Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29938

313 (2023) 216–226
November

A new approach to assess non-revenue water and intervention prioritization in water distribution zones by using Geographic Information System technology

Hatem AbuEltayef[a,*], Khalil Alastal[b], Khaldoun AbuAlhin[c]

[a]*Joint Ph.D. Program in Water Technology, The Islamic University of Gaza and Al Azhar University-Gaza, Gaza, Palestinian Authority, email: hatem.tayef@gmail.com*
[b]*The Islamic University of Gaza, Gaza, Palestinian Authority, email: kastal@iugaza.edu.ps*
[c]*Al Azhar University, Gaza, Palestinian Authority, email: khaldoun.alhin@gmail.com*

Received 4 April 2023; Accepted 31 August 2023

ABSTRACT

A Geographic Information System (GIS) provides a powerful tool for the management, editing, analysis, modelling, and presentation of structural and inspection data. It is a specialized technology used to manage water resources, including non-revenue water (NRW). Many developing countries, such as Palestine (Gaza and the West Bank), face significant challenges with high rates of non-revenue water and limited water supply for domestic use. In 2018, the Water Sector Regulatory Council (WSRC) reported non-revenue water percentages of 34% in the West Bank and 36% in Gaza. A specific case in Khan Younis in 2020 showed a high level of NRW. This study aimed to measure non-revenue water in the 24 water distribution zones (WDZs) of Khan Younis and evaluate the role of GIS in assessing WDZs. Additionally, a set of nine ranking parameters were used to prioritize intervention plans for reducing NRW. The findings of the study revealed that GIS adaptation allows for the classification of non-revenue water into four categories, facilitating prioritization in intervention analyses. The overall assessment showed a 75% correlation between the NRW priorities identified through GIS mapping and those generated by indicator analysis, resulting in an estimated reduction potential of approximately 182,108 m^3/y. The majority (92.52%) of the NRW falls into the high and middle classes, which require intervention measures, while the remaining 7.48% belongs to the low class and does not require NRW reduction efforts.

Keywords: None revenue water; Water loss; Geographic Information System

1. Introduction

Water utilities today face a significant challenge with high levels of non-revenue water (NRW) in the developing countries, particularly in regions experiencing severe water shortages [1–3]. As water transcends geographical boundaries, managing and protecting water resources within a country's borders becomes a complex endeavour. Several factors come into play when it comes to water resources management and supply, such as assessing climate conditions, land use patterns, and pollution levels that directly impact water quality and quantity. Issues like water pressure, infrastructure aging, leaks, and the efficient operation and maintenance of water supply add to the challenges [4]. NRW is the difference between the volumes of system input and billed authorised consumption. Non-revenue water includes not only the real losses and apparent losses, but also, the unbilled authorised consumption [5–7] poses a significant concern for water utilities, especially in regions experiencing severe water shortages [1–5]. NRW has three components: apparent losses, real losses and non-revenue authorized consumption [9]. The water utilities in the

* Corresponding author.

developing world are facing high values of NRW [10]. In the 21st century, approximately 748 million people worldwide still lack proper access to clean drinking water, while nearly one-fifth of the global population resides in regions grappling with water scarcity. Adding to the complexity, the global water demand is projected to surge by 400% in various sectors over the next 50 y [11].

Despite the fact that water scarcity is going to be a global issue, a staggering 32 billion m³ of treated water are lost to urban supply systems around the world [12]. It is one of the main issues discussed with water authorities in the developing world [13]. The World Bank estimates that the average NRW rate in developing countries is 35%, and the loss is about 26 billion m³ [14]. Among them, the Asian Development Bank stated that the annual water production of NRW is about 29 billion m³ [2]. This leads to nearly 9 billion $ in lost revenue every year. Without further investment, A 50% reduction in NRW levels specifically within the developing world would result in an annual availability of over 8 billion m³ of treated water for those facing water shortages, enabling an additional 90–100 million people to access fresh water resources without further burden on water supply systems or reserves [1,10].

Palestinian water scarcity is not far behind the global scenario; the goal of water security has declined in recent years. The population is growing rapidly. Palestine faces significant and growing shortfalls in the water supply available for domestic use. Presently, a mere 4% of the annual extraction of 180 million m³ (MCM) of water from what was formerly the primary drinking water source for Gazans is considered potable. The gap in domestic water supply by 2030 is projected to be approximately 92 MCM/y for the West Bank and 79 MCM/y for Gaza [15]. According to the national strategic plan, reducing NRW from 38% to 35% will increase revenue by US$40 million within 10 y [16]. Similarly, the Water Sector Regulatory Council (WSRC) estimates that the NRW rate is 33% (67–80 MCM of fresh water is lost annually), Fig. 1. Extensive research has revealed significant levels of non-revenue water (NRW). Consequently, there is an imperative need to enhance water resource management to gain a comprehensive understanding and propose improved strategies for water distribution systems [17].

Definitely, water utilities often operate under a weak governance and financial framework [14]. Furthermore, insufficient financial or human resources were not capable of understanding the scale of the NRW problem. In addition, weak internal policies and procedures, contributed to rising NRW levels [19]. The NRW estimates in the Gaza Strip range between 31 and 39 MCM/y (Table 1), with an approximate cost of 12.8 million USD.

The water sector of Khan Younis city has the same multi-sectoral problems as many Palestinian cities. On one hand, there are many technical problems, like: (1) unavailable district water meters; (2) The water meters in the area are of subpar quality, with some having been installed several decades ago. Due to the current challenging economic conditions and a lack of financial resources, the municipality has been constrained in its efforts to replace these aging water meters; (3) the water network is dilapidated; (4) weak mapping components provide a preliminary designed interface which provides limited data queries. On the other hand, financial and management problems are manifested in: (1) a weak accounting system leading to a weak billing system; (2) lack of spatial information interaction between spatial information and account information database; (3) lack of water meter reading monitoring; (4) increasing violations of laws and increased number of illegal connections.

