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Enabled geographic information system technology toward non-revenue water reduction

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ABSTRACT

In recent years, advances in information communications technology have proven their role in reducing water losses in water distribution systems. The geographic information system is a specialized set of Information Communication and Technology, which provides effective methods in the management of the water sector, in particular, non-revenue water. The Palestinian national strategic plan reported that reducing the non-revenue water from 38% to 35% will increase the revenue by US$40 million within 10 y. Similarly, the water sector regulatory council estimates that the non-revenue water rate is 33%. Surprisingly, water utilities have yet to implement extensive water loss management. Approximately 95% of the urban population in Khan Younis is served by a municipal water supply network. A high level of non-revenue water was recorded in Khan Younis in 2012 (about 40%). Many actions have been implemented to reduce the non-revenue water to 30% by 2020. This study aimed to quantify the non-revenue water of each water distribution zone and to classify the non-revenue water loss for distribution zone 20 (DZ20) per house connection. It was concluded that the adaptation of geographic information system made it possible to classify the highest loss rate of non-revenue water between 3% and 5% for DZ23. However, the distribution zone DZ20 showed a very high level of water loss (58.78%). The filed investigations illustrate that the developed map accuracy was presented as 83% accurate, whilst a strong positive correlation was revealed between non-revenue water and the age of the water meter and the number of populations occupying the house connection.

Keywords: None revenue water; Water loss; Information Communication and Technology; Geographic information system

1. Introduction

Innovation is essential for the future effectiveness to drive the water sector in which intelligent water systems and advanced technology have to take the opportunity to advance the water sector and dramatically shift management decision-making [1]. The digital transformation of water supply supports the sustainable development goals (SDG), especially SDG 6 to ensure the availability and sustainable management of water and sanitation for all. In addition, the application of AI numerical tools to the water sector largely contributes to addressing key global water sector challenges, such as water assets, water as a growth-limiting factor, and integrated water resources management [2]. Moreover, smart water infrastructure technologies have the potential to contribute significantly towards improved service delivery and efficiency of water services providers; reducing costs and water losses, and improving data and asset management in water utilities [3].

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Smart water grids are required for water supply systems for use in water management platforms, which integrates Information Communication and Technology (ITC) into a single water management scheme [4].

The smart water concept has tremendous potential for ITC software and analytics, hardware, and developed infrastructure [5]. Smart water technology allows conducting of analysis on sensor data for efficient pressure management and identification of commercial water losses and pipeline leaks, resulting in a decrease in water losses in water distribution systems [6]. ITC and smart water supply systems use sensors to monitor pressure, water flow, water quality, moisture, and other data in real-time, and can detect any abnormalities, such as non-revenue water (NRW) loss [6]. Water utilities are following the lead of other sectors, especially energy, sometimes without fully understanding the underlying assumptions and implications of applying ITC to their operations [2].

In recent years, advances in information technology have greatly opened up opportunities to support data analysis and communication. Geographic information system (GIS) provides exciting new methods for acquiring natural resource data, and also provides effective methods for processing, managing, and integrating these data [7]. Furthermore, GIS is an invaluable tool in water distribution system modeling, because the required information is descriptive and spatial [3].

Although NRW is a problem well identified by the water service providers until now there has not been a comprehensive method to solve it. There are many software tools for evaluating water distribution networks (WDN) and estimating water balance and performance indicators, some of which are more advanced than others. However, no tool can serve as a decision support system for water supply operators in the daily management of water distribution systems [8].

The following forms are to be considered as part of ITC utilization in NRW reduction: (1) Mobile applications: most commonly referred to as an application software designed to run on a mobile device (such as a smartphone or tablet) capable to connect and share or transfer data from one to another [5]; (2) Leakage detection: water loss management has become increasingly important. Leakage is the main source of NRW losses, which largely depends on pressure and water consumption, and increases water pollution [5]. Ground penetrating radar, infrared thermal imaging, and electromagnetic sensors are other development technologies that can be used for leak detection [6]. Leaks can be detected by analyzing these data, especially in night-time traffic with the least amount of normal consumption [5,6]; (3) Smart metering: the smart meter records the water consumption and transmits the supplied water consumption data to consumers, creating them aware concerning water usage. Also, it can provide early warning of abnormal events (such as leaks, high water consumption, etc.) from the perspective of the water user. Smart water meters can communicate or issue command or charge signals from the utility to the meter and on the other hand, they convey water consumption information, and so forth to the utility [6]; and (4) Geographic information technology: is a specialized set of ITC that helps manage and interpret data about area's resources and infrastructure [5]. Within a GIS environment, map interaction and databases permit easy access, production, revision, and dissemination of data [7]. GIS provides an excellent platform for the management of data, particularly in the storage, manipulation, and processing of huge databases. They are also a powerful tool for visualizing simulation results, so that decision-makers and the public can readily understand model results [9]. However, GIS provides innovative and powerful tools for planning, performance monitoring, and life cycle asset management. The water supply system and consumed water are spatial-based systems in which input and output are placed in environmental resources. It can provide mountable solutions, from local environments with desktop solutions to web-based solutions, together with enterprise and city-wide applications [10]. The integration of a hydraulic simulator, within the GIS, offers a series of advantages in various aspects of hydraulic models such as leakage control and disaster management in the network [3].

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 that would help in planning and the management of NRW reduction. Whilst the specific objectives were focused on:

- Quantify the water loss of each water distribution area to classify the NRW of each water distribution area, which will help in determining the priority of intervention plans for the NRW reduction planning strategy of the entire city.
- Identify and classify the NRW loss for specified distribution zone 20 (DZ20) per house connection as a pilot project zone by relating the spatial house agreements and the attribute data related production verse billings.
- Calculate the IWA water balance for DZ20.
- Investigate possible correlation between the number of persons per house connection, parcel area, and water meter age.

1.1. Global and local non-revenue water situation

Non-revenue water is one of the main problems facing water utilities today, especially in areas with severe water shortages. Water resources are under pressure; increasing water demand and climate change conditions endanger their sustainability [7]. Even though water scarcity is going to be a global issue, a staggering 32 billion m^3 of treated water is lost to urban supply systems around the world [11]. The World Bank estimates that the average NRW rate of developing countries is 35%, and the loss is about 26 billion m^3. Among them, the Asian Development Bank stated that the annual water production of NRW is about 29 m^3. This leads to nearly 9 billion dollars in lost revenue every year. It is conservatively estimated that the total annual cost of the global water supply company is 14 billion dollars. Without further investment, only half of this amount can be saved to provide water for another 100 million people [7].

