Water Supply

Effect of unconventional water resources interventions on the management of Gaza coastal aquifer in Palestine

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ABSTRACT

The non-conventional water resources of seawater desalination, wastewater treatment, and stormwater harvesting are promising water resources to enhance the water supply and to cope with the groundwater depletion of the Gaza coastal aquifer (GCA). In total, the current daily operation of the short-term low-volume (STLV) seawater desalination plants produces 36,000 m^3 and, on the large-scale perspective, the seawater desalination capacity is planned to increase from 150,000 to 300,000 m^3 per day by the years 2025 and 2035, respectively. The wastewater treatment and reuse activities are processed through three wastewater treatment plants with a total daily capacity of 130,000 m^3 which is proposed to be increased to a capacity of 235,000 m^3 by the beginning of 2025. Stormwater collecting and harvesting supply the water sector by about 550–820 cubic meters per day. The proposed stochastic and artificial intelligence model that was developed in this study to simulate the interactive conditions between the groundwater and the water intervention plan showed proper performance in terms of (r) = 0.95–0.99 and the root mean square error (RMSE) = 0.09–0.21. The model outputs reveal that the annual groundwater abstractions will reach 192 million cubic meters by 2040 with an annual increasing rate of +3%. By applying the model, the optimum utilization of the unconventional water resources contributes positively to the recovery of the GCA, which is experiencing a decline hot spot in the water level that reaches to −19 m below mean sea level (MSL) and is expected to drop to −28 m MSL by 2040. The impact of unconventional water resources interventions was investigated by simulating the water table trend using stochastic models and artificial neural networks (ANNs) through three scenarios. The first scenario, which addresses the non-intervention status, indicates that the groundwater table will decline by −1.5% in the northern governorates and by −51% in the southern governorates of the Gaza Strip within 2020–2040. The second scenario demonstrates the impact of the existing water interventions that revealed an interim recovery in the groundwater balance until 2025 in which the water consumption tended to increase rapidly. The third scenario illustrates the impact of applying the full water management intervention plan in which the depression cone in the groundwater level will be restored by about +10 m.

Key words: Gaza coastal aquifer, groundwater, modelling, seawater desalination, sustainability, wastewater reuse

HIGHLIGHTS

- The groundwater of GCA is the only available water resource for 2 million people in the Gaza Strip.
- The GCA is experiencing serious depletion that may reach more than 28 m below mean sea level by 2040.
- The water management intervention plans enhance the groundwater balance and adapt the deterioration in the groundwater balance by +10 m over the next 20 years.

GRAPHICAL ABSTRACT
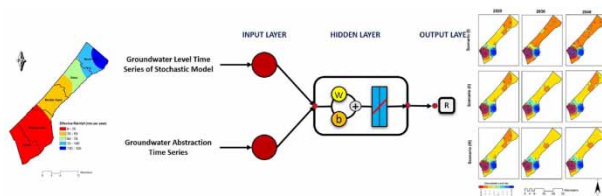
INTRODUCTION

Groundwater is the primary natural water storage for the provision of one-third of the global water requirements (Siebert *et al.* 2010; Famiglietti 2014). Globally, in terms of quantity and quality, groundwater resources face depletion risks impacting the viability of these resources over future decades. The global groundwater extraction in 2020–2021 is projected to be about 960 billion cubic meters based on the increment abstraction rate of 10–11 billion cubic meters per year (Wada *et al.* 2010). Major depletion spots of groundwater are being widely reported in the arid and semi-arid areas of the world due to high population, scarcity of water resources, and periodic drought occurrence. The groundwater resources in the Middle East and North Africa (MENA), the High Plains and California Cantal Valley aquifers in the United States (US), Northwest of India, Northeast of China, Central Yemen, Southern of Spain, and Iran are experiencing hazardous exhaustion by about 243–323 billion cubic meters per year (Fienen & Arshad 2016). The excessive abstraction of groundwater deepens the water table to a level below the mean sea level (MSL), which in turn contributes to the occurrence of seawater intrusion phenomena that adversely affect the groundwater quality (Ye *et al.* 2015; Zekri *et al.* 2017; Hussain *et al.* 2019). In terms of groundwater balance, the aquifer of High Plains in the US shows a water table decline rate of about 0.8 m per year (Dong *et al.* 2019). Moreover, the decline in the groundwater level is reported by 2.8 m per year in the northwestern region of India (Shekhar *et al.* 2020). More specifically, the MENA region is a water resource scarcity area that is experiencing serve implications of climate change that extremely impact the recharge of the groundwater resources (Lattemann & Höpner 2008). The aquifer of Nubian shows a critical declining spot that reaches about 60 m (Gleeson *et al.* 2010). Moreover, the coastal aquifer in the Eastern Mediterranean region of MENA recorded a serious drop in the water table below MSL reaches more than 24 m (Abualtayef *et al.* 2017). Accordingly, integrating the unconventional water resources of seawater desalination, wastewater reuse, and stormwater harvesting into the water cycle is considered a promising alternative to cope with the unsustainable exploitation in the groundwater resources and to remediate the press of drought on the hydrological cycle of the water resources (Alqahtani *et al.* 2021; Golovina & Grebneva 2021). Desalination of seawater is a highly periodized alternative to alleviate the reduction in the traditional water resources and for drought resilience where approximately 32.5 billion cubic meters of the global water demand is supplied by the seawater desalination sources (Rao *et al.* 2018). In China, more than 75 seawater desalination plants have been constructed to provide the water system with about 241 million cubic meters per year of freshwater (Zheng *et al.* 2014). In the US, the annual quantity of water that is supplied through seawater desalination is quantified by 146 million cubic meters (Rao *et al.* 2018). Australia reports high processes in the seawater desalination capacity of about 667 million cubic meters per year (Heihsel *et al.* 2019). The MENA region, especially in the Arabian Gulf, is dependent on the desalinated seawater source to cope with the drought consequences and the water resources scarcity where about 69% of the world seawater desalination capacity is processed in the United Arab Emirates and the Kingdom of Saudi Arabia (Dawoud & Al Mulla 2012). Wastewater recycling and reuse is a globally attractive water source to reduce the deficit in the water budget. In Australia, the agricultural sector is supplied by about 280 million cubic meters of treated wastewater, which represents 14% of the total reclaimed wastewater (Radcliffe & Page 2020). In the US, California, and Florida recycle approximately 1.75 cubic meters per year of wastewater to alleviate the consequences of droughts, saltwater intrusion in coastal aquifers, and the increase in the water demand (Duong & Saphores 2015). In China, wastewater reuse is a key element in the national water resource management plan where the reports indicate that about 14 billion cubic meters of treated wastewater are produced and reused to integrate the water resource management (Chen *et al.* 2015; Lyu *et al.* 2015). The countries of the Arabian Gulf markedly consider wastewater reuse to alleviate the depletion in the groundwater where about 241 wastewater treatment plants are operated to treat nearly 2.8 billion cubic meters per year of wastewater that is mainly used in agricultural irrigation and aquifer recharge (Aleisa & Al-Zubari 2017). In terms of stormwater harvesting, illustrative stormwater capturing is practiced in Los Angeles to enhance the water supply by about 142–239 million cubic meters per year of harvested stormwater (Luthy *et al.* 2019). In Australia, the consequences of the Millennium drought pushed toward utilizing the stormwater in the drought resilience measures where prospective plans were recommended to triple the stormwater harvesting capacity from 20 to 60 million cubic meters per year by 2050 (Kretschmer 2017a, 2017b). In the area of the Gaza Strip, the consequences of prolonged drought and the groundwater over-pumping practices have led to a rapid depletion in the Gaza coastal aquifer (GCA). In response, the water management system adopted mitigation measures or water management interventions to cease the deterioration in the GCA