Khan Younis has one of the highest NRW levels in the Gaza Strip. In 2015, the water department reported that NRW represented 3.0 MCM of water losses, which is equal to more than 1.9 million USD, considered thus as a severe situation. Several factors contributed to conducting the study in Khan Younis: limited water resources, intermittent water supply, weak maintenance response because of limited financial resources, 30% of the entire pipe (water main carrier and distribution network) consists of steel pipe, lack of water conservation public awareness campaigns, poor institutional capacity, and the majority of water meters functional

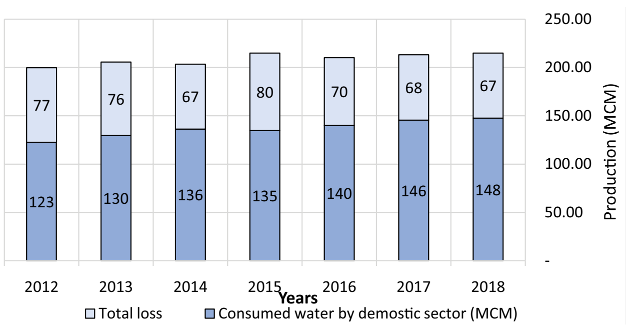

Fig. 1. Water production billed and non-revenue water volume of the state of Palestine from 2012 to 2019 [18].

Table 1
Non-revenue water in Palestine by years

Item	2014	2015	2016	2017	2018	2019
NRW quantity - West Bank (m³/y)	19,531,987	22,514,487	23,281,386	24,956,386	27,122,816	33,837,248
NRW quantity - Gaza Strip (m³/y)	31,683,258	34,152,123	33,389,511	32,354,957	29,384,175	39,684,555
NRW quantity - West Bank and Gaza Strip (m³/y)	51,215,245	56,666,610	56,670,897	57,311,343	56,506,991	73,521,803
NRW cost - West Bank (m³/$)	1.05	1.02	1.01	1.00	0.97	1.08
NRW cost - Gaza Strip (m³/$)	0.30	0.32	0.35	0.36	0.39	0.38
NRW cost - West Bank and Gaza Strip ($/y)	29,977,599	33,953,248	35,222,877	36,773,286	37,868,609	51,644,630

Source: [15].

age exceeded 10 y in service [20]. Geographic Information System (GIS) is indeed a powerful tool that enables utilities to effectively make informed decisions, optimize resource allocation, and implement targeted strategies to mitigate and improve NRW management efficiency.

Kimwatu and Odera [21] in their study utilized the GIS to generate optimal routes for effective and efficient reading of sub-zonal master meters, attending bursts and leakages minimizing time, money, labour, distance; and determining the vulnerability of the region within the zone to bursts and leakages. The GIS helps in installing many layers of water infrastructure components, that is, District Meter Areas (DMAs) meters, primary and secondary distribution networks, consumer meters, service connections, valves etc., that enable networks to manage by reducing NRW. Another study provided an integrated approach to water pipe network calibration and leak quantification. Their approach provided a practical procedure that merges field measurements and mathematical modelling for leak quantification and network calibration. Two pilot networks were selected, a well-known hypothetical network (Hanoi Network) to present the general mathematical model, while a real network (Faisal City Network) is used to test the integrated approach. The model integrates EPAnet for the required hydraulic modelling during the simulation and GIS for input data integration and output representation during the whole procedure. The results proved the approach's accuracy and efficiency [22]. Also, in 2015 a WATERLOSS project in Nicosia, Cyprus, showed that a Decision Support System (DSS) was developed to aid water operators in making informed decisions regarding the reduction of in their water networks. This system assesses the performance level of the water network and presents a prioritized list of NRW reduction measures. The effectiveness of this DSS was evaluated in Nicosia, the capital of Cyprus, for its urban water network. The DSS successfully generated a list of prioritized NRW reduction measures, targeting various causes of NRW in each designated district metered area (DMA) of Nicosia. Water utility officials in Nicosia chose to implement some of the short-listed measures in those DMAs, leading to a significant reduction in NRW and yielding additional benefits. As a result of these measures, the annual water savings amounted to 1 million m^3, equivalent to 4.8% of the total water entering the network. Furthermore, notable economic benefits of over €700,000 were observed [23].

The general consensus is that water utilities should comprehensively address the issue of non-revenue water (NRW) by implementing all necessary measures [23]. Furthermore, these tools lack the provision of essential measures to effectively tackle specific problems. Hence, water service providers need to incorporate robust technology like Geographic Information System (GIS) technology in evaluating NRW. This empowers NRW teams to prioritize water loss reduction interventions. Commonly held among water service providers' engineers is the belief that water loss originates primarily from maintenance-related projects that would substantially decrease water loss and enhance water network efficiency. However, this perspective tends to overlook the significance of commercial losses, including factors such as malfunctioning water meters, unauthorized water usage, illegal distribution, and the presence of agricultural spaces. These factors are vital considerations when formulating strategies to combat NRW. The overall goal of this study is to explore the role of GIS in assessing NRW in Khan Younis by employing attribute and spatial data. This would help in the planning and management of NRW reduction. While the specific objectives were focused on:

- Quantify the NRW percentage of each water distribution zone from the total NRW percentage in Khan Younis city.
- Setting up a group of effective and applicable determinates of NRW for the assessment process of NRW based on available data.
- Prioritizing NRW intervention plans in order to reduce water loss.
- Comparing the percentage match between the produced map and water distribution zones (WDZs) priority classes was conducted to validate the accuracy of the GIS map analysis.

2. Materials

2.1. Study area

Khan Younis city is located in the southern part of the Gaza Strip. It is a major Palestinian city on the east coast of the Mediterranean, with a total area of 54.56 km^2. It is a major commercial centre and transit station on the ancient trade route to Egypt. It is considered the centre of Khan Younis Governorate [24]. It is located on the cross of latitude 31.212 north and longitude 34.18 east at an altitude of 50 m, and it is adjoined by Rafah city from the south, Al Qarara city from the north, eastern villages from the east, and the Mediterranean Sea from the west, Fig. 2a [25]. Khan Younis is considered the largest city in the administrative area with a population of one-fifth of the total population of the Gaza Strip shown in Fig. 2b. The total population of the city is 274,942, of which 95% of the total population is connected to the municipal water distribution system [1,18].

2.2. Water distribution network in Khan Younis

There are around 21,655 active consumer connections (subscriptions) in Khan Younis city, accounting for approximately 90% of the city population. The area is divided into 24 water distribution zones (WDZs). Khan Younis city provides water supply services, where the main source of water is groundwater; it has 30 ground water wells, most of which are located in the western part of the city, accounting for 98% of the city's water production, and the other 2% comes from the southern governorate's desalination plant located in Deir Al-Balah. Desalinated water is considered the second water source. The length of water networks in Khan Younis WDN is about 570 km, of which 34% are carriers, 44% are distribution lines, and the remaining 22% are service lines. UPVC and PE pipes account for about 73% of WDN, while the remaining 27% are steel pipes. Considering budget constraints and emergency funds, steel pipes need to be replaced [26].