NRW is the difference between the volume of water supplied into a distribution system and the authorized billed consumption [12]. NRW has three components: apparent losses, real losses, and nonrevenue authorized consumption [13]. Water is lost through leaking pipes or theft. Eliminating

NRW is not feasible, though reducing the current level to half is a reasonable target in most developing countries [11]. Due to the high level of NRW worldwide, authorities in water companies seek the most effective NRW reduction activities. Despite some proposed approaches for NRW management and reduction in recent years, most WDNs continue to experience high levels of water losses [13].

The Palestinian water sector is not far away from global water scarcity; the Palestinian goal of water security has been withdrawing in recent years. The population is growing rapidly. Palestine faces significant and growing shortfalls in the water supply available for domestic use. Currently, only 4% of the 180 million m^3 (MCM) of water is extracted annually from what used to be the Gazans' main source of drinking water. But 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 [14]. According to the national strategic plan, reducing NRW from 38% to 35% will increase revenue by US$40 million within 10 y. Similarly, the Water Sector Regulatory Council (WSRC) estimates that the NRW rate is 33% (85 MCM of fresh water is lost annually). Despite the mismanagement of the Palestinian water sector, NRW is considered one of the major issues that water utilities are facing in the meantime, especially in areas with severe water scarcity conditions. Previous studies showed high levels of NRW, which needs better management of the water resources to understand these losses and to propose proper management of distribution systems. According to WSRC, the average rate of 33% NRW accounts for US$45 million of more than 85 MCM of fresh water lost annually in Palestine [15]. Fig. 1 illustrates the produced water and the amount of NRW/y for the Palestinian water sector. Between the years 2012 and 2018, NRW ranged from 67 to 80 million m^3. This is a huge amount of water lost every year in a region suffering from water scarcity.

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, for example: (1) there are no district water meters installed, and the city is divided into 36 water distribution zones, (2) low meters quality, some water meters have been installed for decades;

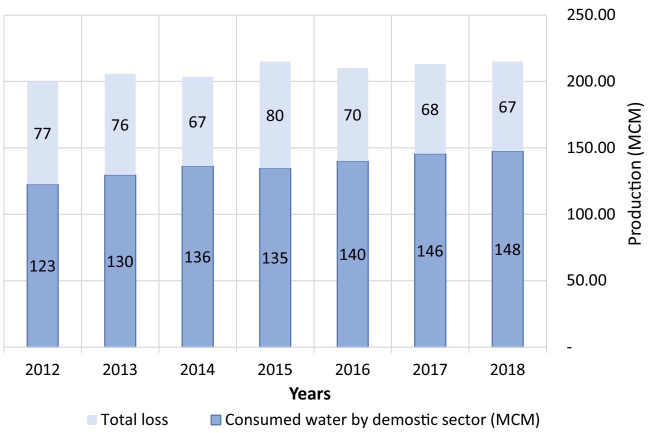

Fig. 1. The yearly water production, billed and non-revenue water volume of the state of Palestine from 2012 to 2019 (PCBS, 2021).

due to the deteriorated economic conditions and the lack of financial resources, the municipality has limited activities to replace the old water meters, (3) the water network is dilapidated and 30% of the water distribution network is steel, and; (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: a weak accounting system leading to a weak billing system, lack of spatial information interaction between spatial information and account information database, lack of water meter reading monitoring, and increasing violations of laws and increased number of illegal connections.

2. Materials and methods

2.1. Study area

Khan Younis city is located in the southern part of the Gaza Strip, shown in Fig. 2b and c. 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 center and transit station on the ancient trade route to Egypt. It is considered the center of the Khan Younis Governorate [16]. Located at the intersection of north latitude 31.212 and east longitude 34.18, at an altitude of 50 m. Khan Younis is considered the largest city with a population of one-fifth of the total population of the Gaza Strip. PCBS (2021) reported that the total population of the city is 274,942, in which 95% of the total population is connected to the municipal water distribution system [17,18].

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 36 water distribution zones (WDZ). Khan Younis city provides water supply services, where the main source of water is groundwater; it has 30 groundwater 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 southern governorates desalination plant located in Deir Al-Balah. Desalination water is considered the second water source. The length of water networks in Khan Younis WDN is about 570 km long, 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 [19].

Since 2015, the NRW in Khan Younis has been treated as a very serious problem that needs to be solved. High levels of NRW are harmful to commercial and physical losses accounting for approximately 40% in the year 2013/2014, which is almost half higher than the set benchmark level of 25% [20]. Khan Younis water department reported that 3.0 MCM were lost in 2015, and then due to the intervention strategies adopted by various departments, the NRW was reduced to 2.3 MCM by 2019, which was delivered to customers but was not invoiced.

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

To meet the international benchmark of 25% NRW, the Khan Younis city water department needs to develop

