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Review

Assessment of Water Balance Dynamics and Resource Stress in the Gaza Strip, Palestine

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Abstract

Water scarcity is one of the most pressing global challenges, particularly in arid and semi-arid regions. In this context, the Gaza Strip, where groundwater is the only available natural water resource, faces severe water stress due to overexploitation and drought conditions. This study aimed to review the recent water budget for the Gaza Strip by collecting data for the years (2021-2022) which was analyzed, discussed, and compared with other studies. The results showed a sharp deterioration in the Gaza Strip in terms of quantity and quality. The value of recharge elements amounted to 109 million m^3. In comparison, the withdrawal was estimated at 242 million m^3, with an increase of approximately (220%) to the recharge, half of which was 122 million m^3 for agricultural consumption. In contrast, the general water deficit was recorded at 133 million m^3. The results also showed that the permissible standards for salinity, Total Dissolved Salts, and nitrates were exceeded. Studying the water balance of the Gaza Strip supports the decision of policymakers to take adequate measures to reduce water depletion and protect the rights of future generations.

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Keywords
Water balance; water resources management; Hydrology; water quality; Gaza Strip

1. Introduction

The water available in Gaza can't meet the basic needs of the people. The United Nations International Children's Emergency Fund (UNICEF) estimates that, as of 2020, only 10% of Gaza's population has direct access to clean and safe drinking water. Overall, it was estimated in 2021 that about one million people (approximately half the population at that time) in Gaza were in urgent need of water and sanitation services [1]. The available resources can no longer meet the water demand, resulting in a severe shortage of water supply. In addition, increased withdrawal rates due to insufficient imported water into Gaza, a growing population, and the drilling and extraction of unauthorized wells have led to saline infiltration [2]. Water supply has also been negatively affected by operational problems with Gaza's existing water management system due to the lack of a continuous electricity supply. Chronic electricity shortages in Gaza have severely affected the delivery of basic services, especially health, water and sanitation, and the agricultural and industrial sectors [3].

Rainfall is the only source of fresh water in the Gaza Strip and is considered an essential part of the hydrologic cycle that directly affects groundwater balance and replenishment. Rainfall data is an integral component of the basic data input for all hydrologic and engineering exploratory surveys [4].

Various studies have been conducted to estimate the amount of recharge/runoff in the Gaza Strip [5-7]. These studies compare the recharge/runoff quantity based on different methods. Groundwater recharge from rainfall is a primary factor in the water balance of an aquifer [8, 9]. Other water supply sources to the Gaza aquifer include streams that cross the Israeli border in the southeast and come from aqueducts, sewers, and rainwater retention basins [10]. The individual fresh groundwater recharge element is rain. All other replenishment sources from human activities and processes, including poor quality water, are filled into the groundwater [11]. The recent non-conventional water alternatives utilized in the Gaza Strip are stormwater recovery, seawater desalination, wastewater reuse, and purchased water from neighboring nations. At this period, seawater desalination tracks are operated over three short-term low-volume (STLV) desalination plants to supply 13 million m^3 of desalinated water [12].

The above confirms the urgent need to study the water budget of the Gaza Strip. Both [13-15] conducted a study to evaluate the water budget. Still, through a closer look at the components of the water balance in the Gaza Strip, it needs to be studied using recent data due to climate change, the increase in water consumption patterns for various uses, and the increase in population.

This paper aims to analyze the data of the components of the water balance of the Gaza Strip - Palestine as a semi-arid region suffering from multiple crises in the water sector, using recent data focusing on the years 2021-2022, to provide indicators and outputs that reflect the actual water situation in the Gaza Strip, which gives decision-makers the right step to take precautionary measures to develop water resources and formulate a rational vision for water consumption in the Gaza Strip.

2. Materials and Methods

2.1 Study Area

Location and Population: The Gaza Strip is a semi-arid area between Egypt and occupied Palestine on the Mediterranean Sea's southeast coast. It lies precisely between latitudes 31°16’ and 31°45’ north and longitudes 34°2’ and 34°25’ east [14]. It is a portion of the Palestinian coastal plain and spans an area of roughly 365 km^2. It is approximately 40 km long along the coast and 6-12 km wide. The Gaza Strip has five governorates, each with twenty-five municipalities [16]. The location map of the Gaza Strip is shown in Figure 1.

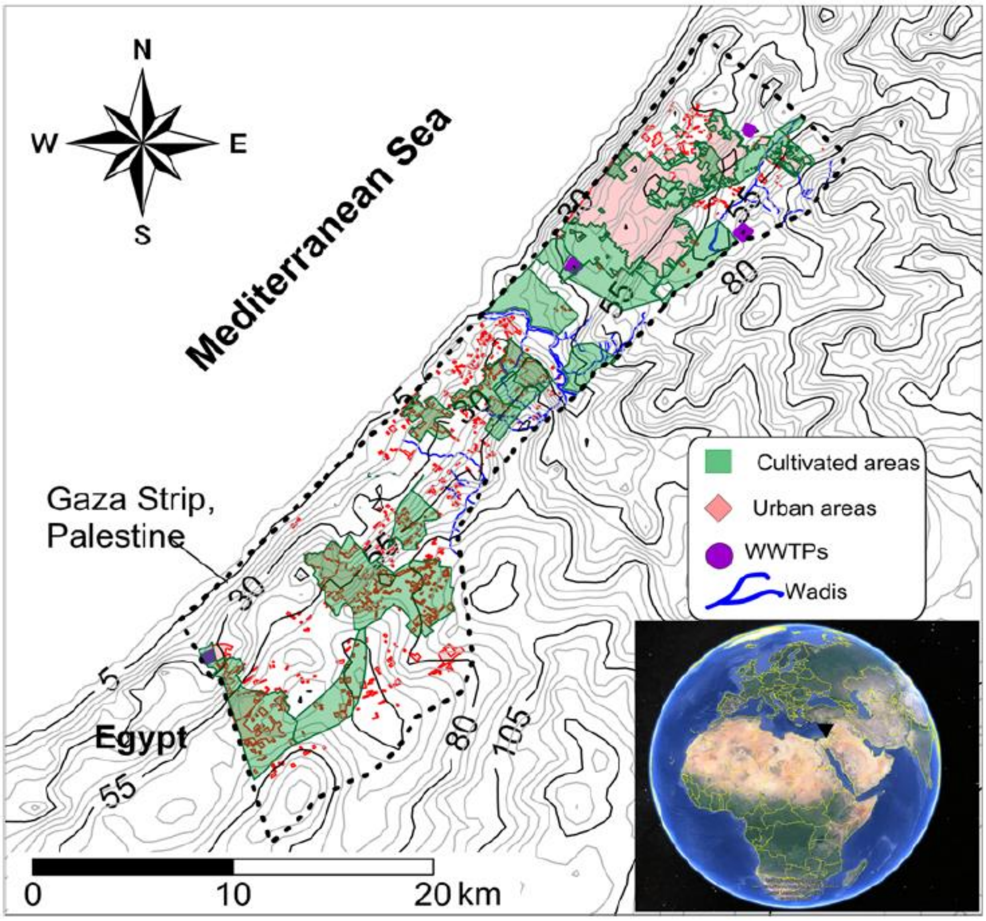

Figure 1 Location Map of the Gaza Strip [17].