The most prominent elements affecting water network efficiency include the quality of water network pipes, illegal connections, broken water meters, and difficulty in readers' access to some counters. Table 2 illustrates the levels of NRW

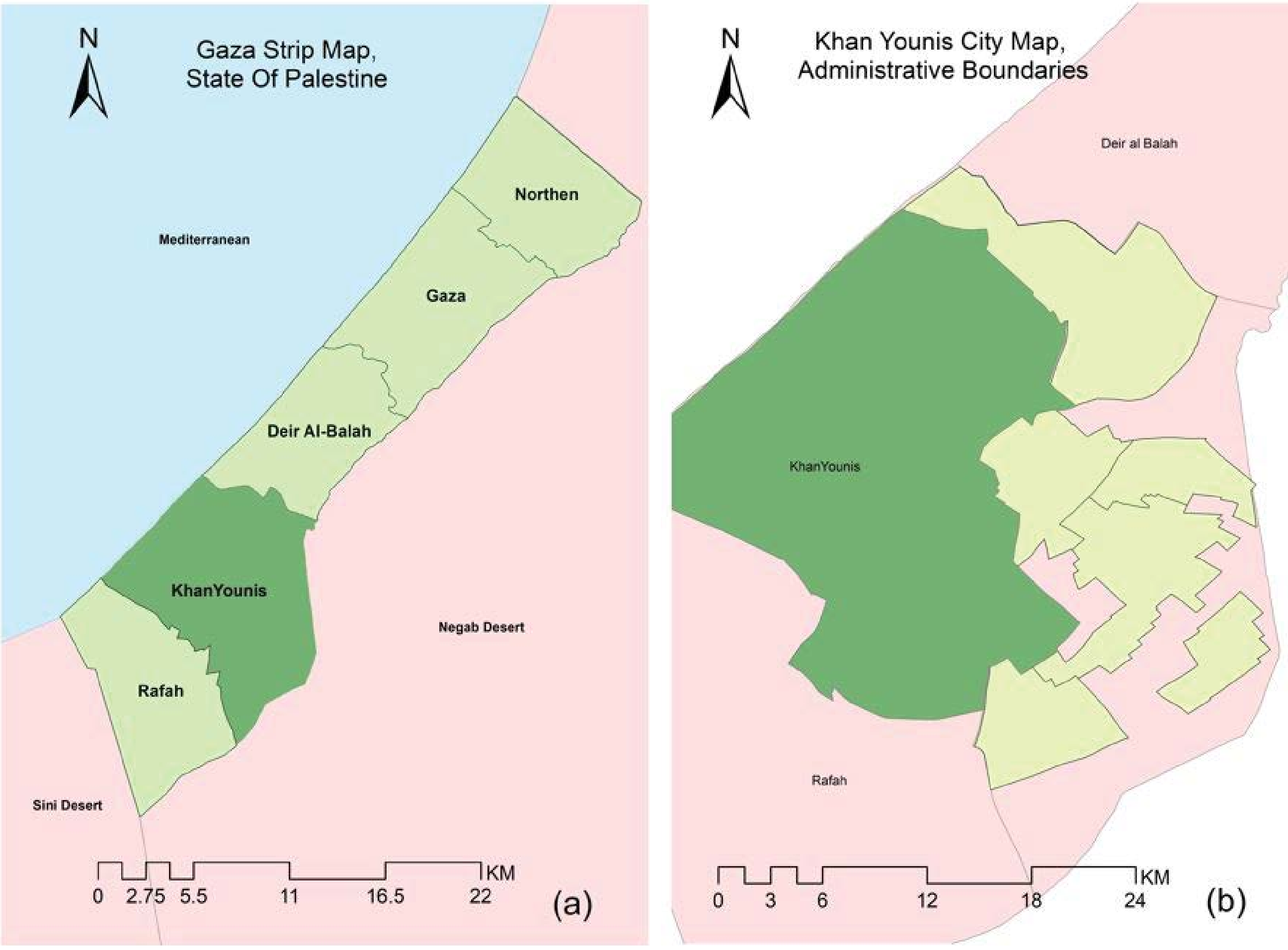

Fig. 2. (a) Gaza Strip, State of Palestine and (b) Khan Younis location in Khan Younis Governorate.

Table 2
Khan Younis water production and NRW over years

Year	Produce water (m^3/y)	Billed water (m^3/y)	Non-revenue water (m^3/y)	NRW (%)	Served population (capita)	Beneficiary population (capita)	Produced water (l/c/d)	Billed water (l/c/d)
2012	9,278,072	5,056,747	4,221,325	45.5	216,580	162,435	156.49	85.29
2013	9,459,266	5,894,734	3,564,532	37.68	224,160	172,603	150.15	93.57
2014	8,676,380	5,520,901	3,155,479	36.37	231,781	183,107	129.82	82.61
2015	8,473,265	5,660,753	2,812,512	33.19	239,429	193,937	119.7	79.97
2016	8,948,124	5,996,673	2,951,451	32.98	241,198	200,194	122.46	82.07
2017	8,607,651	6,278,842	2,328,809	27.06	249,160	209,294	112.68	82.19
2018	9,009,289	6,785,122	2,224,167	24.69	258,096	215,170	114.71	86.39
2019	8,906,040	6,555,097	2,350,943	26.4	266,870	220,300	110.76	81.52
2020	9,882,908	6,857,120	3,025,788	30.62	275360	221850	122.05	84.68
2021	9,714,383	7,031,298	2,683,085	27.62	287,543	224,160	121	88

over the years in Khan Younis city. In 2012, NRW reached 45.5%, the highest level, with a NRW amount of 4.2 MCM, while in 2018 it was 24.69%, and decreased to a level that is acceptable to the IWA (25% NRW). Between the years 2013 and 2018. NRW was steadily declining. This reflects improvements to the water efficiency plans developed by the municipality. As a result of the Coronavirus pandemic, this percentage decreased to 70% in 2020, as the municipal water readers were stopped for several months and water consumption was estimated.