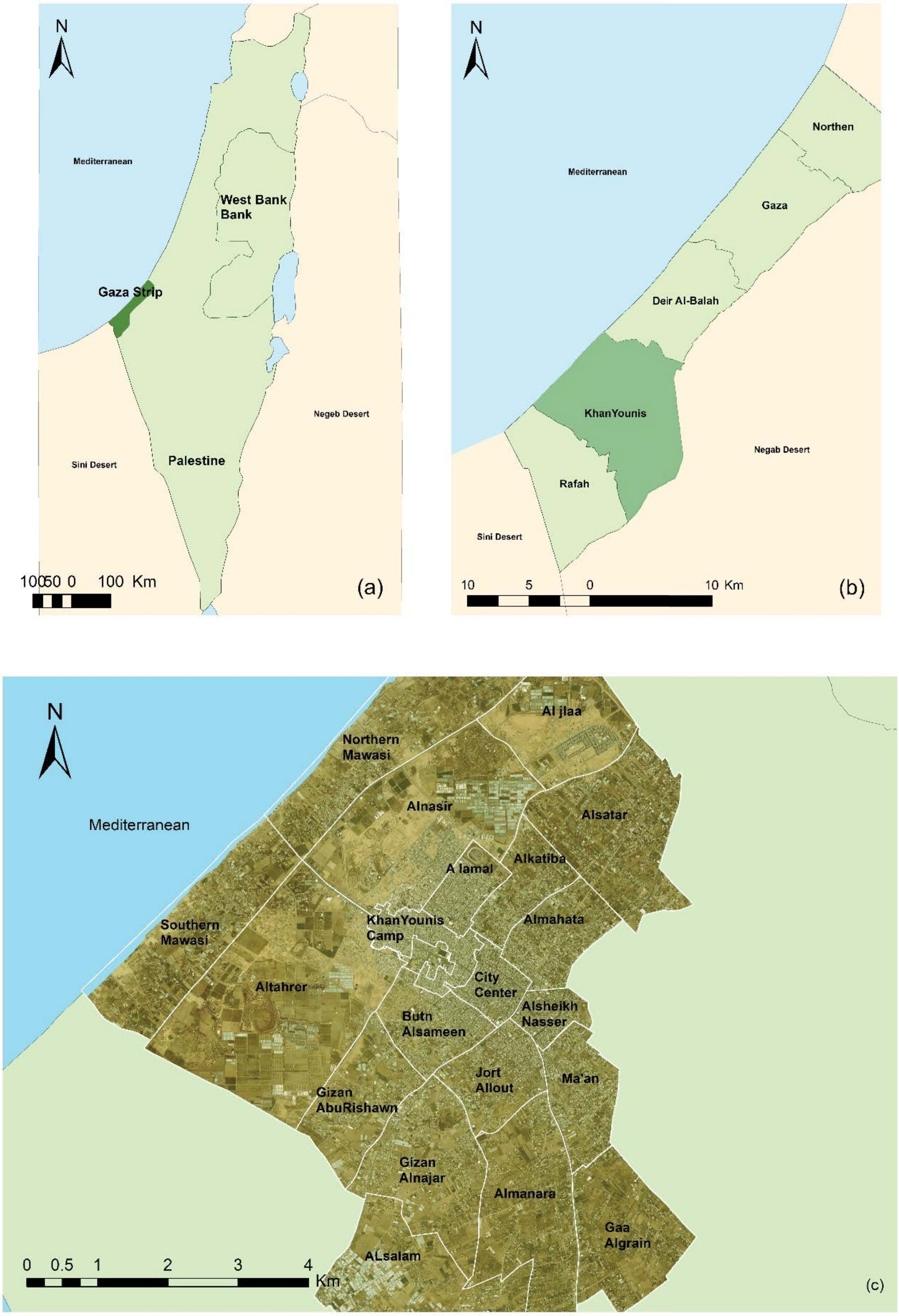

Fig. 2. (a) Gaza Strip location in Palestine, (b) Khan Younis location in Gaza Strip, (c) Khan Younis Districts.

a well-structured plan to reduce non-revenue water and improve water supply services. Despite the lack of leak detection, complex software, hardware, and information transmission technology, operators' weak registration data, weak registration of leak repairs, and insufficient reporting of maintenance activities carried out on the terrain, it is still possible to evaluate and formulate plans to reduce NRW. An attribute database and GIS software were used to assess the water loss in each water distribution area in the city. The monthly production from groundwater wells and the seawater desalination plant for 8 months in 2021. Fig. 3 illustrates the total production over this period is 6,437,830 m^3.

While this amount of around 6.4 MCM of water was pumped into the network in 2021, only 4.7 MCM was invoiced, which represents a loss of 27.5%. The monthly amount of NRW for the same 8 months in 2021 is shown in Fig. 4.

An excel model was developed, which allows collecting information about production and distribution from the worksheets that have been downloaded to the system, but from the municipal database, all billing connections for each house are collected and calculated for each distribution area. The tool can check data, calculate losses between wells, reservoirs, and distribution areas, and calculate the amount and percentage of losses. Analysis and verification have been carried out, and finally, the NRW of each distribution area has been calculated for 8 months in 2021 as shown in Table 1.

2.3. Data analysis of NRW for distribution zone DZ20

Khan Younis is concerned about the NRW problem and its increasing rate, where the municipality is under pressure to find a solution. Therefore, the NRW unit was

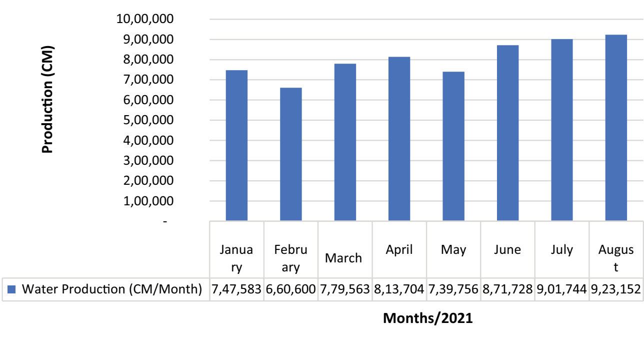

Fig. 3. Water production in Khan Younis city for the year 2021.

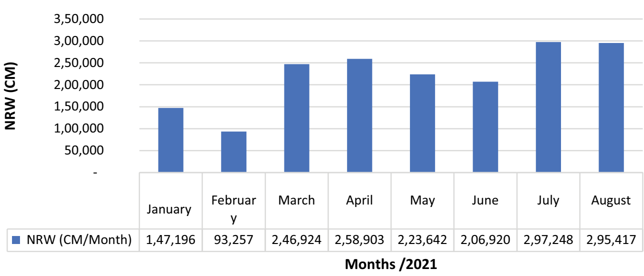

Fig. 4. Non-revenue water in Khan Younis city for year 2021.

established in 2018 to follow up and propose solutions. Our case study is for DZ20 named Salah-Aldine and Satar, shown in Fig. 5a and b, with a total area of approximately 1.6 km^2 and a population of 7,350. The main source of water supply is Alsatar Reservoir; DZ20 experiences intermittent water supply, and the average monthly water supply is about 10,800 CM. DZ20 pipeline network consists of transmission and distribution pipelines. The water transmission network is the carrier of the pipe section from the production unit to the reservoir. The WDN is about 23,217 m, the main carrier network accounts for 3,818 m (16.44%), the water distribution network is 11,674 m (50.28%) and the service network is 7,725 m (33.27%). Although the water distribution network from the reservoir to the water supply network conveys through pipes of different diameters 2", 3", 4", 6", 8", and 12". The service network is embedded with pipe fittings such as valves, pressure gauges, and water meters. The main problem with the DZ20 water supply network is that the NRW level is very high, reaching 58%. The water utility did not take any measures to resolve NRW. By using ArcGIS for assessment, managers can understand the problem and implement an intervention plan.

Step I: Data collection: data collection process was divided into two parts. The first part is concerned with collecting the population of each apartment by a field surveyor group, covering all actively subscribed buildings, and the second part is about collecting data regarding water consumption from the municipality database. Eq. (1) was used to calculate the water production per capita.

$$\text{Water production per capita}(\text{CM}) = \frac{\text{Water production in 8 months}(\text{CM})}{\text{Total number of populations for the same area}} \quad (1)$$

Step II: Data analysis, Excel model development, and data verifications: In this step, the installed data, the developed Excel model, and the equation were used to calculate the recommended consumption for each building and facility. The collected data was uploaded to the developed excel model to calculate the proposed estimated consumption of each house based on the population, considering that the average per capita water consumption is estimated to be 110.78 L/person/d.

$$\text{Proposed consumption per house connection} = \text{Total populations} \times 30\ \text{d} \times 8\ \text{month} \times 110.78\ \text{L/d} \quad (2)$$

The billed consumption for each building (house connection) is equal to the total monthly billed consumption for 8 months (period of study on 2021). The NRW can be calculated through Eq. (3):

$$\text{NRW per house connection} = \text{eq.}(1) - \text{eq.}(2) \quad (3)$$

Step III: Data integration into GIS and NRW maps creation: after running the excel model and getting the calculations for the NRW for each connection in the DZ20, a shape file is prepared and joined with the excel attribute.