According to the Palestinian Central Bureau of Statistics, the Gaza Strip is one of the most densely populated places in the world. The population was estimated to be 2.22 million in December 2022, and the natural rate of population growth is assessed at 3.37% per year. By 2035 the population will reach about 3.7 million [18].

2.1.1 Meteorological Data

The metrological data from 1986 to 2018 were recorded by the Palestinian Water Authority and the Ministry of Agriculture, which shows that the average temperature is 26.5°C in the summer and

13.4°C in the winter. The hottest month is August while the coldest month is January. The relative humidity is 62-78%.

During the summer, there is a sea breeze during the day and a land breeze at night. The wind is strongest around noon and weakens at night. Strong northwestern winds, averaging 3.9 m/sec, blow regularly at specific times. In the winter, southwestern winds average 4.2 m/sec, but there are also storms with winds reaching 18 m/sec. The primary rainy season in the Gaza Strip occurs from October to March, while the dry season from June to August receives very little rainfall. When it does rain, it is often heavy and appears in a short period, rather than as a continuous light rainfall. The risk of extreme and severe drought occurrence is 83% [19].

2.1.2 Geological and Hydrological Data

The geological formations of the Gaza coastal aquifer consist of calcareous sandstone, dunes, silt, clay, and gravel [17]. Kurkar ridges, which are exposed in both continuous and intermittent shapes and are generated from sandstone dunes by Aeolian deposits, are a defining feature of the coastal plain's morphology. Dunes make up the normal soil layer of the Gaza Strip's coastal region. Additionally, the eastern part of the Gaza Strip is dominated by loess soils and sandy loess soils [16].

Rainfall percolation in the eastern side of the Gaza coastal aquifer is restricted due to its lower hydraulic conductivity. Also, it is covered by thick deposits of loess soils (up to 20 m depth) while in central and western parts of the aquifer, recharge occurs through the areas of dunes, calcareous sandstone, and sandy loam [17]. The stratified soil of Gaza is divided into four layers. The aquifer can be considered as one hydrological unit. The coast is in the west, and the marine clay decreases towards the east [20]. The higher sub-aquifer "A" is unconfined, as seen in Figure 2, while sub-aquifers "B1, B2, and C" becoming progressively more confined as they approach the sea. The coastal aquifer configuration is about 120 meters thick along the shore. The saturation thickness at the eastern Gaza border is only 5-10 m in the south of the Gaza Strip and roughly 60 m in the north [14]. The Groundwater level in Gaza declines as abstraction increases. It ranges from 18.2 m below sea level to about 11.8 m above sea level [21].

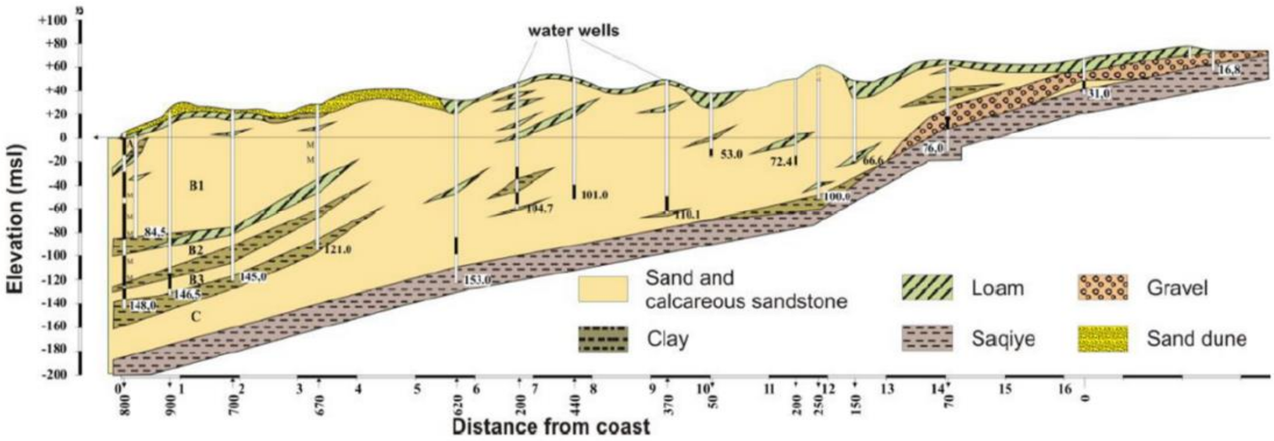

Figure 2 Typical Hydrogeological Cross Section of the Gaza Coastal aquifer [21].

The highest water level exhaustion zones are located in Rafah governorate, which has more than 15 m, owing to high groundwater production rates, but in Jabalia camp, around 5 m [22]. In the intermediate area, the water depletion level is relatively low, where the saturated thickness of the aquifer is characterized by low water quality, high chloride concentration, and low saturated thickness. Hence, the production rates of groundwater are very low for domestic and agricultural use [14].

2.2 Data Sources and Methods

- Raw data about the water quantity from wells, groundwater, and annual rainfall were collected from the Palestinian Water Authority [23].
- The rainfall amount on the Gaza Strip is cumulatively estimated by collecting the daily rainfall records obtained from the 17 manual gauge stations using the Thiessen network method, according to the Ministry of Agriculture.
- The analysis of data collection based on the long-term average seasonal water balance equation: P = S + ET + R, where P is precipitation, S is surface runoff, ET is evapotranspiration, and R is groundwater recharge from the Water Quality & Environmental Authority.
- Gaza Strip and its governorates, land use, and Population data obtained from the Palestinian Central Bureau of Statistics [24].
- The secondary data was collected from a desk review. This includes reports, government publications, and official statistics, the primary source of documentary data.

The methodology used in this study is illustrated in Figure 3, which outlines the steps followed to assess the water balance dynamics in the Gaza Strip.

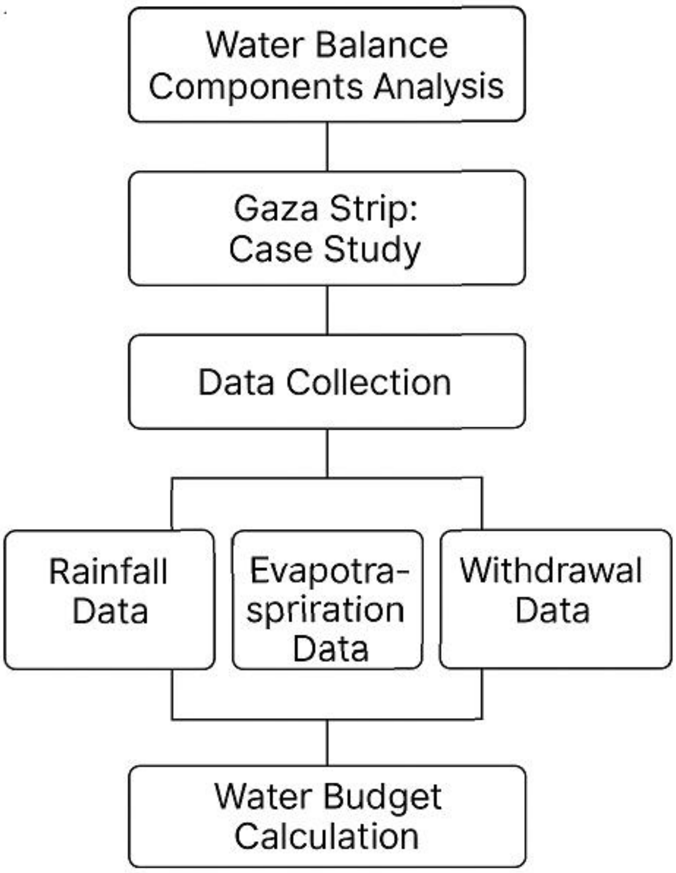

Figure 3 Flowchart illustrating the methodology for assessing the water balance in the Gaza Strip.