2.3. Data analysis of NRW for water distribution zones in Khan Younis

To achieve the international benchmark of 25% NRW, the water department in Khan Younis city must develop a well-structured plan focused on reducing NRW and enhancing water supply services. Despite challenges such as the absence of leak detection equipment, complex software and hardware, inadequate information transmission technology, incomplete data registration by operators, insufficient reporting on maintenance activities, there is still an opportunity to assess and devise strategies to minimize NRW. The assessment of water loss in each water distribution zone within the city was conducted using attribute databases and GIS software. Fig. 3 displays the monthly production data from groundwater wells and the seawater desalination plant for the year 2021, indicating a total production volume of 9,714,383 m^3 over the specified period.

Out of the approximately 9.71 million m^3 (MCM) of water pumped into the network in 2021, only 7.03 MCM, equivalent to 73.0% of the produced water, was invoiced. The estimated population served is around 224,000 inhabitants, resulting in an average production of approximately 121 L per capita. However, the average quantity of water billed per capita is about 88 L.

3. Methods and approach

The case study presented in this article explores the effectiveness of GIS technology in assessing NRW for 24 water distribution zones in Khan Younis Municipality in general. The work is carried out in two ways, combining field work with desktop analysis and GIS development. In order to construct the composite system, the following steps must be taken:

3.1. Field work

The recorded data for the operation of water wells to reservoirs or directly to the water network, imported desalinated water, and the water distribution schedule for distribution zones. The operators record this descriptive data in writing in forms on a monthly basis. The data is not loaded onto a computer and validated. Thus, the first step is to collect raw data from operators. Then, data is loaded into an Excel spread sheet through a model designed for this purpose. Data is then analysed, checked in the field, and validated. These data provide insight into total water distribution and water consumption.

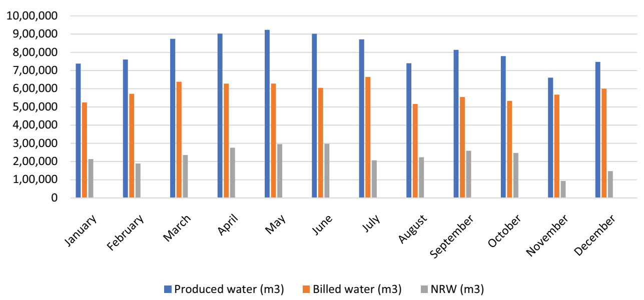

Fig. 3. Produced, billed and NRW in Khan Younis City, year 2021.

3.2. Desktop review

By constructing an excel model for this purpose, the basic collected data from the field, such as the water meter, gauge of the boosters, and production hours and pressure, was customized and formatted as needed. This allows us to calculate the total consumption for each WDZ from the billing system. The distributed water was calculated from the readings of the wells and reservoirs as shown in Eq. (1).

$$\text{NRW per WDZ} = \text{water production}\left(\text{WDZx}\right) - \text{water billed}\left(\text{WDZx}\right) \quad (1)$$

where x is being the number of the water distribution zone.

Then after, all data from various database sources is integrated, whereby attribute data is added to the spatial data. Further analyses were carried out using the generated and developed Excel model, as well as showing the spatial distribution of NRW in the water distribution zones. This allows us to produce a NRW map for the whole water distribution zone of the city. Fig. 4 illustrates the steps that were conducted to assess NRW percentage in WDZs and set the prioritization for NRW intervention reduction.

3.3. Intervention prioritizing approach

The study introduced nine parameters that take into account the specific characteristics of the Khan Younis city environment and water distribution network, rather than

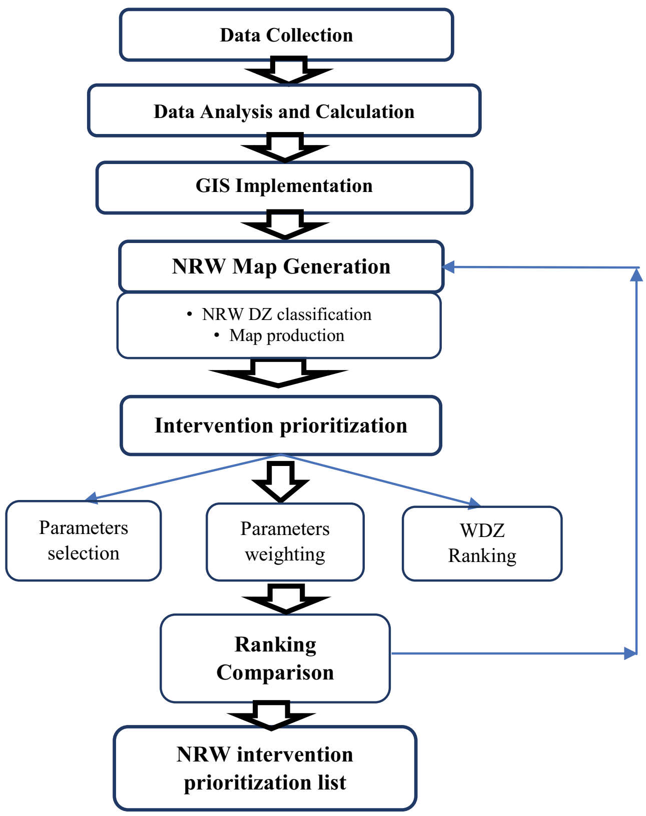

Fig. 4. Flowchart of the methodology for the NRW assessment in the water distribution zones.

relying on international standards. These parameters serve as fundamental indicators for ranking non-revenue water (NRW) and encompass both physical and commercial loss indicators that can be calculated and evaluated. The following indicators are recommended:

The study established a set of prioritization criteria aimed at identifying the most critical water distribution zones (WDZs) requiring urgent and immediate interventions. These criteria, presented in Table 3, assigned priority to NRW based on its weight, considering its impact on