Table 1
Produced, distributed, billed, and non-revenue water for each distribution zones of Khan Younis City for 8 months in 2021

DZ number	Produced water (m^3)	Distributed water (m^3)	Production loss (m^3)	Billed water (m^3)	NRW (m^3)	NRW (%)	Number of service connections	Number of consumers
18	161,654	154,473	7,181	108,387	53,267	0.87	509	7,185
6	176,673	174,300	2,373	63,204	113,469	1.85	321	2,695
13	217,624	214,700	2,924	138,641	78,983	1.29	711	12,250
21	167,956	165,700	2,256	138,582	29,374	0.48	643	5,145
43	24,327	24,000	327	13,653	10,674	0.17	30	221
42	34,058	33,600	458	7,161	26,897	0.44	2	12
44	12,163	12,000	163	3,924	8,239	0.13	40	294
1	217,600	217,600	–	212,768	4,832	0.08	1,122	14,088
2	247,800	247,800	–	147,664	100,136	1.63	1,040	12,863
3	368,800	368,800	–	304,134	64,666	1.05	1,685	12,056
4	233,800	233,800	–	221,920	11,880	0.19	1,311	9,380
10	353,690	353,690	–	341,014	12,676	0.21	2,181	24,757
5	127,900	127,900	–	115,448	12,452	0.20	755	11,451
22	235,026	216,600	18,426	168,539	66,487	1.08	1,083	6,633
24	267,179	227,800	39,379	196,551	70,627	1.15	1,263	7,736
26	16,500	16,400	100	14,784	1,716	0.03	95	582
27	146,524	146,524	–	22,631	32,187	0.52	85	1,722
28	79,757	79,757	–	36,740	79,757	1.30	162	2,796
29	25,415	25,415	–	6,325	25,415	0.41	51	481
30	54,084	54,084	–	48,641	54,084	0.88	290	3,702
12	12,543	12,543	–	5,169	7,374	0.12	30	643
8	86,086	73,086	13,000	84,821	1,265	0.02	453	2,879
7	360,564	358,097	2,467	290,754	69,810	1.14	1,270	12,333
9	155,097	154,036	1,061	143,337	11,760	0.19	680	7,027
11	129,523	128,637	886	60,054	69,469	1.13	126	4,924
36	306,396	304,300	2,096	183,032	123,364	2.01	1,135	10,592
32	260,784	259,000	1,784	227,615	33,169	0.54	276	2,177
39	43,296	43,000	296	6,770	36,526	0.60	41	1,185
37	36,248	36,000	248	–	36,248	0.59	170	992
38	16,110	16,000	110	16,000	110	0.00	5	441
20	241,144	204,396	36,748	99,409	141,735	2.32	696	7,350
23	375,825	318,553	57,272	70,379	305,446	4.99	463	12,250
40	78,990	66,953	12,037	–	78,990	1.29	15	123
41	28,315	24,000	4,315	11,812	16,503	0.27	5	37
14	263,246	251,551	11,695	199,455	63,791	1.04	1,132	16,590
15	174,784	167,019	7,765	127,902	46,882	0.76	551	5,513
16	166,768	159,359	7,409	111,683	55,085	0.90	653	12,860
17	247,377	236,387	10,990	225,096	22,281	0.36	1,170	17,428

DZ = distribution zone

Step IV: Map classification: to classify the generated maps, the international NRW matrix assessment is usually used. According to the water department's measurement, the average pressure level is 2 bar. A category of low- and middle-income countries is suitable, which is being used in this study as shown in Table 3. It is worth noting that the NRW evaluation results of each connection show that the billed water consumption of many houses is higher than normal of housing unit consumption compared to the number of residents. Therefore, an additional category is added to the map that holds negative values.

2.4. Methodology

The case study presented in this article explores the effectiveness of GIS technology in assessing NRW for the water distribution zones in Khan Younis Municipality in general and provides in particular a detailed study for water

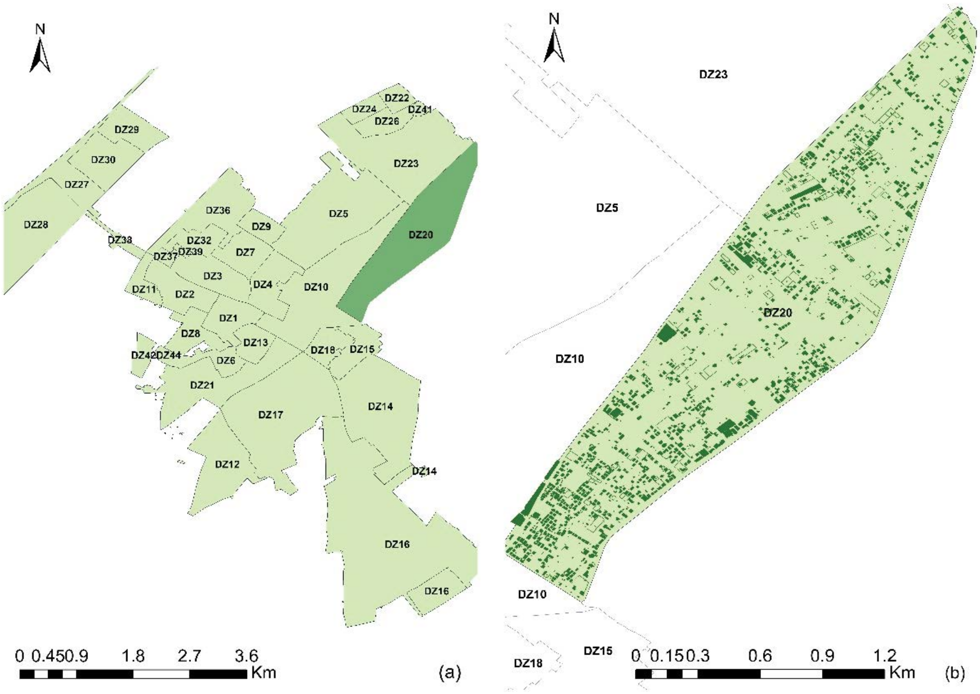

Fig. 5. (a) Water distribution zones in Khan Younis city, and (b) study area distribution zone 20.