balance. This study aimed to discover the effect of inserting the new nontraditional water resources alternatives in the water cycle on the replenishment of the GCA during the timeframe of 2020–2040.

THE ECONOMY OF SEAWATER DESALINATION AND WASTEWATER RECYCLING

Water treatment and purification treatment are being continuously improved to meet the increasing trend in the water supply system. In the desalination industry, reverse osmosis (RO) technologies form about 53% of the water desalination processes. Typically, energy consumption to desalinate one cubic meter of seawater costs about 3.5 kWh (Shahzad *et al.* 2017). In Palestine, as shown in Figure 1, the cost of 1 kWh is equivalent to 0.15 USD and based on that estimate, the annual cost of seawater desalination practices is expected to increase from 1.95 million USD over 2020–2025 to about 17.36 million USD over 2035–2040.

On the level of wastewater treatment, 1.7 kWh of power is required to treat a cubic meter of water (Pearce 2008). Therefore, the annual cost of the wastewater treatment process in the Gaza Strip is projected to be 5.7 million USD over 2020–2025 and 10.7 million USD over 2025–2040. The source of energy that is designed for the desalination plants is designed to be supplied by installing photovoltaic cells (peak load) as a source for renewable energy on site. The Palestinian Water Authority (PWA) recommends grid connection with additional energy supplies from neighboring countries or expanding Gaza Power Generation Plant capacity (PWA 2015).

CLIMATE AND WATER STATUS IN THE GAZA STRIP, PALESTINE

The geographical extent of the Gaza Strip, shown in Figure 2, covers an area of 365 km^2 located on the southeastern coast of the Mediterranean Sea. The area is classified as one of the most populated regions in the world with a population of more than 2.1 million (PCBS 2021).

The climate of the Gaza Strip is the Mediterranean climate with an average daily mean temperature ranges between 25.8 °C in summer and 13.4 °C in winter. The average annual rainfall is about 474 mm in the northern regions and about 250 mm in the southern governorates of the Gaza Strip and the risk of extreme and severe drought occurrence is 83% (Al-Najjar *et al.* 2020). The wind storms are recorded in winter with a maximum hourly speed of 18 m/s and on average the wind blows with a speed of 4.2 m/s (PWA 2014). The Gaza Strip is a serious water scarcity area where the only available water resource is the underground water of GCA. The arbitrary groundwater extraction and the impact of chronic drought seriously affect the integrity of the aquifer. The legal and illegal annual abstraction of groundwater is nearly estimated by 180–200 million cubic meters which is four times the sustainable yield of the aquifer (PWA 2014). On a quality basis, the GCA shows an unacceptable level of deterioration where high levels of chloride (above 2,000 mg/L) and nitrate (above 300 mg/L) were detected due to the seawater intrusion phenomena and anthropogenic practices (PWA 2014; El Baba *et al.* 2020). From a legislative view, the Palestinian Water Laws (PWLs), The Palestinian Environmental Law (PEL), and the Palestinian Standard (PS) are the basis for developing and managing the GCA in terms of the preservation and protection of the groundwater from pollution and depletion by developing an integrated groundwater resources management system (PEL 1999; PWL 2002; PS 2003; PWL 2014). The intuitional framework, shown in Figure 3, responsible for the water management system in Palestine is divided into three levels: the policy-making level, the regulatory level, and the operational level.