Table 3
Priority criteria type and description

#	Priority criteria type	Description
1	Water distribution network indicator	From the perspective of the effect evaluation of operational water technical condition: leakage, and breaks on transmission and distribution pipelines, pipe failure, failure rate, and theoretical service life of the pipe material etc. According to the study, low-quality infrastructure components such as pipes, joints, and valves have reached the end of their useful life, causing water leaks and breaks. Therefore, the length of water distribution pipelines in kilometers is crucial to managing and reducing NRW.
2	Steel pipe length indicator	The use of steel and iron pipes can result in catastrophic failure due to the presence of chlorine dioxide. This can lead to corrosion and deterioration of the WDN, an effect of NRW. Sediment accumulation, on the other hand, can reduce the diameter of the water pipes and decrease the normal pressure within the water system. Approximately 30% of the steel pipes in Khan Younis's city water system need to be replaced.
3	NRW indicator	Reducing NRW is the goal of all water utilities, and the water loss in each water distribution zone can be used to measure how well NRW is being managed. This can be determined through monthly production, distribution, and billed (consumed) water. Therefore, the study considers that the quantity of NRW for each WDZ is a key indicator for the proposed ranking.
4	Subscribers' indicator	In each WDZ, the number of connections or subscribers is considered a real factor that is directly related to water loss. The relationship between number of subscribers and NRW is linear, therefore the density of service connections has been calculated for the 24 WDZs.
5	Courtyards indicator	Most WDS within the city have a piece of land surrounded by a fence. This is usually planted with trees, and this is the place where the owner spends his week. Sadly, no one was at the place when the water reader came to read the meter, so the reading was probably underestimated since there were no real readings.
6	Broken water meters indicator	Dilapidated, damaged or out-of-order meters, in addition to the low accuracy in recording small flows and initial outputs, are key factors accounting for the apparent losses. New meters can reduce non-revenue water in the system.
7	Water meter age indicator	In the case of aged meters, there is a potential discrepancy between old and newly developed meter readings, in which the extent of customer meters' inaccuracies was revealed. The problem has to be investigated and, if necessary, the recorded quantity has to be adjusted to reflect the real situation. These errors are caused by inappropriate meter types, purchasing the cheapest products on the market, a number of meter manufacturers producing meters that "on paper" meet the specifications but deteriorate at an amazing rate in the field and the lack of high-quality meter testing facilities. This makes it easy for manufacturers to supply meters of low-quality manufacturing. Older meters hinder the improvement of customer meter accuracy.
8	Land use indicator	There is a widespread belief that urban areas have no space for water theft or trespass similar to agricultural areas that possess advantages that contribute to significant encroachment on the network, especially since the way these encroachments are detected is not a disadvantage. In this manner, three categories of land use have been adopted: an urbanized area, a mixed-use area of residential and agricultural use, and a predominantly agricultural area with a minor water user.
9	Informal settlements indicator	The city of Khan Younis is dominated by vacant governmental land adjacent to previously Israeli settlements. Due to the weakness of the land authority in pursuing them, these areas posed a problem of encroachment. This created informal settlement environments near residential areas, particularly near refugee camps. Because of their restrictions, there was no expansion of housing and the population was forced to expand horizontally and encroach on government land. In order for them to survive, they intruded on nearby water distribution networks. The nature of the slums is difficult to control as there are no clear-cut streets or planned construction. Khan Younis has about 7 informal settlements and there are problems with trespassing on water systems. As an indication of the level of loss caused by the large quantities of water lost from the distribution areas adjacent to these slums, this criterion is considered worthwhile.

the per capita water supply, which experienced a significant decline. The prioritization of NRW interventions was determined using nine components, including the length of the water distribution network (km), length of water pipes (km), number of subscribers, non-revenue water usage (m^3/y), number of courtyards, number of broken water meters, water meter age, land use, and informal settlements.

3.4. Scoring, weight and priority class

To assign weights to each parameter, a questionnaire was administered to 11 experts specializing in NRW, aiming to determine the relative importance of each parameter. The assigned weights for each parameter can be found in Table 4. By applying these criteria and classifications to the 24 water distribution zones (WDZs), the WDZs that receive the highest scores, approaching 90 points, are highly likely to be prioritized for intervention.

It is essential to evaluate the factors influencing NRW when determining the priority of monitoring the water distribution system [13]. The concept of prioritizing NRW interventions at the WDZ level aims to provide clarity on the necessary actions for each zone while considering the overall picture of the entire WDZ. This prioritization is based on the levels of priority and overall rankings assigned to each zone. The study categorized all WDZ rankings into five distinct categories. For example, the “high” category signifies the need for urgent intervention, while the “medium-high” category represents the second highest priority for intervention after the “high” class. The “low” category follows the “medium” class. On the other hand, the “lower” and “no need” categories indicate the least level of involvement or absence of any intervention requirement. Subsequently, a weighting scale was formulated, assigning specific weights to each priority. Each priority is further divided into 5 or 6 classes, with scores represented as a percentage of the overall priority weight, as illustrated in Table 5. The WDZ that obtains the highest score will be accorded the highest priority for intervention.

Table 4
Names of the applied criteria and the scoring for each criterion

#	Parameter	Value
1	Water network	11
2	Steel pipe (km)	9
3	NRW (m^3/y)	16
4	Number of subscribers	12
5	Number of courtyards	8
6	Number of broken water meters	10
7	Water meter age	18
8	Land use	3
9	Informal settlements	3
Total		90

4. Results and discussion

4.1. Evaluation of NRW for water distribution zones in Khan Younis

A spreadsheet was created, allowing for the collection of production and distribution data from various worksheets, including the municipal database and billing information for each household connection. Mathematical calculations were performed for each distribution area, enabling the tool to examine data, calculate losses across wells, reservoirs, and distribution areas, and determine the volume and percentage of losses. Thorough analysis and verification were conducted, resulting in the calculation of NRW for each distribution area in 2021, as displayed in Table 6.

NRW production map was generated, which includes the last phase for the city’s water distribution zones, as shown in Fig. 5.

The utilization of GIS for map creation stands as one of the most influential tools at our disposal. It efficiently merges spatial and attribute data to categorize various NRW areas. The resultant map unveils that distribution zones 11, 13, and 16 experienced the most significant water loss, accounting for 2.41% to 3.50% of the total water loss. Following closely were WDZs 6, 9, 10, and 17, showing a water loss range of 1.61% to 2.40%. Subsequently, WDZs 1, 3, 7, 12, 14, 18, 19, and 23 exhibited a water loss range of 0.70% to 1.60% of the total NRW. In sequence, WDZs 15, 20, 21, and 21 experienced water loss ranging from 0.31% to 0.70% of the total NRW, and finally, WDZs 2, 4, 5, 8, and 24 showed the lowest levels of water loss. By employing this map, the NRW team can delve into the reasons behind the high-water loss in the identified distribution zones and create interventions aimed at reducing water loss.

4.2. Prioritizing interventions analysis

The calculation of the overall ranking for the 24 WDZs was carried out. Each ranking was determined by summing the weighted and normalized values across nine non-revenue water (NRW) indicators. These indicators were selected based on their effectiveness in evaluating water distribution losses.