Table 2
Sample of the calculated non-revenue water per conception per day

Index	Agreement number	No. of consumers	Estimated consumers consumption (m^3/y)	Billed consumption (m^3/y)	NRW/service connection (m^3/y)	NRW service connection (L/d)
24887	30535	7	194.66	184	11	44.42
34267	54818	6	166.85	77	90	374.39
34265	54819	6	166.85	156	11	45.22
34264	54817	7	194.66	100	95	394.42
34262	15782	12	333.71	222	112	465.44
34688	23118	6	166.85	197	–30	(125.61)
24713	28778	7	194.66	151	44	181.92
24739	16712	14	389.32	309	80	334.68
35018	30693	6	166.85	136	31	128.55
24913	30694	13	361.51	198	164	681.31
24120	29885	4	111.24	139	–28	(115.69)
25402	16180	9	250.28	343	–93	(386.34)
33498	52521	7	194.66	164	31	127.76
24743	15789	9	250.28	264	–14	(57.17)
24821	10563	4	111.24	38	73	305.15

distribution zone number 20 (DZ20) as a pilot area. After this, the research developed objectives were guided on the relevant data to be collected pertaining produced, distributed, and billed water. Then all data from various database sources were integrated whereby attributes data were added to the spatial data. The generated and the developed excel model led to further analyses as well as showing the spatial distribution NRW within the water distribution zones and house connection levels.

A specified number of house connections with a high level of NRW were selected to conduct a deep – field investigation and analysis of the NRW loss. This aided in determining the real causes of water loss. Moreover, this field survey enabled validation of the generated NRW maps, by showing how come the collected and developed data was reliable. This was achieved by considering – the number of occupancies per house connection, the number of water subscriptions in the parcel, the provided water sources, and

Table 3
IWA matrix for non-revenue water classifications per house connection [21]

NRW management performance category		Non-revenue water in liters/connection/d when the system is pressurized at an average pressure of:				
		10 m	20 m	30 m	40 m	50 m
High income countries	A1		<50	<65	<75	<85
	A2		50–100	65–125	75–150	85–170
	B		100–200	125–250	150–300	170–350
	C		200–350	250–450	300–550	350–650
	D		>350	>450	>550	>650
Low- and middle-income countries	A1	<55	<80	<105	<130	<155
	A2	55–110	80–160	105–210	130–260	155–310
	B	110–220	160–320	201–420	260–520	310–620
	C	220–400	320–600	420–800	520–1,000	620–1,200
	D	>400	>600	>800	>1,000	>1,200

water meter classification. The results were represented in form of maps, tables, graphs, and pie charts. The overall approach of the project was shown in Fig. 6.

3. Results and discussion

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

NRW production map was generated, which includes the last phase for the city's water distribution zones, as shown in Fig. 7.

The production map is one of the most important tools that GIS has been able to create to link both spatial and attribute data to identify the most NRW areas. The map shows that the highest loss rate between 3%–5% was in the distribution zone number DZ23, followed by DZ20–DZ36 at a range of 2%–3% from the total water loss. The lowest water loss level was recorded in the distribution zones of DZ1, DZ4, DZ5, DZ8, DZ10, and DZ12, shown in Fig. 10a and b. Through this map, the NRW unit can direct its efforts to investigate the causes of high loss in the distribution zones and develop plans to treat and reduce water loss.

3.2. Evaluation of NRW for distribution zone DZ20

Typically, the map illustrates the amount of NRW per house connection on five classifications (<80, 80–160, 160–320, 320–640, and >640) which abide with IWA NRW classes for the distribution zone number 20 as shown in Fig. 8. This standard framework shows the assessment impact of NRW by percentage. It is evident that class >80 was much more significant (55%) than those of the rest of the classifications. Other notable classes (i.e., 80–160 and 160–320) were considerably lower accounting for approximately 15% and 25%, respectively. On the other hand, class 320 to 640 accounts for 5%, while class >640 was the lowest accounting for 1%.

3.3. Water balance and NRW calculation for distribution zone 20

The water balance of the water supply system is the basis for any NRW analysis related to both real losses and apparent losses. It is based on measurements and assessments of components of water produced, distributed, exported, billed, or lost [22]. The water balance is one of the indications that shows the level and amount of water loss both physically and non-physically in the water supply system [23]. Table 4 shows the available data for distribution zone DZ20.

NRW volume calculation: NRW volume is obtained by deducting billed authorized consumption from system input volume (or by deducting billed metered and unmetered consumption from water supplied, in the case of distribution systems). NRW consists of 3 principal components: unbilled authorized consumption (UAC), apparent losses (AL), and real losses (RL). The computed NRW was 141,735 m^3/y, which represents 58.78%. It exceeded the international water association (25% acceptable level). The result shows that NRW can be classified as high level because the water losses are more than 50% of the distributed water, then it needs some strategies for reducing the water loss [23]. Table 5 presents the amount of NRW of 141,735 m^3/y (58.78%) with a very high level of water loss of about 100,075 m^3 (41.50%) classified as apparent losses and 41,660 m^3 (17.28%) as real losses.

The results revealed that the real loss percentage is lower than the commercial loss. This is related to the water distribution networks in the study area. The material quality of water pipe and the competence municipal water team (technical and operational) and the expertise and the expertise that specifically contributes to reducing actual losses. On the other hand, apparent losses require special management and awareness of the decision makers and the technical teams. This study enlightens that the water service providers should recognize the importance of apparent loss in the region and to build employee capacities to deal with apparent loss reduction.

3.4. Map accuracy assessment

For the purpose of map evaluation, the category of the map is usually used to stratify the sample to ensure the smallest sample size in each layer and to obtain a more accurate estimate of the rare category.

An observation sample of 76 connections, which account for 12% of the total number of house connections,