On the policy-making level, the National Water Council (NWC) is the responsible body for setting the water and environmental policies and standards as well as approving the water management resources development plans. The PWA in turn is the regulator body responsible for executing the water policies and achieving water security by suggesting new water resources for protecting the natural water resources. At the operational level, the Coastal Municipalities Water Utility (CMWU) takes the actions of groundwater extraction and the technical operating of water, wastewater, and stormwater systems. In this regard, the Palestinian governmental water
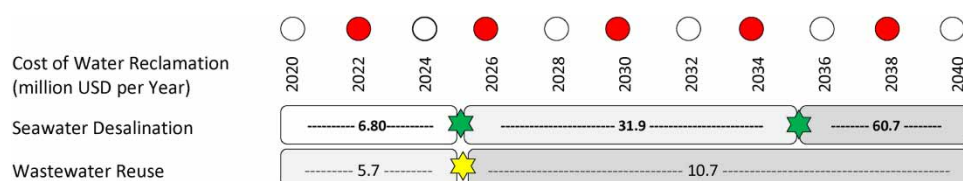
Figure 1 | Economy of seawater desalination and wastewater reuse in the Gaza Strip.
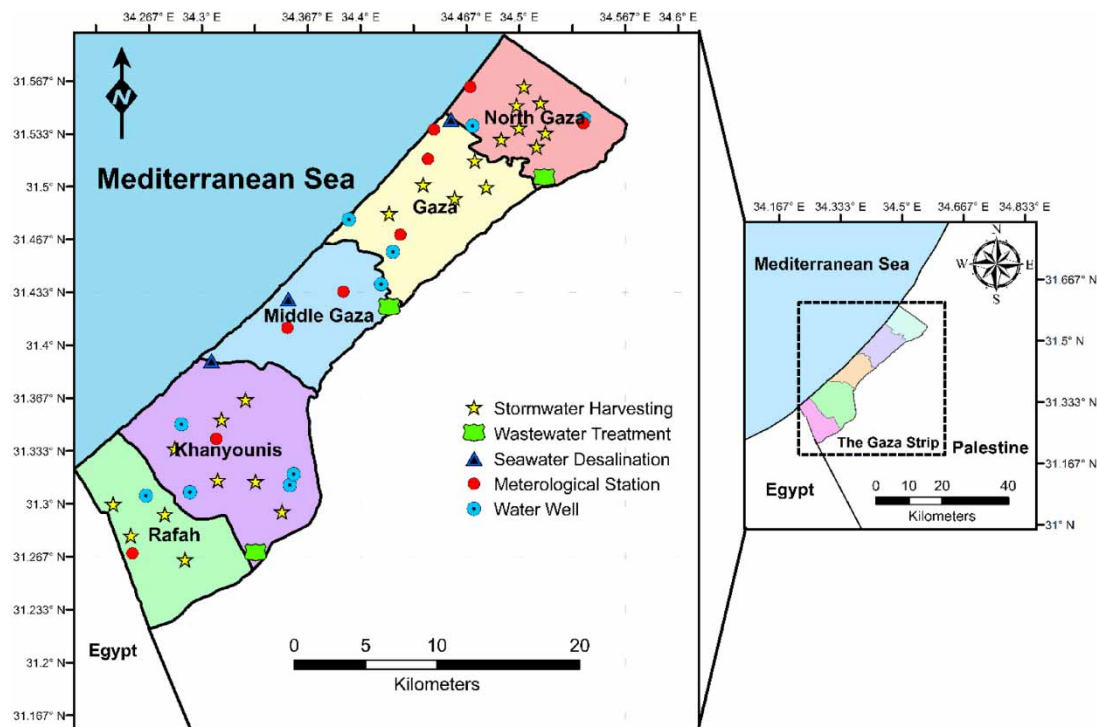
Figure 2 | Geographical location of the Gaza Strip.
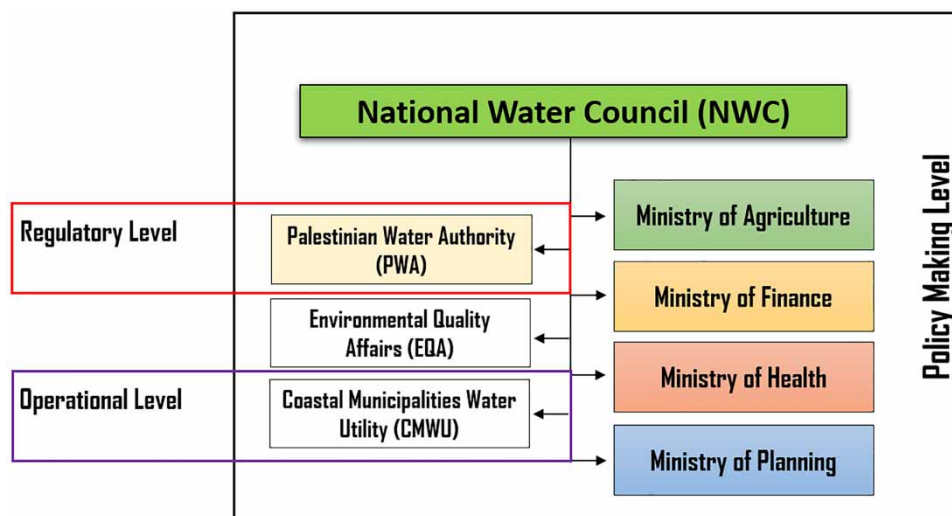
Figure 3 | Institutional groundwater management framework in Palestine.

institutions have initiated mitigation strategies to alleviate the continued depletion in the GCA and to cope with the hazardous of chronic drought implications (MoA 2016). The PWA started taking practical steps towards groundwater sustainability by implementing the plans of Strategy for the Water and Wastewater Sector, the Draft Water Resources Management Strategy, the National Water Policy, Water Sector Strategy Planning Study (WSSPS), the Coastal Aquifer Management Program (CAMP), the National Water Plan (NWP), the Stormwater Infiltration Plan, Gaza Emergency Technical Assistance Program (GETAP) on Water Supply to the Gaza Strip, and the Comparative Study of Water Supply Options for the Gaza Strip (CSO-G) where these plans investigate the possibility of using the nonconventional water supplies such as seawater desalination, wastewater treatment, and stormwater harvesting as a new valuable water resource to balance the water management system in the

Gaza Strip. The applicability of reusing wastewater in Palestine is investigated throughout the adopted guidelines and standards by the PS. The PS strictly prohibits the direct use of treated wastewater for irrigation and groundwater recharge and categorizes the treated wastewater quality, shown in Table 1, into four classes.

The PS restricts the irrigation activities for gardens, playgrounds, and parks to be by a reclaimed wastewater quality of class (A). However, the processes of groundwater replenishment by infiltration through Soil Aquifer Treatment (SAT) and the offshore disposal of about 500 m into the sea should be by wastewater quality of not less than class (C).