Table 7 presents the highest-ranked WDZ for each category, with an overall score of 90 points. Among the 24 WDZs, WDZs 11, 13, 16, and 17 are ranked as the top four priorities that require immediate intervention to address water loss. Following closely behind, WDZs 4, 6, 9, and 10 occupy the second position in the priority ranking. Additionally, WDZs 1, 3, 7, 12, 14, 18, 19, and 23 are ranked in the third position. The remaining nine WDZs, which are not included in the top-ranked list, range from low priority (5 WDZs) to no need for intervention (3 WDZs).

4.3. Comparison outcome between NRW produced map by GIS and NRW prioritization criteria for WDZs

Through the utilization of appropriate prioritization criteria aligned with the attributes of each WDZ, we conducted an assessment that aimed to avoid biased decision-making and determine the significance of potential interventions for NRW reduction. With the implementation of a well-defined framework and a sound decision-making process, it becomes feasible to effectively reduce non-revenue water (NRW) by establishing sustainable NRW reduction plans.

Table 5
NRW for WDZ's response prioritization criteria in Khan Younis city

Water network length		Steel pipe length (Km)		NRW (m³/y)	
(km)	Score	(km)	Score	(m³)	Score
1 > 6	0	>2.0	0	<60,000	0
6.1 > 12	2.2	2.1 > 5.0	1.8	60,001–120,000	3.2
12.1 > 18	4.4	5.1 > 8.0	3.6	120,001–180,000	6.4
18.1 > 24	6.6	8.1 > 12.0	5.4	180,001–240,000	9.6
24.1 > 30	8.8	12.1 > 15	7.2	240,001–300,000	12.8
>30.1	11	>15.1	9	>300,001	16
Number of subscribers		**Number of courtyards**		**Number of broken water meters**	
(No.)	Score	(No.)	Score	(No.)	Score
>400	0	>20	0	<40	0
301 > 800	3	20.1 > 40	1.6	41 > 80	2
801 > 1,200	6	40.1 > 60	3.2	81 > 120	4
1,201 > 1,800	9	60.1 > 80	4.8	121 > 160	6
>1,800	12	80.1 > 100	6.4	161 > 200	8
		>100.1	8	>201	10
Water meter age		**Land use**		**Informal settlements**	
(>10 y) Count	Score	Type	Score	Type	Score
>100	0	Urbanized	1.00	Not exist in WDZ	1.00
101 > 200	3.6	Mixed	2.00	Close to WDZ	2.00
201 > 300	7.2	>50 Agriculture	3.00	Inside the WDZ	3.00
301 > 400	10.8				
401 > 500	14.4				
>501	18				

Table 6
Produced, distributed, billed and NRW for each distribution zones of Khan Younis city in 2021

DZ-number NEW	Produced water (m³/y)	Billed water (m³/y)	NRW (m³/y)	NRW % for each WDZ	NRW % from the total NRW
1	283,294	115,208	168,086	59.33	1.80
2	289,339	261,542	27,797	9.61	0.30
3	315,166	215,452	99,714	31.64	1.07
4	241,759	215,000	26,759	11.07	0.29
5	269,241	245,000	24,241	9.00	0.26
6	454,624	300,000	154,624	34.01	1.66
7	365,181	300,000	65,181	17.85	0.70
8	209,320	190,844	18,476	8.83	0.20
9	530,224	373,320	156,904	29.59	1.68
10	1,161,991	1,007,815	154,176	13.27	1.65
11	809,802	580,400	229,402	28.33	2.46
12	230,924	150,000	80,924	35.04	0.87
13	535,884	258,274	277,610	51.80	2.98
14	586,021	510,549	75,472	12.88	0.81
15	292,988	248,786	44,202	15.09	0.47
16	368,084	49,772	318,312	86.48	3.41
17	566,043	351,980	214,063	37.82	2.29
18	310,776	220,000	90,776	29.21	0.97

Table 6 (Continued)

Table 6

DZ-number NEW	Produced water (m^3/y)	Billed water (m^3/y)	NRW (m^3/y)	NRW % for each WDZ	NRW % from the total NRW
19	634,916	392,000	142,916	26.72	1.53
20	86,472	54,878	31,594	36.54	0.34
21	86,472	54,878	31,594	36.54	0.34
22	115,296	73,171	92,125	55.73	0.99
23	470,827	370,000	150,827	28.96	1.62
24	114,162	110,000	4,162	3.65	0.04
	Total NRW (m^3)		2,679,937	NRW (%) of the total production	28.72

DZ = distribution zone.

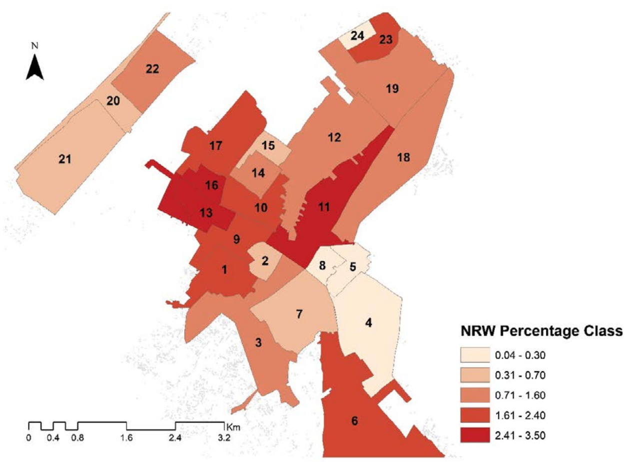

Fig. 5. Final NRW production map for Khan Younis distribution zones.

The results of the ranking process unveiled a combination of interventions with varying degrees of impact. It can be inferred that 82.34% of the NRW losses were classified as high or medium priorities, indicating the need for significant attention. Additionally, 14.52% of the losses were categorized as having minimal impact, while 3.14% were identified as not requiring any intervention. A comprehensive breakdown of these priorities and the corresponding ranking list can be found in Table 8, presenting the statistical figures associated with each priority category.

Based on the analysis of indicators and the corresponding map produced in Fig. 5, the preceding table presents the identified priorities for intervention in reducing water loss. The NRW is classified into categories based on the level of agreement between the results obtained and the prioritization depicted on the intervention map. Table 9 displays the classifications, WDZ numbers, and corresponding quantities of NRW, comparing the results from the produced map with those derived from the prioritization analysis.