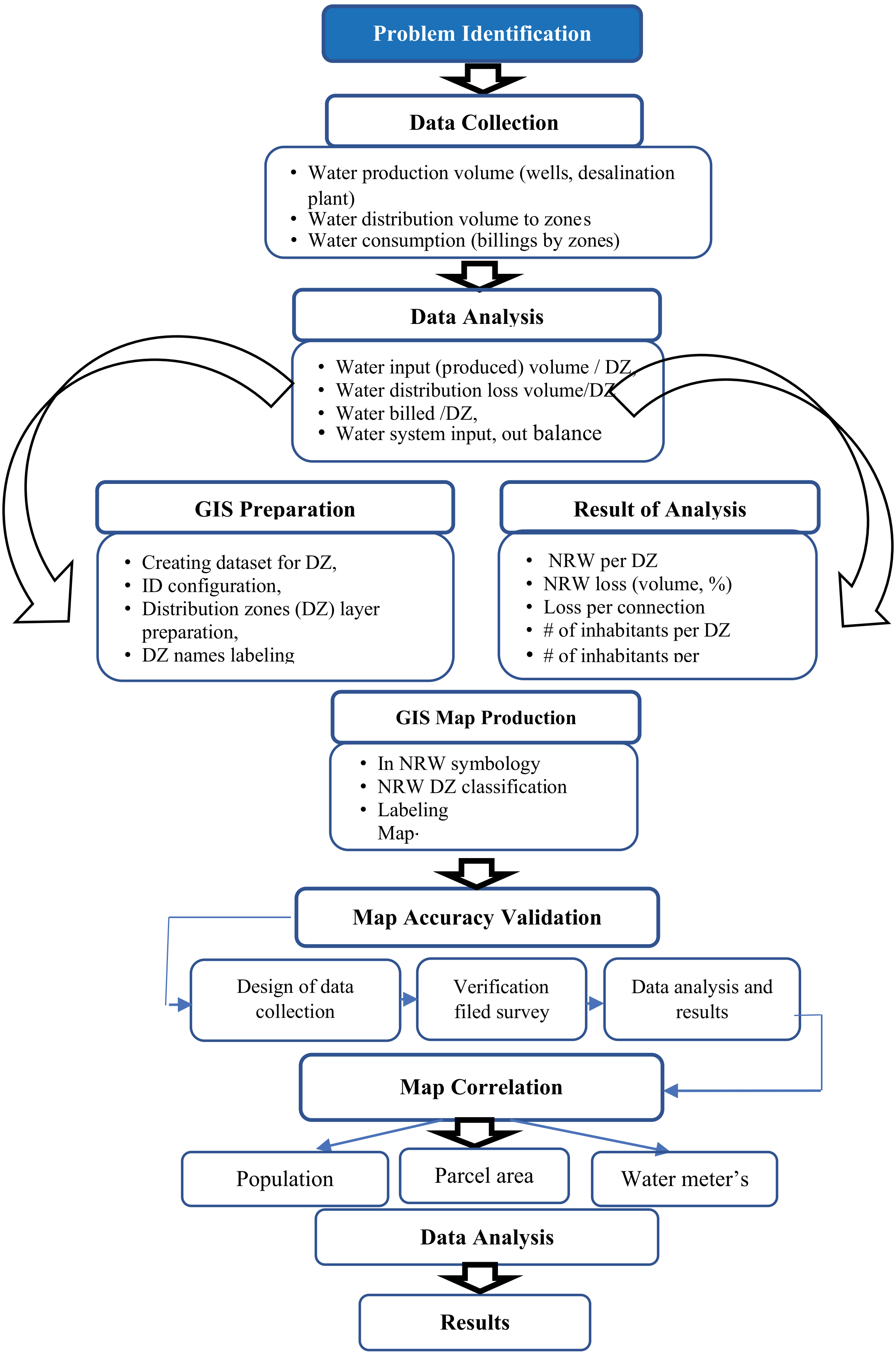

Fig. 6. Flowchart of the methodology for the non-revenue water assessment in the water distribution zones.

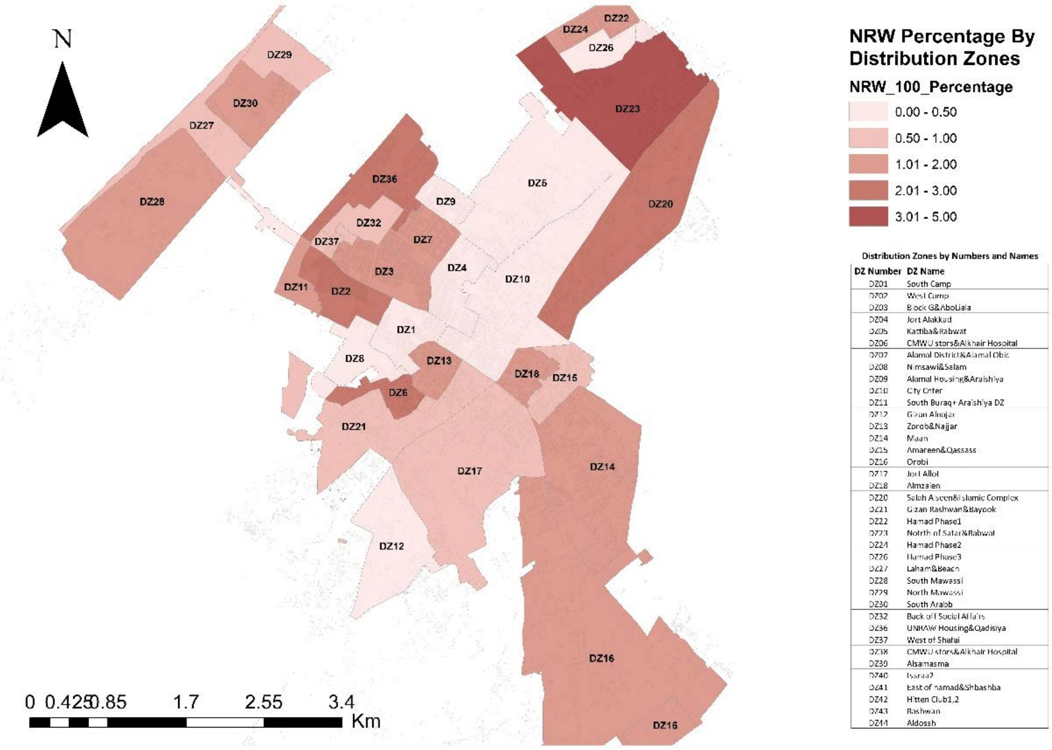

Fig. 7. Final non-revenue water production map for Khan Younis distribution zones.

was selected for data verification in DZ20. Collecting and analyzing reference data is important for assessing the quality of the map data, and thus for deriving bias-corrected area estimates. The reference data collected from the terrain were compared to billed ones aided to generate the NRW map, while the new assessment and data validation gave the real visual interpretation of NRW. Fig. 9 illustrates the results for 74 house connections (two connections were outliers), which were investigated deeply in the terrain to validate the produced NRW map and to identify the accuracy percentage.

It is readily apparent that a majority of 19.19% of the samples go to the houses that has two water sources (one is a municipal water source and the other private well), normally the second one is not connected to the municipal water meter. On the other hand, 18% was for courtyards and agriculture areas, which naturally means the consumption will be higher. These water meters, however are classified as regular water meters, and reading this can be interpreted that water meters malfunctioning is being covered under this category. A notable sample that represents 1% was considered as broken water meters (dysfunctional meters errors). Surprisingly, as presented in the graph with a percent of 11, the result showed reading errors by water reads, the collected reads are greater than what is billed registered reads.

Moreover, the interpretation of the remaining 15% is 5% for the existence of multiple subscriptions in the same building, 8% for vacant houses, and 1% for the collected data of the number of subscription occupancy were less than the collected data, shown in Fig. 10.