3. Water Resources Environment

3.1 Water Availability

Palestinian Water Authority report (2021) through the Water Information System presented an indicator for Water Statistics in the Gaza Strip. Around 90% of the available water is obtained from groundwater wells (192.5 million m^3). This includes the unsafe pumping from the coastal aquifer in the Gaza Strip (and does not include the abstraction of the unlicensed wells in Gaza), of which the safe pumping and the basin's sustainable yield do not exceed 50-60 million m^3 from the abstracted. About 100 million m^3 of seawater is from return flow (seawater intrusion). Furthermore, 97% of the water pumped from the coastal aquifer does not satisfy the water quality standards of the World Health Organization, as summarized in Table 1 [23].

Table 1 Indicators for Water Statistics in Gaza Strip 2021 [23].

Indicator	**Unit: million m^3**
Annual Available Water Quantity	214.4
Annual Pumped Quantity from Groundwater Wells	192.5
Desalinated Drinking Water	7.5
Annual Quantity of Water Purchased from Israeli Water Company (Mekorot)	14.4
Quantity of Water Supply for the Domestic Sector	113.3
Daily Consumption Rate per capita (liters/capita/day)	82.7

The available resources can no longer meet the water demand, resulting in a severe shortage of water supply. Water supply has also been negatively affected by Israel's restrictions on the import of materials and equipment classified as "dual-use," including those needed to maintain, repair, and improve water supply and sewage systems. Because of these challenges, Gaza's water system remains archaic and prone to leaks, unable to meet the demands of a growing population or deal with damage from repeated military escalations. Poor infrastructure also increases a community's risk of being impacted by overloaded stormwater systems and sewage pumping stations [3].

3.2 Water Quality

The general average of water quality indicators in the Gaza Strip for 2021 is deteriorating. The results of chemical tests showed a significant deterioration in the quality of the groundwater reservoir for all indicators (TDS, CI, NO), where the general average of chloride ion (CI) concentration ranged to 772 mg/L, exceeding This value is the maximum limit of the World Health Organization, which is 250 mg/L. As for the nitrate ion concentration (NO_3), the general average reached 102 mg/L. This value exceeds the maximum limit of the World Health Organization, which is 50 mg/L, as the total average concentration of Dissolved substances (TDS) reached 2308 mg/L [11, 25].

Figure 4 and Figure 5 show the contour maps of the concentration of groundwater reservoir water quality indicators in the Gaza Strip for 2021. A change in water salinity in both horizontal and vertical directions is noticed, as the chloride ion concentration ranges from less than 100 mg/L to more than 5,000 mg/L, and the concentration of total dissolved salts ranges from less than 200 mg/L to more than 10,000 mg/L as indicators of water salinity. It is clear from Figure 4 that the chloride ion concentration has increased significantly in most of the western parts of the Strip, especially in the southern western parts of the North Governorate, the northern western parts of Gaza Governorate, the western parts of the Central Governorate, the north western parts of Khan Yunis Governorate, and the western parts of Rafah Governorate. The chloride ion concentration in these parts reaches more than 5000 mg/L, more than 20 times the World Health Organization's maximum limit for chloride ion concentration, which is 250 mg/L. The total concentration of dissolved salts in these dangerous parts reached more than 7000 mg/L. The area of these parts is approximately 55 km^2, which is approximately 15% of the area of the Gaza Strip.

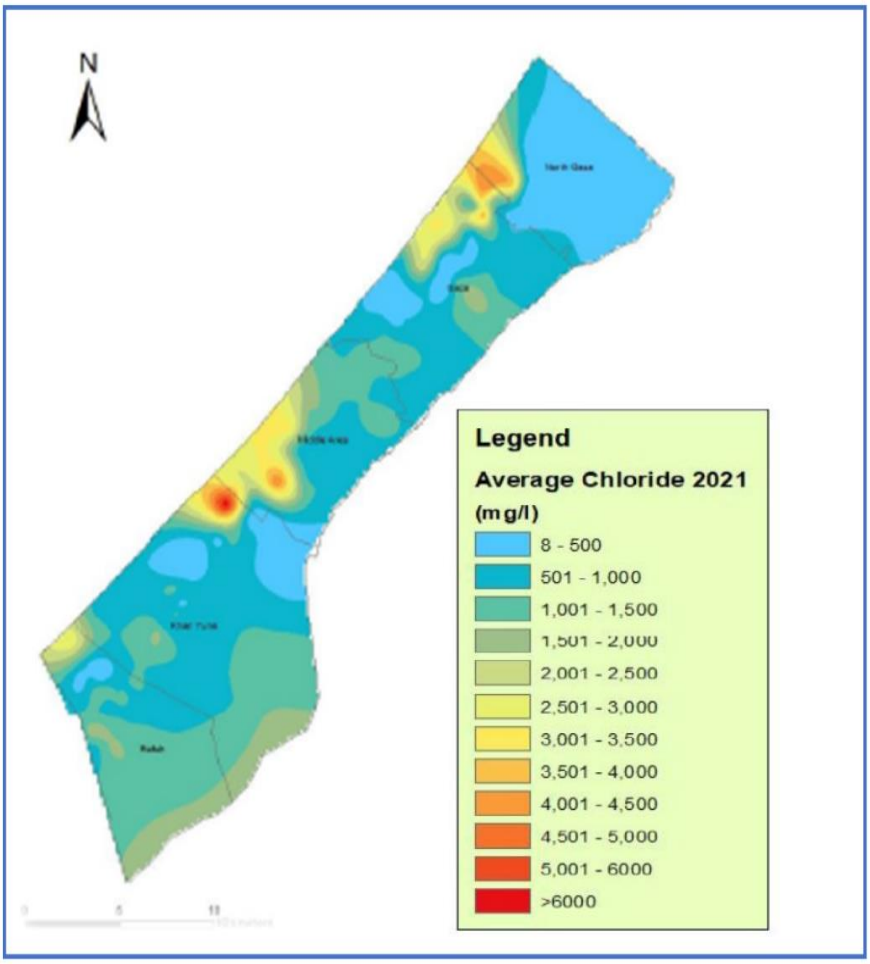

Figure 4 Average Chloride Ion Concentration (Cl) in the Groundwater of the Gaza Strip, 2021 [11].