Table 7
Prioritizing criteria elements and total ranks

DZ-Number	Population	Water network	Steel pipe	NRW	Subscribers	Courtyards	Broken water meters	Water meter age	Land use	Informal settlements	Total rank	Priority Class
11	22,849	11	5.4	9.6	9	0	6	18	2.0	1.0	62.00	Priority I
16	2,205	4.4	1.8	16	6	1.6	6	18	1.0	2.0	56.80	Priority I
13	10,168	2.2	1.8	12.8	6	0	6	18	3.0	3.0	52.80	Priority I
17	12,246	6.6	1.8	9.6	9	1.6	10	7.2	3.0	3.0	51.80	Priority I
4	14,489	8.8	7.2	0	6	0	10	10.8	2.0	1.0	45.80	Priority II
9	10,752	6.6	0	6.4	9	0	6	14.4	1.0	1.0	44.40	Priority II
10	29,834	4.6	1.8	9.6	9	0	6	10.8	1.0	1.0	43.80	Priority II
6	9,894	11	0	6.4	3	6.4	4	7.2	3.0	1.0	42.00	Priority II
12	5,905	6.6	0	3.2	9	4.8	2	7.2	3.0	1.0	36.80	Priority III
7	15,058	6.6	5.4	3.2	6	0	4	7.2	2.0	1.0	35.40	Priority III
3	16,279	8.8	7.2	3.2	3	0	4	3.6	3.0	2.0	34.80	Priority III
14	18,833	4.4	1.8	6.4	9	0	4	7.2	1.0	1.0	34.80	Priority III
18	7,972	6.6	3.6	3.2	3	4.8	2	7.2	3.0	1.0	34.40	Priority III
1	6,489	2.2	0	6.4	3	0	2	14.4	3.0	3.0	34.00	Priority III
23	9,662	4.4	0	6.4	12	0	2	0	3.0	3.0	30.80	Priority III
19	6,255	4.4	3.6	3.2	3	3.2	4	3.6	2.0	2.0	29.00	Priority III
15	9,177	2.2	0	0	6	0	2	3.6	1.0	1.0	15.80	Priority IV

Table 7 (Continued)

Table 7

DZ-Number	Population	Water network	Steel pipe	NRW	Subscribers	Courtyards	Broken water meters	Water meter age	Land use	Informal settlements	Total rank	Priority Class
22	3,543	2.2	0	0	0	1.6	2	3.6	3.0	3.0	15.40	Priority IV
2	8,897	2.2	0	0	3	0	4	3.6	1.0	1.0	14.80	Priority IV
5	6,836	2.2	0	0	3	0	4	3.6	1.0	1.0	14.80	Priority IV
8	6,632	2.2	1.8	0	3	0	4	0	1.0	1.0	13.00	Priority IV
20	1,440	2.2	0	0	0	0	0	0	3.0	3.0	8.20	No need
21	3,133	0	0	0	0	1.6	0	0	3.0	3.0	7.60	No need
24	3,007	0	0	0	3	0	0	0	1.0	1.0	5.00	No need

Table 8
Priority rankings against NRW quantities and percentage

Priority	Range	WDZ numbers	NRW (m^3/y)	NRW (%)
High	(>46.1)	11,13,16,17	1,039,387	39.18%
Medium high	(36.1–46)	4,6,9,10	465,704	17.55%
Medium low	(18.1–36)	1,3,7,12,14,18,19,23	873,896	32.94%
Low	(10.1–18)	2,5,8,15,22	206,841	7.80%
No need	(<10)	20,21,24	67,350	2.54%
Total			2,653,178	

Table 9
Number of WDZs match with prioritization and GIS map

Produced NRW map			NRW priorities			Matching analysis		
Priority rank	WDZ number	NRW (m^3/y)	Priority	WDZ number	NRW (m^3/y)	WDZ number	NRW (m^3/y)	Match %
High (2.41–5.00)	11,13,16	825,324	High (>50)	11,13,16,17	1,039,387	11,13,16,17	825,324	79
Medium high (1.61–2.40)	6,9,10,17	679,767	Medium High (40–49)	4,6,9,10	465,704	6,9,10	465,704	69
Medium low (071–1.60)	1,3,7,12,14,18,19,23	873,896	Medium Low (28–39)	1,3,7,12,14,18,23	873,896	1,3,7,12,14,18	873,896	100
Low (0.31–0.70)	15,20,21,22	199,515	Low (10–27)	2,5,8,15,22	206,841	15,22	136,327	96
No need (0.04–0.30)	2,4,5,8,24	101,435	No Need (<10)	20,21,24	67,350	24	4,162	66
Total	24	2,679,937	Total	24	2,653,178	16	2,305,413	86

The comprehensive evaluation indicates a 86% (equivalent to 2,305,413 m^3/y) alignment between the priorities of NRW derived from the GIS map and those determined through the analysis of indicators. Notably, approximately 93.91% of the water loss falls within the high and middle priority classes, signifying the areas that require immediate attention. On the other hand, 6.09% of the water loss is classified as low priority, indicating that no intervention is necessary. In line with the obtained results, WDZs numbers 11, 13, 16, and 17 were categorized as first-class priorities for the water loss reduction plan, while WDZ numbers 6, 9, and 10 were classified as second-class priorities.

5. Conclusion

In recent decades, water service providers have faced chronic water loss, the rapid population growth, and the negative impact of climate change. This has warned that water is much less available than it once was. Therefore, reducing the amount of NRW in the world by only one third, the savings would be sufficient to supply 800 million people. The Palestinian Water Authority estimated that if NRW reduced from 38% to 35%, this would increase revenues by $40 million over a period of 10 y. This study proposes the adaptation of GIS to estimate NRW losses per water distribution zone in Khan Younis city.

The utilization of GIS technology has proven to be instrumental in the management of NRW. By employing GIS, the NRW management team will be able to concentrate on addressing frequent losses within each distribution zone, conducting thorough analyses of potential causes of water loss based on the specific characteristics of each water distribution area. This technology facilitated the identification of the highest NRW rates, ranging between 3.01% and

5.00%, primarily observed in DZ11, DZ13, DZ16, and DZ17. Conversely, the lowest levels of water loss, ranging between 0.51% and 1.00%, were identified in DZ2, DZ4, DZ5, DZ8, and DZ24. This study developed a set of nine priority parameters to evaluate NRW in the 24 water WDZs of Khan Younis. The parameters were weighted and ranked, resulting in a maximum total score of 90 points, representing the highest NRW value. The findings revealed a 75% alignment between the NRW priorities identified by the GIS map and those determined through indicator analysis. The majority of the WDZs (92.52%) fell into the high and medium priority classes, while a smaller portion (7.48%) belonged to the low priority class, indicating no need for water loss intervention. Thus, the analysis of NRW in the water distribution zones demonstrated that GIS technology is highly effective in producing NRW maps and should be utilized to support NRW management and reduction efforts.