The overall map accuracy is about 85%, whereas the remaining 15% is interpreted as errors in data collection during the preliminary data survey.

3.5. Correlation and regression

The correlation and regression of the NRW relation are carried out for: the number of occupying populations, water meter age, and property area to which the house connection belongs.

Fig. 11 shows a linear relationship between the non-revenue water and the number of populations per each house connection, the correlation coefficient (R) was 0.82 for a sample size of 144 house connection. Therefore, there is significant strong positive relationship.

Fig. 12 demonstrates the nonlinear relationship between the non-revenue water per house connection and the house parcel area, the correlation coefficient was 0.0662 for the sample same size of 144 house connection. Therefore, there is no significant relationship.

Fig. 13 illustrates the correlation between the non-revenue water and the age of the water meter per each house connection, where R = 0.269 for a sample size of 144. Thus, there is a significant positive relationship.

This paper introduces a GIS technology that enables the production of NRW maps of water distribution zones. By means of which enables the NRW unit to directly investigate the causes of high loss in the distribution zones and develop plans to treat and reduce water losses. Also, at the house connection level, undertaken GIS plays a vital role in

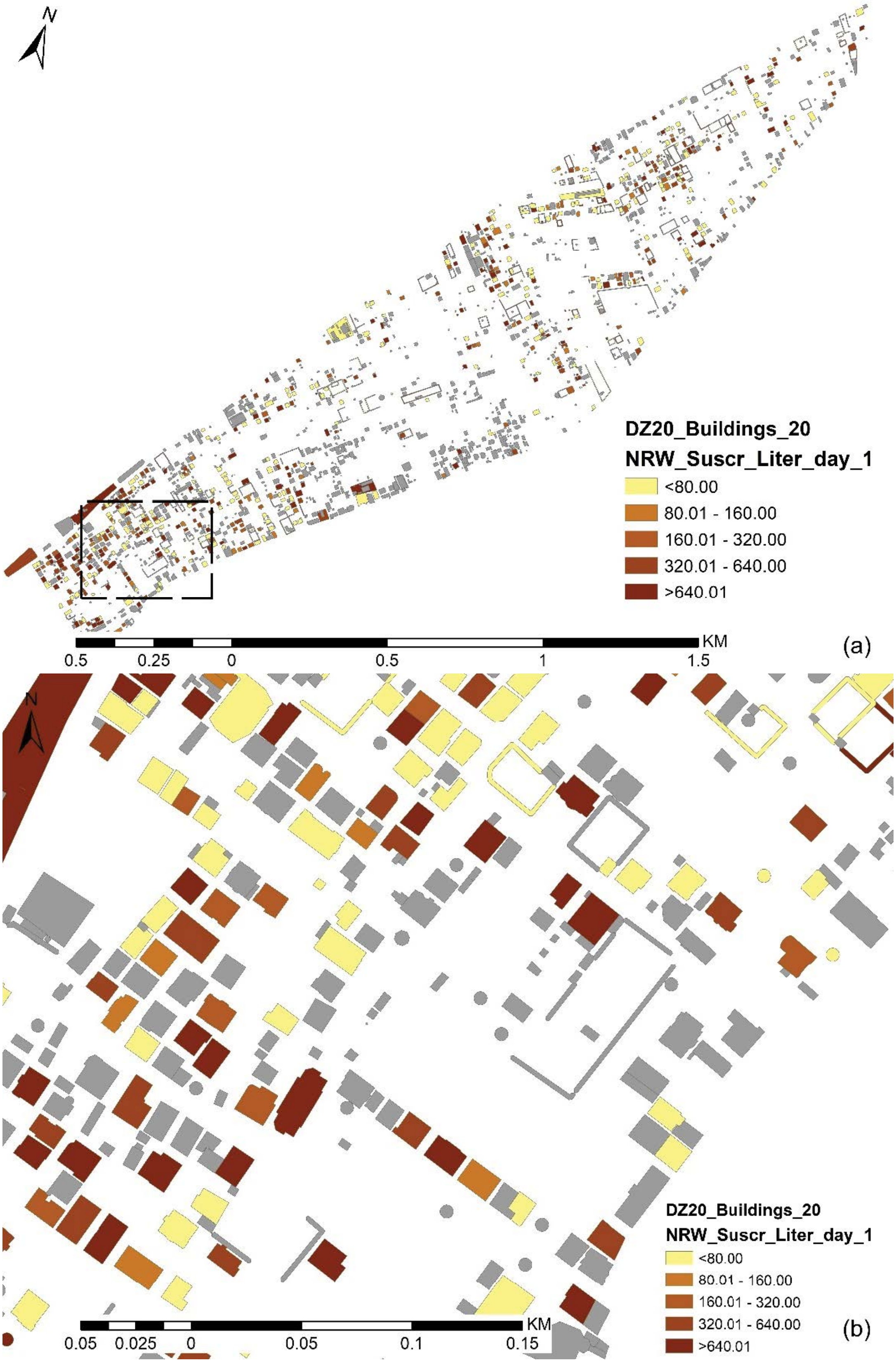

Fig. 8. (a) Generated non-revenue water evaluation map for each house connection in DZ20 and (b) detailed non-revenue water map classification per house connection.

Table 4
Available data for distribution zone DZ20

Item	Quantity
Population (inhabitant)	7,350.00
House connection numbers	696.00
Produced water DZ20 (m^3)	241,144.21
Distributed water DZ20 (m^3)	204,396.00
Production loss DZ20 (m^3)	36,748.21
Billed water DZ20 (m^3)	99,409.00
NRW DZ20 (m^3)	141,735.21
# People/subscriptions	10.56
Produced water/people share (L/cap/d)	115.87
Consumed water/people share (L/cap/d)	56.35

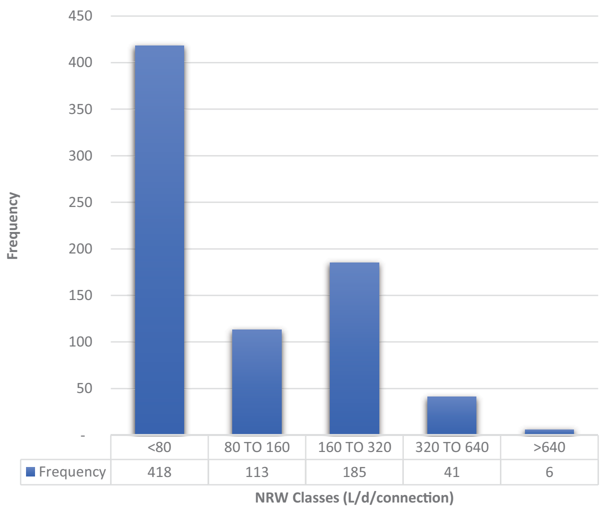

Fig. 9. Non-revenue water classes frequency.