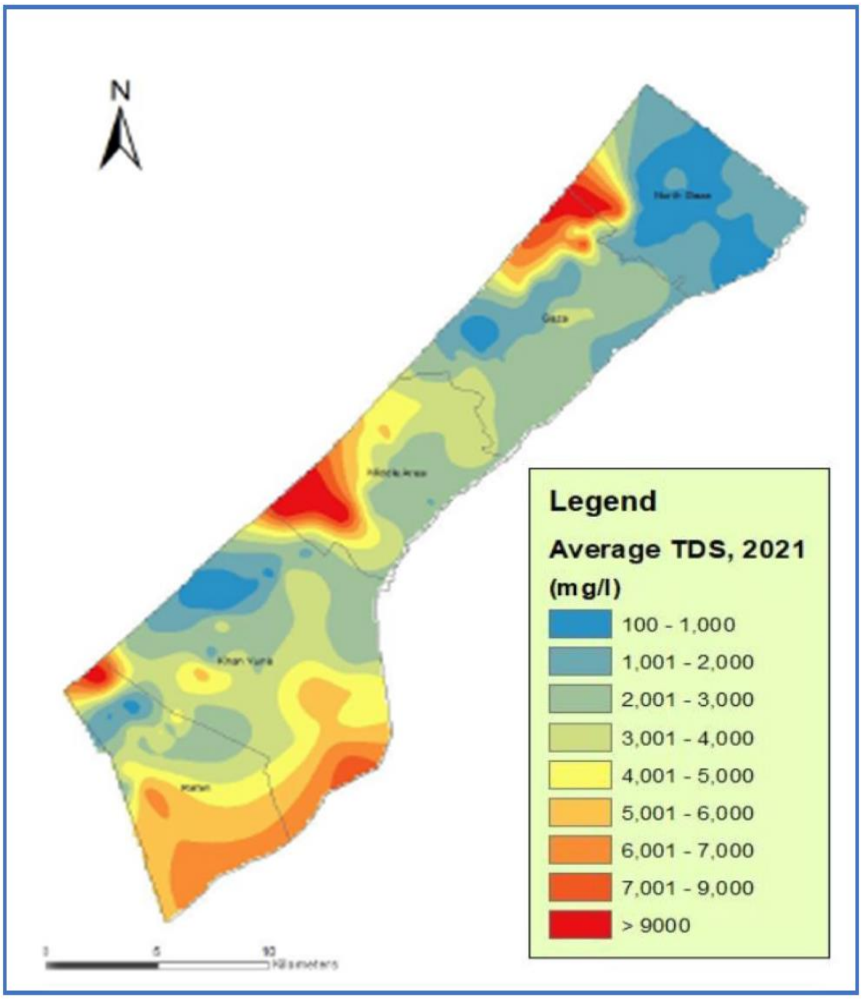

Figure 5 Average Concentration of Total Dissolved Salts (TDS) in the Groundwater of the Gaza Strip, 2021 [11].

Figure 6 shows the contour map of nitrate ion concentration in the Gaza Strip for the year 2021. It's notable that the concentration of nitrate changes randomly in the form of spots. As the nitrate ion concentration ranges from less than 10 mg/L to more than 700 mg/L, the cause of this pollution is due to the leakage of wastewater into groundwater from several sources, such as surface wastewater leakage or the presence of a leak in the wastewater pipeline network sanitary facilities or near wastewater treatment plants and solid waste collection places, in addition to agricultural pesticides that contain high amounts of nitrates, which mix with irrigation water and then filter into the groundwater. Therefore, the concentration of nitrate ions increases in these areas, especially if these sources of pollution are located in areas with sandy soil.

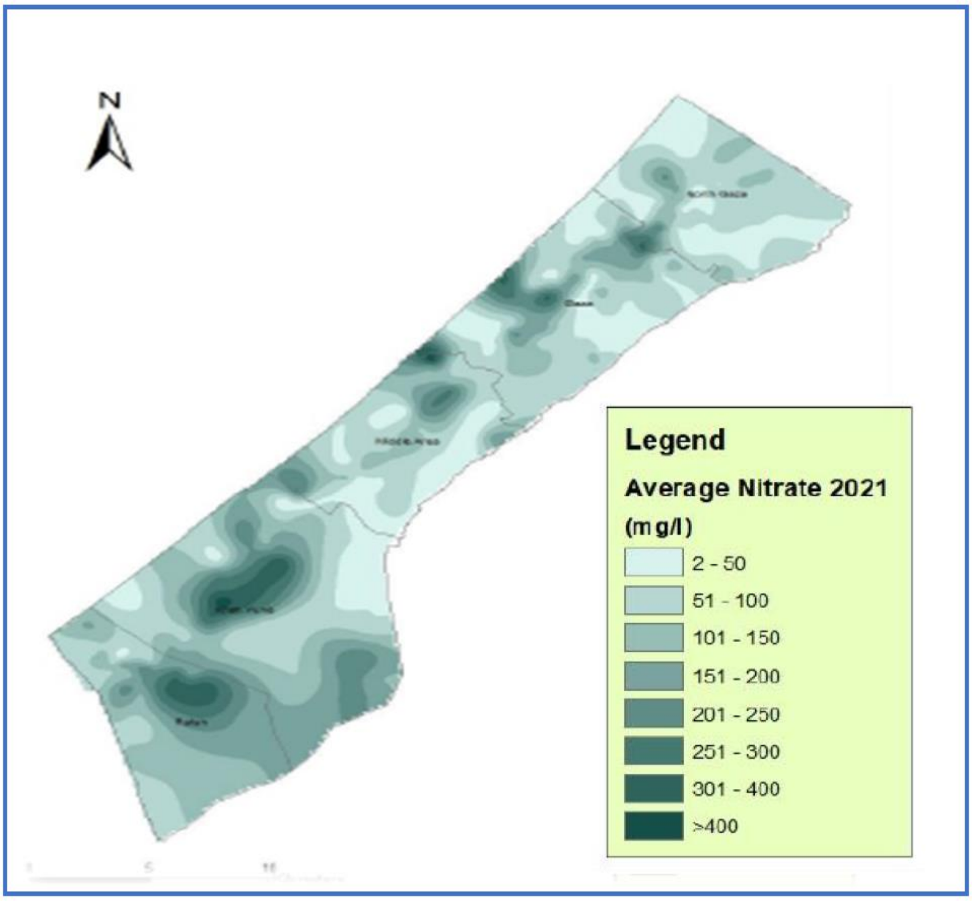

Figure 6 Average Concentration of Nitrate ion NO_3 in the Groundwater of the Gaza Strip [11].

Water quality indicators change over time. The change or increase in salinity of the groundwater produced over time varies from one place to another due to several reasons, the most important of which are the location of the well, the rate of water production, the depth of the well, and the pumping period. In general, there are several patterns of this increase, the wells near the coast were significantly affected by the phenomenon of increased salinity, and the rate of growth in salinity in these wells, represented by the chloride ion concentration, was so noticeable that it reflected the significant effect of seawater interference [11].