MATERIALS AND METHODS

Assessing the impact of adding new water resources to enhance the integrity of the GCA over the timeframe of 2020–2040 is the main goal of this study. The approaches that were followed to meet that goal depend on surveying the available data about the undergoing unconventional water resources in the Gaza Strip and after that simulating the impact of these water interventions on the recovery of the groundwater status of GCA. The

Table 1 | Wastewater quality classifications

Parameter Quality	Unit Type	Class (A) High	Class (B) Good	Class (C) Medium	Class (D) Low
BOD5	mg/L	20	20	40	60
TSS	mg/L	30	30	50	90
Fecal coliform	CFU/100 mL	200	1,000	1,000	1,000
COD	mg/L	50	50	100	150
DO	mg/L	>1	>1	>1	>1
TDS	mg/L	1,200	1,500	1,500	1,500
pH	mg/L	6.00–9.00	6.00–9.00	6.00–9.00	6.00–9.00
Fat, oil and grease	mg/L	5.00	5.00	5.00	5.00
Phenol	mg/L	0.002	0.002	0.002	0.002
Methylene Blue Active Substance (MBAS)	mg/L	15	15	15	25
NO3-N	mg/L	20	20	30	40
NH4-N	mg/L	5	5	10	15
Total-N	mg/L	30	30	45	60
Cl	mg/L	400	400	400	400
SO4	mg/L	300	300	300	300
Na	mg/L	200	200	200	200
Mg	mg/L	60	60	60	60
Ca	mg/L	300	300	300	300
SAR	mg/L	5.83	5.83	5.83	5.83
PO4-P	mg/L	30	30	30	30
Al; Fe	mg/L	5	5	5	5
As; Cr	mg/L	0.1	0.1	0.1	0.1
Cu, Mn, Ni, Pb	mg/L	0.2	0.2	0.2	0.2
Se	mg/L	0.02	0.02	0.02	0.02
Cd	mg/L	0.01	0.01	0.01	0.01
Zn	mg/L	2	2	2	2
CN; Co	mg/L	0.05	0.05	0.05	0.05
Hg	mg/L	0.001	0.001	0.001	0.001
B	mg/L	0.7	0.7	0.7	0.7
E. coli	CFU/100 mL	100	1,000	1,000	1,000
Nematodes	Eggs/L	≤1	≤1	≤1	≤1

new nontraditional water alternatives that are managed in the Gaza Strip are reported by seawater desalination, wastewater reuse, stormwater reclamation, and purchased water from neighboring countries. At this time, seawater desalination processes are practiced through three short-term low-volume (STLV) desalination plants to supply 13 million cubic meters of desalinated water. The regional STLV seawater desalination plant that was constructed on the land of the large-scale Gaza Central seawater desalination plant produces daily 20,000 cubic meters of freshwater that is pumped through the water networks of the southern governorates of Khanyounis and Rafah. In the Middle Governorate, Deir Al-Balah STLV desalinates 6,000 cubic meters per day for potable uses and domestic supplies. In the governorate of Gaza, the third STLV seawater desalination plant is daily operated with a capacity of 10,000 m^3. The time schedules indicate that the large-scale Gaza Central seawater desalination plant is planned to be operated in two phases. The desalination capacity of the first phase that is going to be run by the year 2025 to produce nearly 55 million cubic meters per year while the second phase is planned to be operated by 2035 to lift the annual capacity to 110 million cubic meters. In terms of wastewater reuse, three strategic wastewater treatment plants of Khanyounis, AlBurij, and North Gaza Emergency Sewage Treatment (NGEST) are operated in the Gaza Strip to reclaim 46.8 million cubic meters per year in 2020–2025. The treatment capacity is planned to increase to 85.8 million cubic meters per year by the beginning of 2026. In addition, the water management system in the Gaza Strip exploits stormwater harvesting to balance the water budget by collecting rainfall for the processes of irrigation and groundwater recharge through 22 basins that cover an area of 0.45 km^2. In terms of climate changes, the effective precipitation projected, shown in Figure 4, up to 2040 by Al-Najjar et al. (2020) reveals that the total amount that is expected to be harvested through 2020–2037 is 0.03 million cubic meters per year while an amount of 0.02 million cubic meters per year is going to be collected in 2038–2040.

The political situation in the study area is the main drive that governs the implementation of water management plans on time. However, all dates are postponed and the water intervention practices are still operated in a small-scale manner. In total, the available additional water quantities from the unconventional resources are approximately 70 million cubic meters in 2020 and it is planned to triple to around 212 million cubic meters by the beginning of 2035. The new water resources are designated to fill the gaps in the water supplies for domestic, industrial, and agricultural purposes in the Gaza Strip. Consequently, three scenarios were identified in this study to evaluate the impact of the unconventional water resources interventions on the GCA. The three scenarios were specified and designed based on the scheduled operation of the water projects.
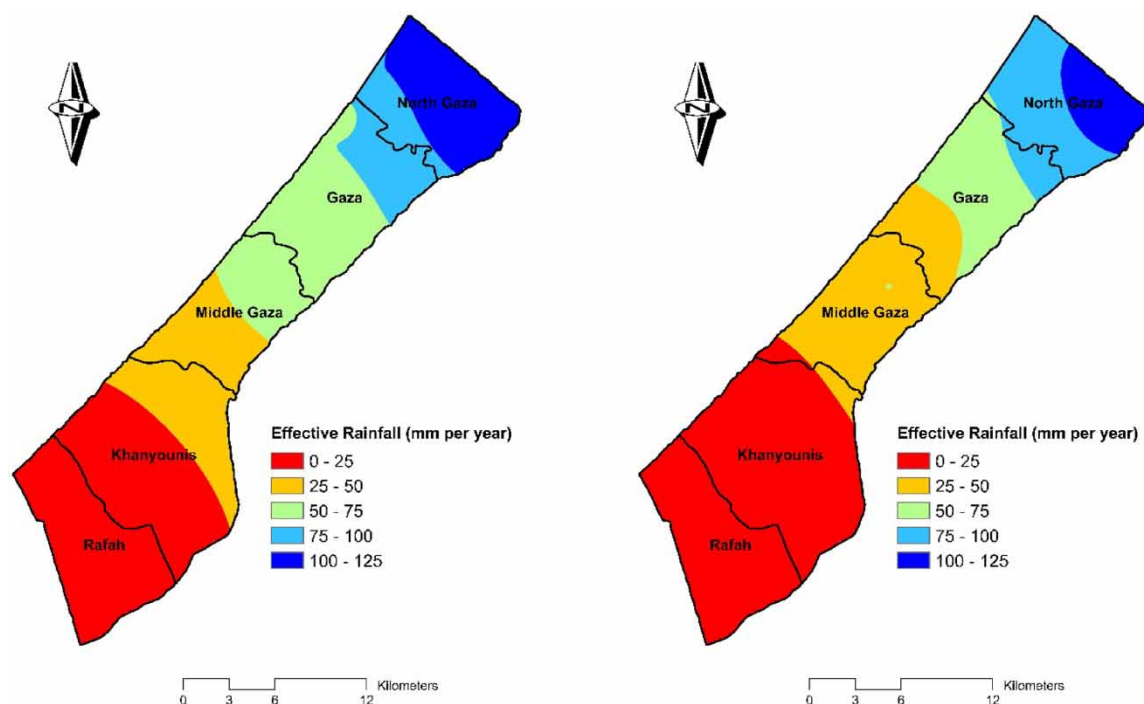
Figure 4 | Projection of effective rainfall for (a) 2020–2030, (b) 2031–2040 (based on Al-Najjar et al. 2020).

