should be carried out to study the impact of this contamination from Wadi Gaza on the pollution of the groundwater as well as marine organisms and on persons bathing in the sea opposite it.

6. Conclusion and Recommendations

The flow accumulation, the watershed and the stream orders inside and outside the Gaza Strip are determined based on a DEM which involves a radar terrestrial scanning of Palestine carried out by NASA's Endeavor Space Shuttle. The area of the watershed inside Gaza is estimated to be equal to 58.792 km^2. The study also shows that the total amount of contaminated water that flows into the sea can be estimated to reach 146.5 mm^3/year. The total coastal sea area of contamination approximately reaches 38.8 km^2 and is aligned to the north direction on the coastal shore and its influences can extend further than Gaza seaport, 10 km apart from the Wadi. It is strongly recommended to consider the output of this study into account by setting laws and legislations for the preservation of Wadi Gaza environment as well as solving the problem of wastewater and removing it from the valley area.

Acknowledgements

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