In conclusion, the utilization of GIS technology as a powerful tool for evaluating the status of NRW in water distribution zones has been demonstrated through the application of the prioritizing parameters weighting and ranking method. The findings highlight the substantial influence of the selected parameter settings on the prioritization process and the development of intervention plans for NRW reduction. This reaffirms the value of GIS technology in effectively assessing and managing NRW in water distribution zones.

Funding

The authors are grateful to Middle East Desalination Research Center MEDRC for funding the research (MEDRC Project No.: 18-PG-04) and Khan Younis Municipality for their support and cooperation during data capture and evaluation phases.

Declarations

Conflict of interests

The authors declare that they have no conflict of interests.

References

[1] D.N. Kuria, D.E. Musiega, M.M. Ngigi, S. Kibue Ngigi, An open source Geographic Information System (GIS) approach to water supply management, distribution and billing, Water (Switzerland), 3 (2012) 55–62.
[2] V. Kanakoudis, S. Tsitsifli, Urban water services public infrastructure projects: turning the high level of the NRW into an attractive financing opportunity using the PBSC tool, Desal. Water Treat., 39 (2012) 323–335.
[3] H. Abueltayef, K. Abualhin, K. Alastal, Enabled Geographic Information System technology toward non-revenue water reduction, Desal. Water Treat., 292 (2023) 233–246.
[4] V. Kanakoudis, S. Tsitsifli, A. Papadopoulou, B. Cencur Curk, B. Karleusa, Water resources vulnerability assessment in the Adriatic Sea region: the case of Corfu Island, Environ. Sci. Pollut. Res., 24 (2017) 20173–20186.
[5] H. Alegre, J.M. Baptista, E. Cabrera, Jr., F. Cubillo, P. Duarte, W. Hirner, W. Merkel, R. Parena, Performance Indicators for Water Supply Services, Vol. 15, IWA Publishing, January 2000, 2006.
[6] R. Hanjahanja, C. Omuto, Do prepaid water meters improve the quality of water service delivery? The case of Nakuru, Kenya, Smart Water, 3 (2018) 4, doi: 10.1186/s40713-018-0010-9.
[7] J. Lee, J. Keck, Embracing Analytics in the Drinking Water Industry, IWA Publishing, 2022, pp. 399–408.
[8] V. Kanakoudis, S. Tsitsifli, A. Papadopoulou, B.C. Curk, B. Karleusa, Estimating the water resources vulnerability index in the Adriatic Sea region, Procedia Eng., 162 (2016) 476–485.
[9] M. Tabesh, A. Roozbahani, B. Roghani, N.R. Faghihi, R. Heydarzadeh, Risk assessment of factors influencing non-revenue water using Bayesian networks and fuzzy logic, Water Resour. Manage., 32 (2018) 3647–3670.
[10] V. Kanakoudis, S. Tsitsifli, Urban water services public infrastructure projects: turning the high level of the NRW into an attractive financing opportunity using the PBSC tool, Desal. Water Treat., 39 (2012) 323–335.
[11] V. Kanakoudis, A. Papadopoulou, S. Tsitsifli, B. Cencur Curk, B. Karleusa, B. Matic, E. Altran, P. Banovec, Policy recommendation for drinking water supply cross-border networking in the Adriatic region, J. Water Supply Res. Technol. AQUA, 66 (2017) 489–508.
[12] K.S. Thajudeen, Developments in Islamic Finance, 2017, pp. 21–42.
[13] M.R. Elkharbotly, M. Seddik, A. Khalifa, Toward sustainable water: prediction of non-revenue water via artificial neural network and multiple linear regression modelling approach in Egypt, Ain Shams Eng. J., 13 (2022) 101673, doi: 10.1016/j.asej.2021.101673.
[14] B. Kingdom, R. Liemberger, P. Marin, The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries How the Private Sector Can Help: A Look at Performance-Based Service Contracting, No. 8, 2006.
[15] WSRC, Performance Monitoring Report For Water and Wastewater Service Providers in Palestine for the Year 2018, 2020.
[16] PWA, Non-Revenue Water Reduction Strategy Non-Revenue Water Reduction Strategy, 2003.
[17] WSRC, Bridge to Sustainability Water Water and Wastewater Service Providers Performance Monitoring Report for the Year 2016, Palest. Water Sect. Regul. Counc. Annu. Rep., 2018.
[18] PCBS, Estimated Mid-year Population of Khanyouns Province, 2017–2021, 2022. Available at: https://pcbs.gov.ps/Portals/_Rainbow/Documents/KhanyunisA.html (Accessed: 19-Feb-2022).
[19] R. Frauendorfer, R. Liemberger, The issues and challenges of reducing non-revenue water, Water, 41 (2010).
[20] H. AbuEltayef, R. Leham, Water and Wastewater Yearly Achievement Report 2020, p. 2021, 2021.
[21] D.M. Kimwatu, P.A. Odera, Application of geospatial technology in curbing non revenue water: a case study of Murang'a Municipality, Int. J. Sci. Res., 3 (2014) 734–741.
[22] A. Ayad, A. Khalifa, M.E.L. Fawy, A. Moawad, An integrated approach for non-revenue water reduction in water distribution networks based on field activities, optimisation, and GIS applications, Ain Shams Eng. J., 12 (2021) 3509–3520.
[23] V. Kanakoudis, S. Tsitsifli, G. Demetriou, Applying an integrated methodology toward non-revenue water reduction: the case of Nicosia, Cyprus, Desal. Water Treat., 57 (2016) 11447–11461.
[24] UNRWA, Khan Younis Camp, 2022. Available at: https://www.unrwa.org/where-we-work/gaza-strip/khan-younis-camp (Accessed: 19-Feb-2022).
[25] UNHABITAT, Khan Younis, Gaza, Palestine: Wide Public Space Assessment Report, UNHABITAT, 2021.
[26] H. AbuEltayef, R. Leham, Khan Younis Municipality Water and Wastewater Department Annual Achievement Water and Wastewater Status Report, 2018, 2019.