3.3 Groundwater

Water resources in the Gaza Strip mainly include rainfall, surface runoff, and groundwater. Groundwater is the primary source of water in Palestine. It is used for agricultural purposes to irrigate the agricultural fields, as well as for domestic and industrial purposes [26]. Aquifers are depleted due to overexploitation: recharge rates cannot compensate for withdrawals, and saline intrusion occurs. This intervention led to further deterioration of water quality. In addition to the inability of Gaza's coastal aquifers to receive enough rainwater to recharge, Israel's water policies also hinder the renewable production of westward surface and groundwater flows. This water embargo has been achieved by installing numerous deep wells and diversions around the border of the Gaza Strip [27].

Groundwater is directly supplied to households after disinfection, while they are also used for agricultural irrigation, therefore groundwater pollution is probably the immediate cause for local health problems and growth-hindrance issues for crops—groundwater pollution mechanism. The total number of groundwater wells in the Gaza Strip is estimated at 12,000, and the number of licensed groundwater wells in the Gaza Strip is estimated at 2560, representing 20% of the total number of wells. The number of violated groundwater wells in the Gaza Strip is about 9400 wells, which represents 80% of the total number of wells according to the Water Quality & Environmental Authority.

Groundwater wells for agricultural purposes represent the vast majority of water wells at 53% of the total number of wells, followed by domestic water wells at 30%. The number of counted groundwater wells (licensed and illegally counted) is estimated at 5972, representing 71% of the total wells [28]. Groundwater level is annually monitored by the PWA monitoring team at the wells located all over the Gaza Strip. Groundwater elevation maps have been generated to describe the groundwater behavior in the abstraction and recharge scheme of the Gaza coastal aquifer. Due to primary pumping focused, large cones of depression have formed over the past decades, which create a pressure difference between the groundwater table and the Mediterranean Sea. This pressure difference will cause seawater intrusion towards those areas [23]. This finding was explored after conflict in Gaza as presented in Abderrahmane Noui and Zineb Guesbaya [29].

3.4 Surface Water

There are three wadis in the Gaza Strip, moving through different locations; between Gaza city and the Middle Governorate (Wadi Gaza), the southern part of the Gaza Strip (Wadi Al Salqa), and the northern part of the Gaza Strip (Wadi Beit Hanoun). Wadi Gaza is considered to be the most significant watercourse in the Gaza Strip, however currently, only minimal amounts of the higher winter flows reach Gaza due to the diversion of water from Wadi Gaza towards artificial recharge and irrigation within Israeli occupation [30]. Its watershed is estimated to cover more than 3,500 km^2 of the northern Negev Desert and Hebron Mountains, as well as the smaller catchment within Gaza.

Wadi Al Salqa watershed is estimated to cover 40 km^2, while Wadi Beit Hanoun watershed is estimated to cover 729 km^2 of the Hebron Mountains; around 5.5% of the total catchment area is located in the Gaza Strip.

In Gaza, most wadis originate to the east of the border, with Israel blockading the flow of water for irrigation. This keeps the wadis dry, except for years with heavy rains. Because Gaza's topography is shallow and the land scarcity is limited, there is limited scope to store and use the remaining water. Wadi's surface water extraction has not been included in total national volumes, as despite considerable interest, it has not yet been significantly developed. The investment required is high, and Israel's occupying forces also impose strict constraints on the construction of dams [31].

3.5 Non-Conventional Water Resources

The recent non-conventional water alternatives utilized in the Gaza Strip are stormwater recovery, seawater desalination, wastewater reuse, and purchased water from neighboring nations. At this period, the seawater desalination track is operated over three short-term low-volume (STLV) desalination plants to supply 13 million m^3 of desalinated water.

Deir Al-Balah STLV in the Alwosta Governorate, desalinate 6,000 m^3/day for domestic supplies and potable uses. The second STLV seawater desalination plant is located in the Gaza governorate and has a capacity of 10,000 m^3/day. At the same time, the third is the regional STLV seawater desalination plant, which produces 20,000 m^3/day of freshwater that reaches the southern governorates of Khanyounis and Rafah through the water networks. This large-scale desalination plant was upgraded in two phases, the first phase to produce 55 million m^3/year by 2025 and the second phase to produce 110 million m^3/year by 2035 [19].

Regarding wastewater reuse, the Gaza Strip has operated three wastewater treatment plants: North Gaza Emergency Sewage Treatment (NGEST), AlBurij, and Khanyounis to reclaim 46.8 million m^3 annually from 2020 to 2025. Until 2026 the treatment capacity is prearranged to rise to 85.8 million m^3.

The Gaza Strip has 27 basins that cover an area of 0.45 km^2 for storm water collections with a total capacity of 1.9 × 106 m^3 to balance the water budget by gathering rainfall for the groundwater recharge and processes of irrigation as exploited in the Gaza water management system [32].

The combined capacity of the three wastewater treatment facilities' treatment and reuse operations is approximately 130,000 m^3/day; the output of the short-term low-volume (STLV) seawater desalination plants is 36,000 m^3/day. The water sector receives between 550 and 820 m^3/day from stormwater harvesting. Overall, there will be about 70 million cubic meters of extra water available in 2020 from unconventional sources. The new water resources are intended to fill the gaps in the Gaza Strip's water supplies for residential, commercial, and agricultural uses. Therefore, including unconventional water sources into the water cycle is seen as a viable way to address the unsustainable degradation of groundwater supplies and alleviate the strain that drought is placing on the water resources' hydrological cycle [12, 33].

4. Water Balance Component

4.1 Rainfall Amount

The rainfall amount on the Gaza Strip is cumulatively estimated by the observed rainfall records (seasonal and monthly) collected from 17 rainfall gauge stations spatially distributed across the different governorates covering all areas of the Gaza Strip. They are operated and managed by the Ministry of Agriculture and all data received from these gauge stations were collected daily during rainy seasons.

The rainfall amount and intensity over the Gaza Strip are shown in Figure 7 based on the records of the 17 manual gauge stations for the 2019-2021 rainy season, where the stations are distributed to represent all Gaza governorates adequately. Before 2015, only 12 manual gauge stations were available in the Gaza Strip, where another 5 additional manual gauge stations were added to bring 17 manual gauge stations into operation, which has improved the estimation accuracy of the rainfall depth and amounts.