- **Scenario (I):** No water intervention and addressing the general trend of the groundwater level.
- **Scenario (II):** Proceeding with the existing applied water intervention plan, Figure 5, and representing the groundwater level after adding water resources from the STLV projects as described in the following conceptual timeframe.
- **Scenario (III):** Applying the full water intervention plan, Figure 6, and representing the groundwater level after adding water resources from the large-scale projects as described in the following conceptual timeframe.

To meet these objectives, the monthly groundwater table level and the monthly groundwater abstraction data were collected from the PWA for 10 municipal groundwater wells, as shown in Figure 2, distributed governmentally over the area of the Gaza Strip. The selected groundwater wells have representative records of reading over the period of 1974–2020 and exhibit significant abstraction rates among other minor groundwater wells. To provide a projection for the trend of groundwater level and groundwater abstraction up to 2040, the stochastic seasonal autoregressive integrated moving average (ARIMA) model was calibrated and run for each of the groundwater level time series as well as for the time series of groundwater abstraction. Based on the indications of the Autocorrelation Function (ACF) and the Partial Autocorrelation Function (PACF), an example is shown in Figure 7, the inherence in the time series data revealed that the stochastic model of $(1,1,1)$ $(2,1,2)_{12}$ and $(2,1,2)$ $(2,1,2)_{12}$ are the threshold models to represent the time series of groundwater level and groundwater abstraction rate, respectively. However, to minimize the misleading and redundancy in the models, the stochastic model structure of $(2,1,2)$ $(2,1,2)_{12}$ was adopted in this study to simulate both the groundwater level and groundwater abstraction time series. The mathematical structure of the stochastic ARIMA model is generalized in the following equation:

$$\left[1 - \sum_{i=1}^{p} \emptyset_i B^i\right] . \left[1 - \sum_{i=1}^{P} \emptyset_{is} B^{i \times s}\right] . (1 - B)^d . (1 - B^s)^D x_t = \left[1 + \sum_{i=1}^{q} \theta_i B^i\right] . \left[1 + \sum_{i=1}^{Q} \theta_{is} B^{i \times s}\right] . \varepsilon_t \tag{1}$$

where;

ϕ_i: the ith autoregressive (AR) parameters.
Φ_{is}: the ith seasonal autoregressive (AR) parameters.
Θ_i: the ith moving average (MA) parameters.
Θ_{is}: the ith seasonal moving average (MA) parameters.
B: the backshift operator.
d: the differencing.
D: the seasonal differencing.
S: the seasonality period.
ε_t: a noise random component.