classifying the water loss for each house connection. Field investigation confirmed that the maps produced for NRW per-house connection has, with an overall map accuracy of approximately 85%. The output of GIS technology proves

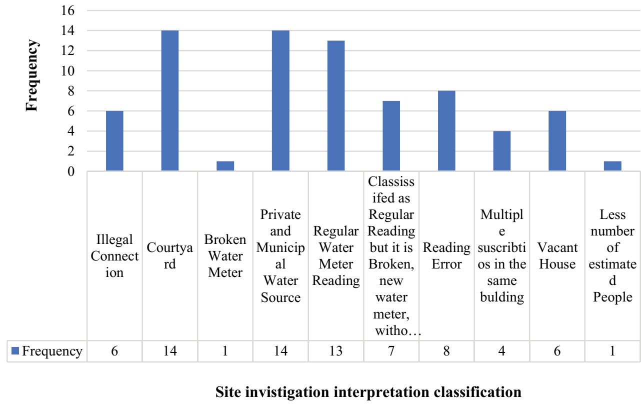

Fig. 10. Non-revenue water per house connection field survey results site interpretation.

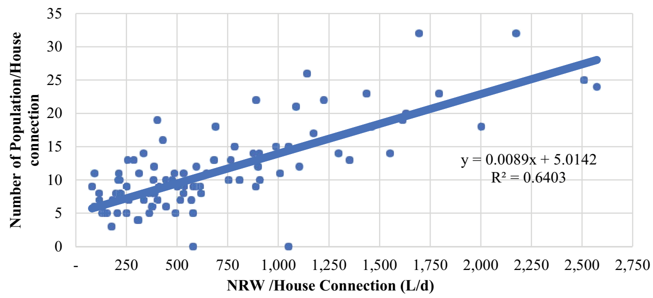

Fig. 11. Correlation between non-revenue water per house connection per day and the number of population by suscribtion.

Table 5
Water balance for DZ20

System input volume (SIV) 241,144 CM (100%)	Authorized consumption (AC) 99,409 CM (41.22%)	Billed authorized consumption (BAC) 99,409 CM (41.22%)	Billed metered (BMC) 99,409 CM (41.2%)	Revenue water (RW) 99,409 CM (41.2%)
			Billed unmetered (BUC) 0 CM (0.00%)	
		Unbilled authorized consumption (UAC) 0 CM (0.00%)	Unbilled metered (UMC) 0 CM (0.00%)	Non-revenue water (NRW) 141,735 CM (58.78%)
			Unbilled unmetered (UUC) 0 CM (0.00%)	
	Total losses (WL) 141,735 CM (58.78%)	Apparent losses (AL) 100,075 CM (41.50%)	Unauthorized consumption (UC) 53,437 CM (22.16%)	
			Metering inaccuracies (MI) 46,638 CM (19.34%)	
		Real losses (RL) 41,660 CM (17.28%)	Leakage and overflows at utility's storage tanks 36,748 CM (15.24%)	
			Leakage on transmission mains/distribution pipes and service connections up to point of customer metering 4,912 CM (2.04%)	

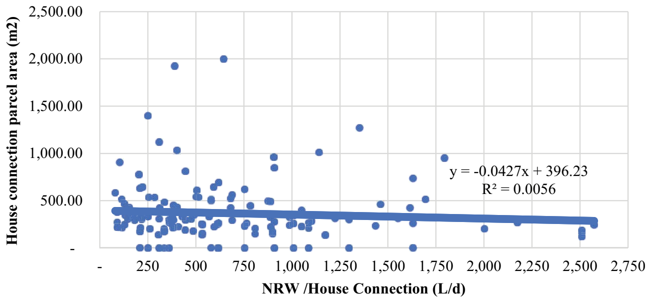

Fig. 12. Correlation between non-revenue water per house connection per day and house connection parcel area.

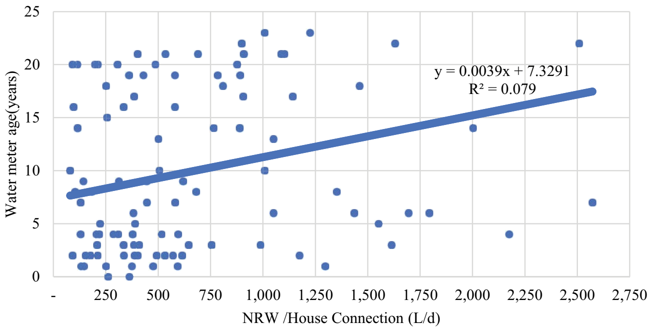

Fig. 13. Correlation between non-revenue water per house connection per day and water meter age.

that GIS is a comprehensive and powerful tool for better management of the NRW.

4. Conclusion

Water service providers without a doubt consider NRW to be one of the biggest problems they face, therefore, water utilities recognize that ITC, and GIS in particular, play a key role in the assessment of water loss reduction and management. This study proposes the adaptation of GIS to estimate NRW losses per distribution area in Khan Younis City. It allows the water supply team to classify the highest loss rate between 3% and 5% as in DZ23, and the lowest loss in the range between 2% to 3% of the total water loss in Khan Younis. In addition, GIS technology came into play, allowing the NRW management team to focus on the frequent losses in each distribution area, with an in-depth analysis of potential water loss causes based on the characteristics of each distribution area.

GIS maps support NRW guidance and prioritization through in-depth investigations of high NRW levels. A special committee was dispatched to the site to investigate. To ensure the accuracy of the data collected, a questionnaire-based field survey was conducted, followed by a desk review of 76 housing connections. However, the study investigations resulted in 85% map accuracy, while the remaining 15% was due to GIS errors in data collection and updates to municipal databases. Therefore, house connectivity level data and GIS maps should be regularly and systematically updated to support the management of NRW reduction. GIS confers a high-performance technology that improves map accuracy by evaluating NRW map results against submitted surveys. However, this study should be replicated in the remaining distribution regions to better understand NRW behavior in each region.

In general, GIS implementation tools have proven to be powerful tools for assessing the NRW status at the connection level of a house, so if you compare the standard consumption per house connection with billing, it directly helps to reduce each house connection's water loss. It details the houses in which the GIS management team will engage and conduct effective site investigations so that the activities resulting from these direct actions have a significant impact on the intervention plans developed for positive problem-solving.

Finally, it was found that there is a strong positive correlation between NRW and the age of the water meter and the number of people connected to the house, while there is a negative correlation between the NRW and the size of the plot to which the respective house is connected. The presented case study shows that the database system and GIS installation is one of the best practices to assess water loss in every house connection.

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Declarations

Conflict of interests

The authors declare that they have no conflict of interest.

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