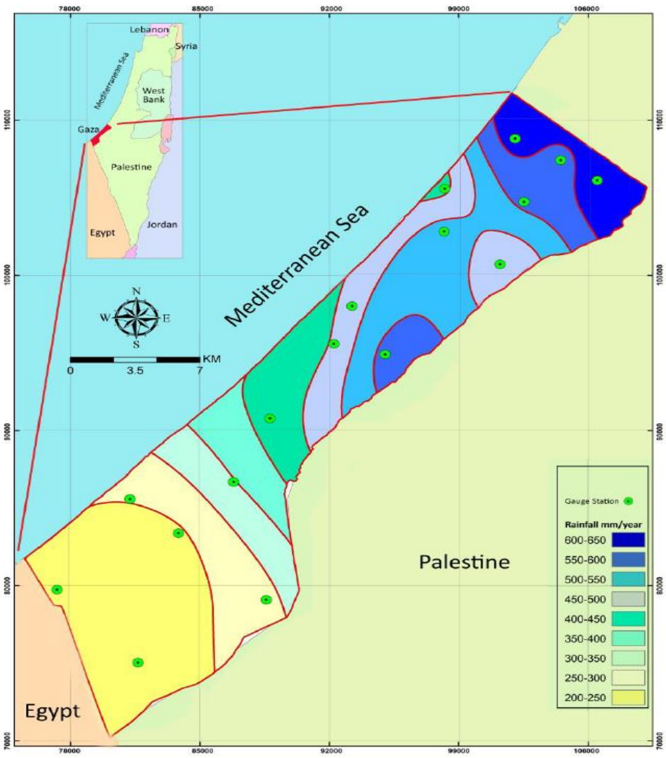

Figure 7 Seasonal Rainfall Depth Contour Map in the 2019-2020 Rainy Season, (Ministry of Agriculture).

In the last ten years, rainfall amounts in the Gaza Strip governorate fluctuated from 260 mm/year in the south to 450 mm/year in the middle, 600 mm/year in the north, and 450 mm/year in Gaza.

The total average rainfall depth in mm over 2022 is 385 mm. Data was collected from the Ministry of Agriculture. The rainfall amount over the year amounted to about 135 MCM.

4.2 Runoff and Recharge Estimations

All studies that estimated recharge/runoff from rainfall in the Gaza Strip were based on long-term average rainfall or a specific year of rainfall data. In contrast, the outcomes were applied as fixed quantities that the decision makers and researchers used in water management and water budget assessment for the Gaza Strip. Besides, the runoff calculations have a widespread estimation range (5.8 to 37 million m^3/year). No study used actual historical daily rainfall data to evaluation the recharge/runoff from rainfall except Moe, Hossain [34] who used data from only 5 out of 12 rainfall stations but they unnoticed the growth of land use and replacing it with a percentage of runoff from rainfall and using a recharge coefficient for the soil.

The first study to calculate the runoff for the whole Gaza Strip using the Soil Conservation Services Curve Number Method (SCS-CN), which uses elevation, land use and soil maps had carried out by Mushtaha, Van Camp [9] they calculated the recharge and runoff for the Gaza Strip based on available historical data from 1973 to 2014 and finding the long-term average recharge is 24.5×10^6 m^3/year (21.6% of rainfall) and The long term average runoff is 8.2% of rainfall (9.4 million m^3/year). This result is lower than that of prior studies. This could be due to the ignoring of daily evapotranspiration in some previous studies that also measured runoff input and used a short time step to separate factors that were likely to be accurate estimates.

Another study by Mushtaha, Van Camp [9] used a new GIS tool based on daily records of rainfall and evapotranspiration with pre-defined GRID maps for soil texture, land use and topography. Spatial daily rainfall and evapotranspiration variations for the previous 43 years were compiled to estimate the runoff and recharge in the Gaza Strip. The long-term average (1973 to 2016) runoff is 13.4 million m^3/year (9.6% of the rainfall). The long-term average recharge is 24.5 million m^3/year (19.2% of the rainfall). Figure 8 shows the long-term average spatial distribution of runoff and recharge (1973–2016) from the GIS tool.

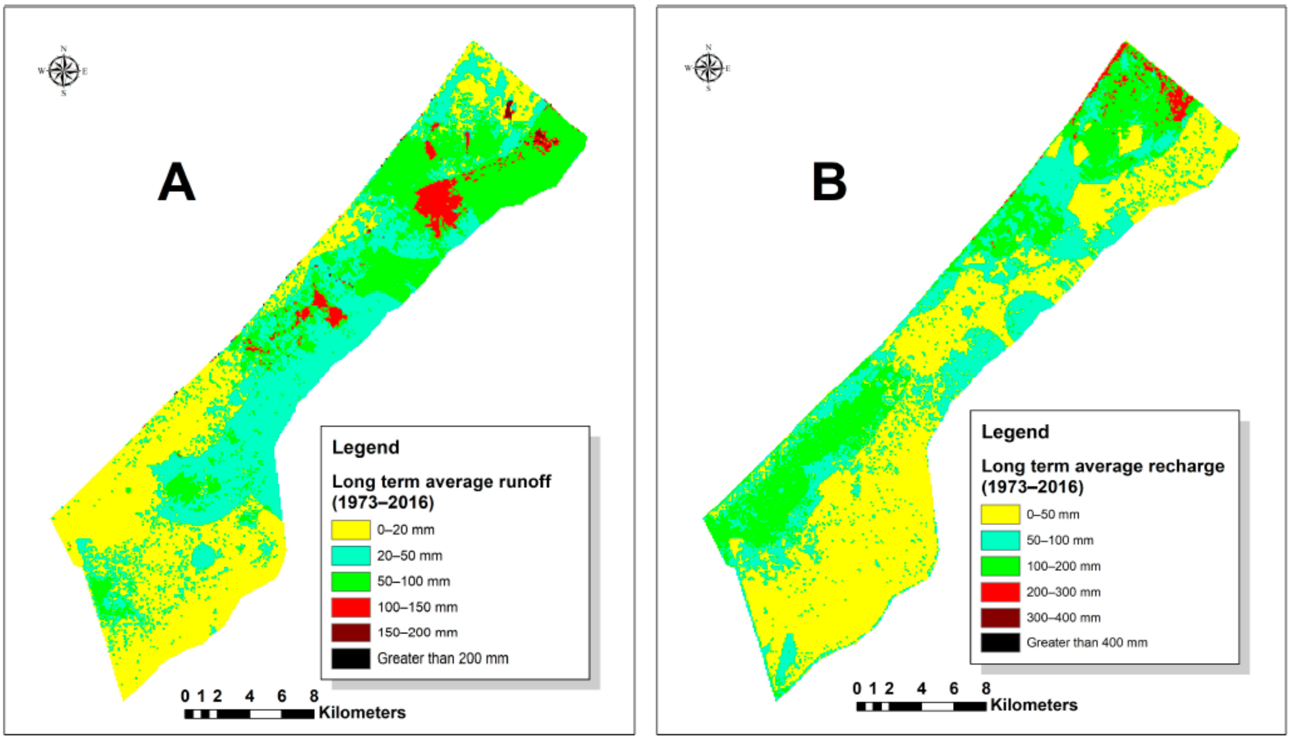

Figure 8 (A) Spatial Distribution of Long-term Average Runoff, (B) Spatial Distribution of Long-term Average Recharge.

The comparative between the result obtained from Thiessen polygon method and the new GIS tool for the same time display that GIS results are most accurate than Thiessen polygon method in estimating recharge or runoff because it does not provide an expressive spatial distribution of rainfall, also land use and soil texture, in reality, are changing within the Thiessen polygons. The GIS tool offers better value for runoff and recharge in less rainy years compared to the Thiessen polygon method.