The simulation outputs of the stochastic models, shown in Figure 8, reveal the acceptable level of performance where the accuracy is r = 0.94–0.99 and the RMSE is less than 0.2 for groundwater level time series and less than 50,000 for the groundwater abstraction time series.
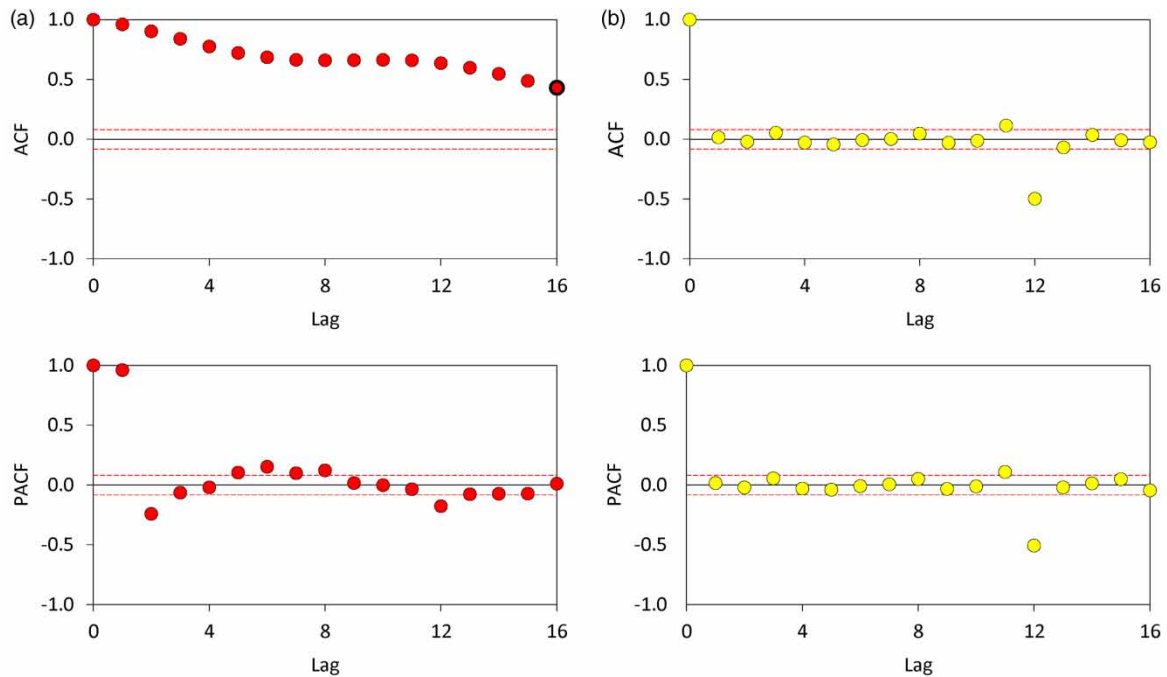
The non-seasonal and seasonal parameters of the proposed stochastic models are summarized in Table 2.
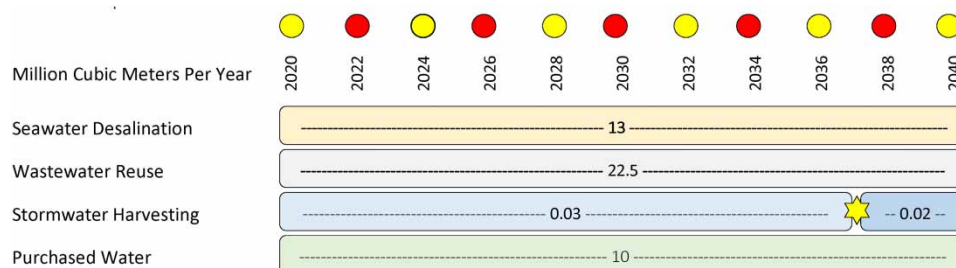
Figure 5 | Progress of scenario (II).
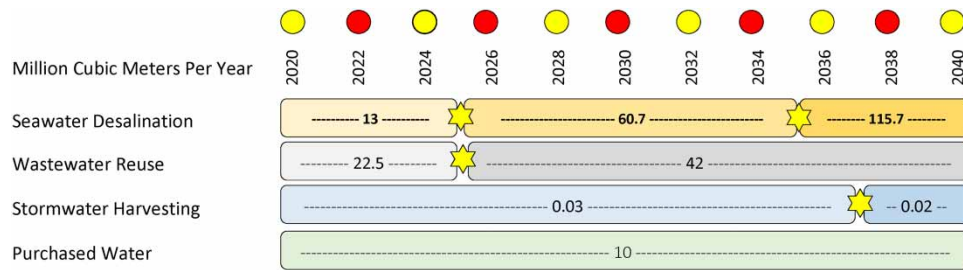
Figure 6 | Progress of scenario (III).

Figure 7 | Autocorrelation function (ACF) and partial autocorrelation function (PACF) analysis for (a) non-differencing, (b) first-order differencing.

The inherent nonlinearity that governs the relationship between the groundwater level and the groundwater abstraction rate could be properly described by the Artificial Neural Networks (ANNs) model.

The stochastic time series models efficiently simulate the trend of groundwater level time series and the groundwater abstraction time series and future projections up to 2040 were forecast. However, to establish a representative relationship between the groundwater level and groundwater abstraction, an ANNs of one hidden layer with 25 neurons was identified as shown in Figure 9. The model was calibrated based on the monthly historical data gathered from the stochastic models over 46 years. The model shows an acceptable level of accuracy where the correlation coefficient (r) = 0.95–0.99 and the root mean square error (RMSE) = 0.09–0.21.

RESULTS AND DISCUSSION

The area of the Gaza Strip is experiencing rapid changes in the groundwater balance of GCA due to the climate change effects and the over-pumping activities. The ambiguous condition of the hydrological time series data prevents the stockholders from monitoring the ongoing and future status of the GCA. This study investigates the conditions of the GCA under three different water intervention scenarios. The three scenarios were examined by employing the stochastic models and ANNs to simulate and the projections of the groundwater level and groundwater abstraction time series over 2020–2040 as shown in Figure 10.