The main reason for runoff increasing is the evolution of residential area, where previously 1992, the total built-up area the Gaza Strip was 30.1 km^2 and the average runoff between 1973 until 1992 was 9 million m^3 (7.9% of the rainfall); after development of the area, the Gaza Strip covered a residential area around 92.1 km^2, and the runoff had enlarged to 22.9 million m^3 (18.1% of the rainfall). On the other side, the lessening size of the dune area disturbs the recharge quantities, where previously 1973, the area of dune was 114.8 km^2 of the Gaza Strip, and the average recharge was 27.3 million m^3 (23.9% of the rainfall) from1973 to 1992; while after progress of the area, the total dune area decreased to 31.5 km^2 of the Gaza Strip, and the recharge had declined to 23 million m^3 (18.2% of the rainfall).

4.3 Evapotranspiration

One factor that determines the water balance is evapotranspiration. The evaporation of water that is intercepted by vegetation, the transpiration of the vegetative cover, and the evaporation from the bare soil in between the vegetation make up the total actual evapotranspiration [35]. See Figure 9.

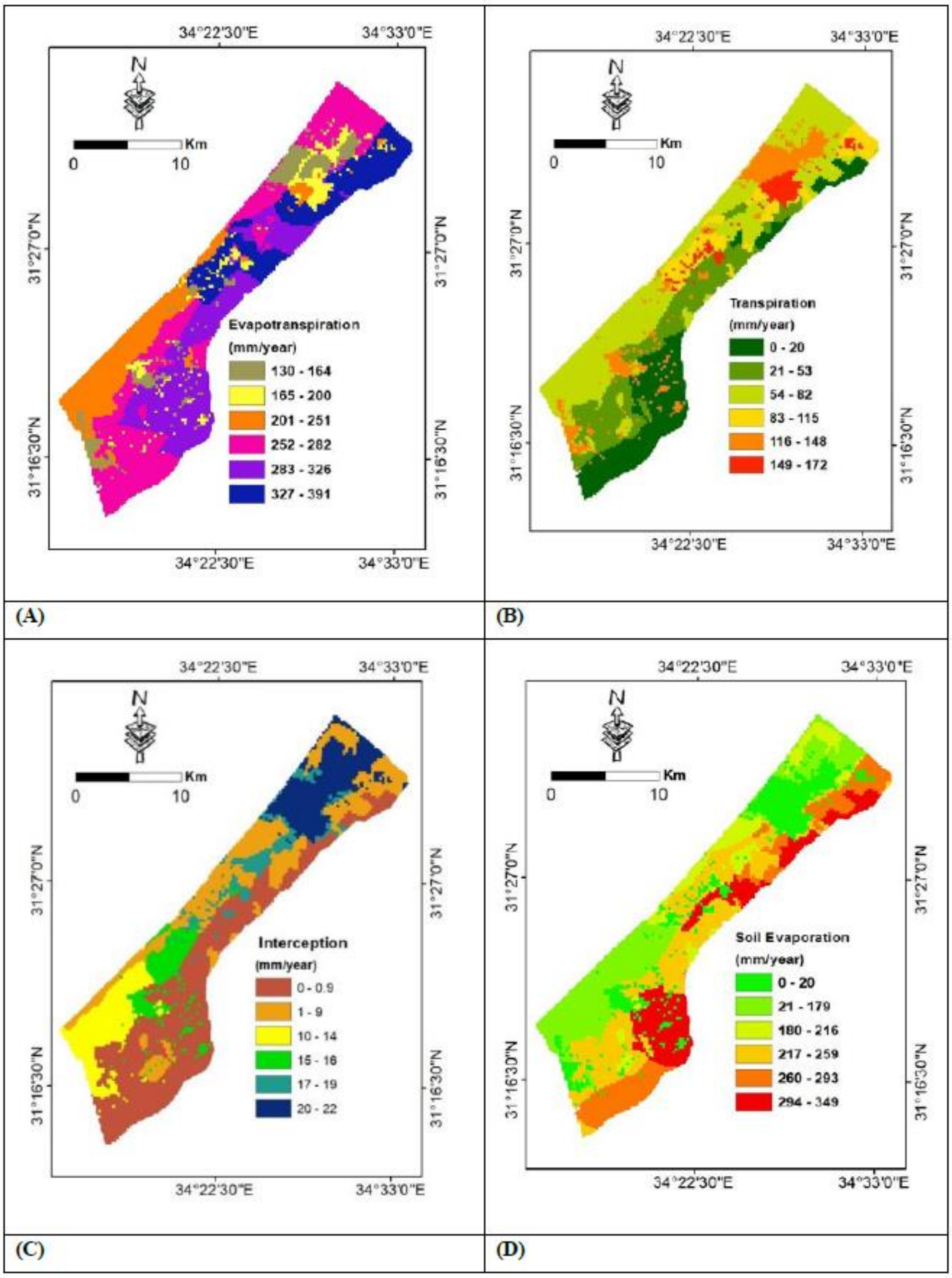

Figure 9 (A) Simulated actual evapotranspiration with WetSpass model. (B) Simulated actual transpiration with the WetSpass model. (C) Simulated actual interception with WetSpass model. (D) Simulated actual soil evaporation with the WetSpass model.

Aish [14] calculates the total actual evapotranspiration and finds its range from 100 to 300 mm/year with a mean value of 206 mm/year, which is the total of soil evaporation, transpiration, and interception. The average simulated annual transpiration is 49 mm, the average yearly simulated interception is 6 mm, and the average yearly simulated soil evaporation is 151 mm. Approximately 77% of the total rainfall is accounted for by the average evapotranspiration. The outcome demonstrates a variation in evapotranspiration correlated with annual rainfall and vegetation cover. The refugee camps and Gaza City are primarily urban regions with little greenery. [6] advanced the study and have an average result of annual evapotranspiration value of 268 millimeters per year, and an average value of transpiration, interception, and soil evaporation are 64, 8, and 196 millimeters per year, respectively. as shown in Figure 9 (A, B, C, and D). The average of evapotranspiration is about 77% of the annual rainfall average. These outcomes were comparable to the results of the study [36].

In the winter of the Gaza Strip, evaporation rates vary from 2 to 3 m/day over a seven-year record period. Whereas through summer, an extreme rate of over 6.7 mm/day was reached between June and August. The middling annual evaporation rate in the Gaza Strip is around (5.2 mm/day) 1900 mm/y [30].

4.4 Discussion of the Water Balance for the Gaza Strip

Water budget essentially represents the net result of the inflow and outflow of water. The latest data for the year 2022, according to the Ministry of Agriculture, for the 2021-2022 rainy season, there were 37 rainy days distributed temporally over the season, the first storm event occurred on 23/09/2021, and the last one on 25/03/2022. The total amount of stormwater in the Gaza Strip was summed as 142.05 MCM in the 2021–2022 rainy season. The rainfall percentage is estimated as 118.9% of the average annual rainfall, with an average rainfall depth of 420.4 mm.

The quantities of water extracted from wells for various purposes amounted to about 242.5 million m^3 during 2022, while the quantities of water supplied to the coastal aquifer from the various feeding elements amounted to about 109.2 million m^3, which led to a large water deficit. It reached 133 million m^3, which constitutes two and a third times compared to the quantities of the categories feeding the aquifer. The water budget for the Gaza Strip is summarized in Table 2.

Table 2 Water Balance of the Gaza Strip During the Year 2022.

	Categories	**Quantity million m^3**	**Percent%**
Inflow	Quantities of groundwater recharge from rain + filtration basins (21% rainfall)	29.8	27.3%
	Irrigation water filtration	28.6	26.2%
	Treated wastewater is filtered into filtration basins	19.48	17.8%
	Sewerage network leaks	16.8	15.4%
	Lateral flow from the eastern Gaza Strip	8	7.32%
	Leaks in water distribution networks	3	2.75%
	Wastewater and rain filter into the Gaza Strip valley	2	1.83%
	Rainwater filters into Wadi Beit Hanoun and Salqa	1.5	1.4%
	Total inflow	**109.18**	**100%**
Outflow	Withdrawal for agricultural purposes	122.6	50.5%
	Municipal withdrawal + UN	95.88	38.5%

Withdrawal of special desalination plants	4.4	18%
Water withdrawal for industrial purposes	5.65	2.3%
Towing chalets	0.4	0.2%
Licensed service wells	6	2.5%
Unlicensed service wells	5.5	2.3%
Mosque wells	0.77	0.3%
Withdraw the desalination wells, passerby	1.93	0.6%
Total outflow	**242.59**	**100%**
Total Deficit	**133.34**	

Water & Environment Quality Authority estimated the amounts of water recharge into the groundwater reservoir from rain, about 29.8 million m^3 for the season, which constitutes about 21% of the total rainfall, which is the first inflow component.

The percentage of quantities recovered from the groundwater reservoir due to the irrigation process is estimated at 22% to 24% of those quantities (122.6 million m^3), depending on the type of upper soil of the agricultural areas. It constituted the second percentage of water seeping into the groundwater reservoir after groundwater recharge. A relatively large portion of the wastewater produced in the various governorates of the Gaza Strip leaks into groundwater as a result of leaks in the networks collecting this water or due to the use of cesspits in areas not served by sanitation services.

With regard to water leaks from water distribution networks, the total leaks in the Gaza Strip during the year 2021 were about 3 million m^3, as the loss of sedimentation is considered not noticeable within those networks, which will not exceed 3% of the total quantity pumped into those networks in all governorates. This is because in the Gaza Strip, 70% to 80% of the municipal water distribution networks were installed after the year 2000, as these networks are distinguished by their strength and technical quality, and this statistic is confirmed by the study conducted by the Water Regulatory Sector Council in the year 2022. Figure 10 illustrated all components.

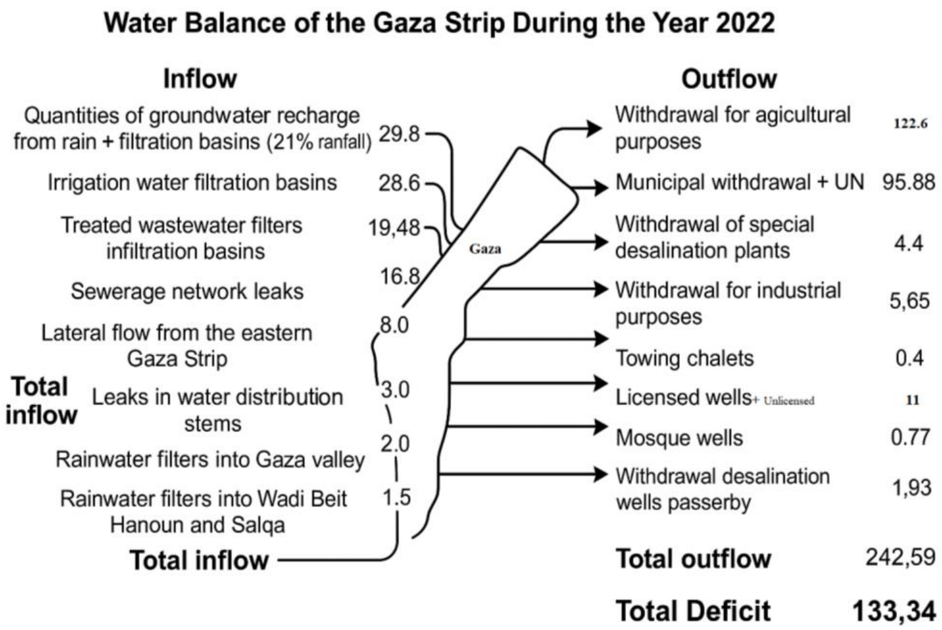

Figure 10 Water balance of the Gaza Strip during the year 2022.

The average runoff is 25.5 million m^3/year (18% of rainfall), which is a higher result than the earlier research [9] due to the evolution of the residential area and the lessening size of the dune area, which disturbs the recharge quantities. The evapotranspiration rate for the Gaza Strip is estimated to be about 77% of the rainfall, as in the specialized study [37].

The Palestinians in the Gaza Strip are consuming groundwater for agricultural, domestic, and industrial purposes. The total water abstracted from local resources by the Gaza Strip residents from wells is 242.59 million m^3/year out of which 122.6 million m^3/year is used for agricultural purposes (Q_{AWW}) (irrigating crops and livestock) with percent 50.5%; 114.3 million m^3/year is used for domestic (Q_{DWW}) and other desalination purpose in addition 5.65 million m^3/year for industrial purposes (Q_{IWW}).

The findings of this study underscore the urgent need for policy interventions aimed at regulating groundwater abstraction and promoting sustainable agricultural practices. Moreover, enhancing non-conventional water resources and implementing artificial recharge projects can contribute to mitigating the growing water deficit in the Gaza Strip.

5. Conclusion

This paper reviewed data related to the water situation in the Gaza Strip - Palestine as a study area. Data on geographical, hydrological, and climatic parameters were clarified and interpreted regarding their environmental implications. The water environment of the Gaza Strip was analyzed, and it was found that its water resources are considerably deteriorated, and the levels of pollutants such as nitrate, chlorine, and total dissolved salts exceed permissible international standards. The results also showed that the Gaza Strip relies mainly on groundwater extracted from 1,200 wells, more than 80% unlicensed. The types of non-traditional water sources were highlighted, most notably water desalination plants, wastewater treatment, rain harvesting, and collection ponds. These sources constitute 70 million m^3.

The study concluded that the Gaza Strip suffers from a water deficit of 133 million cubic meters, which is the difference between the inflow (109 million cubic meters) and the outflow (242 million cubic meters). This requires further research into developing water resources and rationalizing consumption, especially in the agricultural sector, which consumes half the available water. Diagnosing the water balance of the Gaza Strip supports decision-makers and local authorities in taking essential measures for effective management of water resources and focuses research towards their sustainability.

Author Contributions

The author did all the research work for this study.

Competing Interests

The author has declared that no competing interests exist.

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