The consumption of groundwater is expected to increase sharply in terms of population growth and terms of lack of alternative water supplies. The model expectations confirm that the extracted groundwater from the GCA
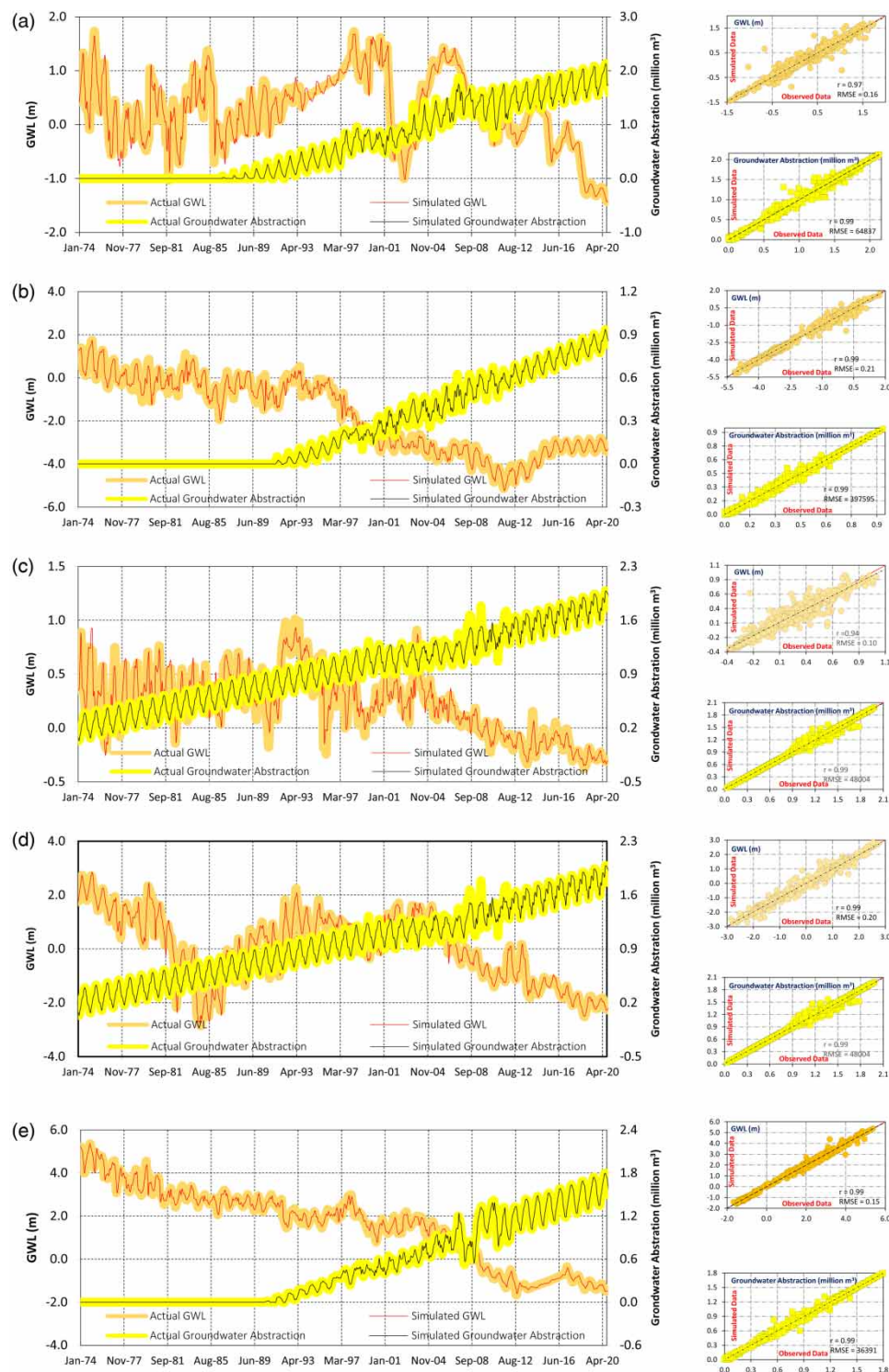
Figure 8 | Groundwater level and abstraction for: (a) C/48, (b) E/45, (c) G/24B, (d) F/68B, (e) S/15, (f) L/86, (g) L/66, (h) N/12, (i) N/16, (j) P/48H. (*continued*.)

will rise from 124 million cubic meters in 2020 to about 191 million cubic meters in 2040 with an annual increasing rate of about +3%. The stochastic time series models indicate that the groundwater balance of the GCA exposes serious exhaustion where the groundwater level severely decreases below MSL. The groundwater simulation findings of the stochastic-ANN model for scenario (I) illustrate that the drop in the groundwater level is between −0.38 and −18.49 m below MSL in 2020 and between −1.13 and −27.77 m below MSL in 2040. Geographically, the southern governorates of the Gaza Strip, especially in Rafah, show more deficit in the
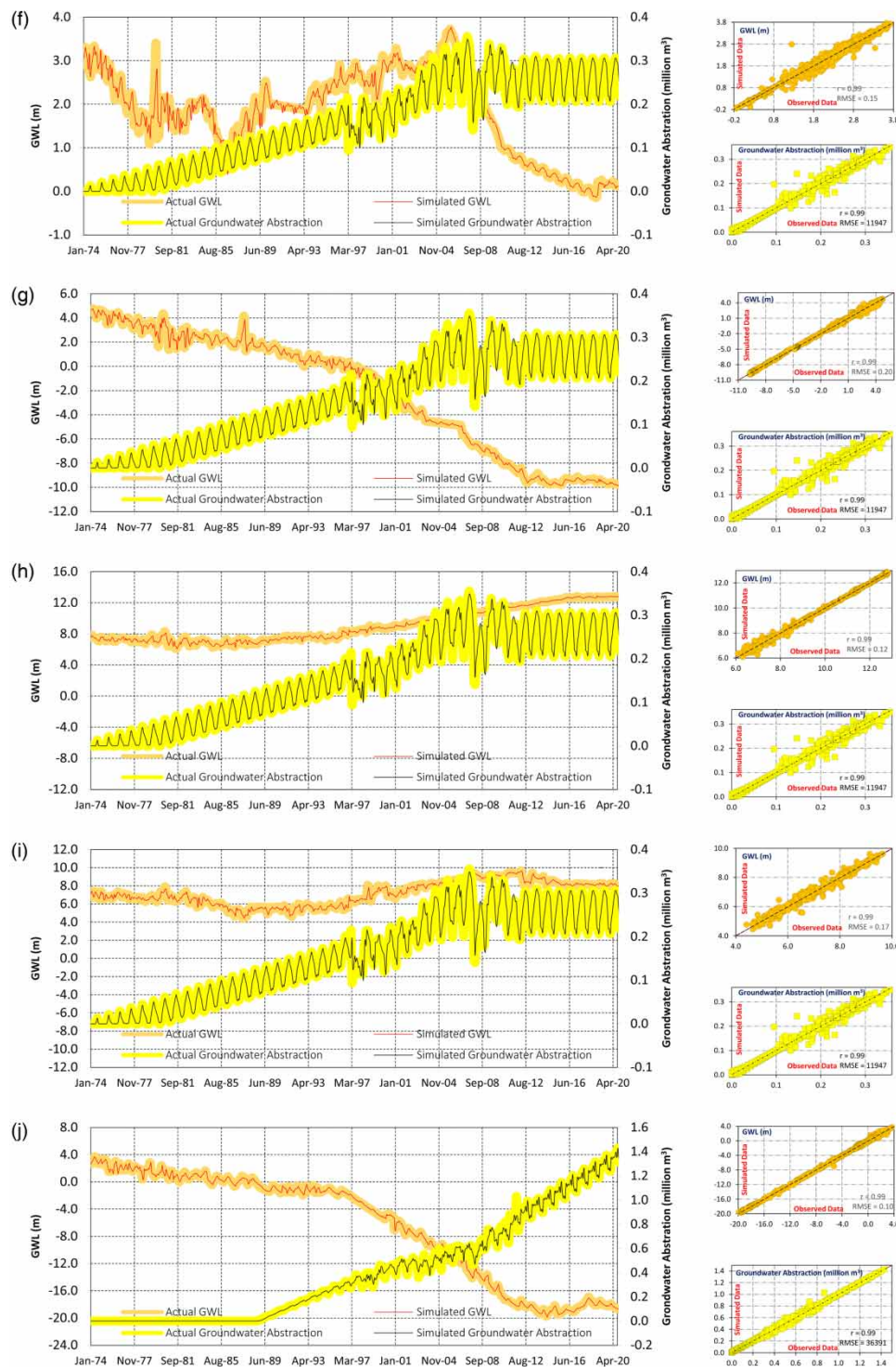
Figure 8 | Continued.

groundwater balance than other locations where the decline in the groundwater will reach −27.77 m below MSL in 2040. The southern part of the Gaza Strip demonstrates the most populated area in the Gaza Strip where the originated cone depression will have a diameter that reaches 4–5 km in 2040. However, the water management intervention plan of scenario (II) will enhance the recovery of GCA within the coming 10 years to cope with the increase in water scarcity due to population growth and drought consequences. Successively, doubling the quantities of unconventional water resources after the year 2030 as described in scenario (III) will cease the expected

Table 2 | The models autoregressive and moving average parameters

|		Non-seasonal parameters				Seasonal parameters			
Well ID	Model	Φ_1	Φ_2	Θ_1	Θ_2	Φ_{1s}	Φ_{2s}	Θ_{1s}	Θ_{2s}
C/48	GWL	−0.6086	0.0519	0.6995	−0.0105	−0.3127	0.0287	−0.6011	−0.2918
	Abstraction	0.3770	0.2508	−0.9049	−0.0365	0.2732	−0.2188	−0.6846	0.0147
E/45	GWL	1.5408	−0.6746	−1.6804	0.7672	0.4515	−0.0069	−1.3463	0.4329
	Abstraction	−0.4377	0.2639	−0.1224	−0.6543	−0.4001	0.1567	−0.2154	−0.5125
G/24B	GWL	−0.1347	0.8226	0.0146	−0.9854	−0.7871	−0.0943	−0.0118	−0.6735
	Abstraction	0.5365	0.1454	−1.3302	0.3512	−0.2613	0.0235	−0.4876	−0.2415
F/68B	GWL	0.9996	−0.2123	−0.7595	−0.0865	−0.5102	0.0456	−0.3656	−0.5739
	Abstraction	0.5365	0.1454	−1.3302	0.3512	−0.2613	0.0235	−0.4876	−0.2415
S/15	GWL	1.6517	−0.8720	−1.6020	0.7482	−0.7293	−0.0960	−0.3185	−0.5084
	Abstraction	−0.1573	−0.8809	0.0588	0.8992	−0.5833	−0.2878	−0.3804	−0.0787
L/86	GWL	−0.3642	0.4740	0.1348	−0.5975	−0.4646	0.0483	−0.3823	−0.5083
	Abstraction	−0.1422	0.6620	−0.0709	−0.8377	−0.4698	−0.1198	−0.3720	−0.2710
L/66	GWL	0.7182	−0.1721	−0.5816	−0.1946	−0.7044	0.0249	−0.3047	−0.6952
	Abstraction	−0.1422	0.6620	−0.0709	−0.8377	−0.4698	−0.1198	−0.3720	−0.2710
N/12	GWL	0.6061	0.1184	−0.1354	−0.4555	0.0341	0.0084	−1.0328	0.0858
	Abstraction	−0.1422	0.6620	−0.0709	−0.8377	−0.4698	−0.1198	−0.3720	−0.2710
N/16	GWL	0.7176	−0.1869	−0.6264	−0.0977	0.0028	0.0857	−1.0636	0.0636
	Abstraction	−0.1422	0.6620	−0.0709	−0.8377	−0.4698	−0.1198	−0.3720	−0.2710
P/48A	GWL	0.9044	−0.3775	−0.7011	0.1156	−0.8874	−0.0253	−0.0225	−0.9043
	Abstraction	0.5022	−0.3413	−1.1147	0.4824	0.5137	−0.2139	−1.1417	0.3808
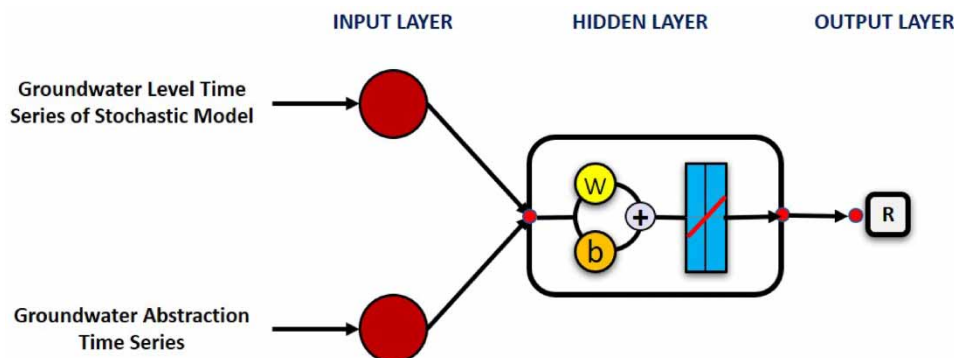
Figure 9 | Configuration of ANN.

drop in the groundwater level in comparison with scenario (I) by 47% in the critical area of southern governorates of the Gaza Strip. In comparison with the results of the numerical model that was calibrated and run by Abualtayef *et al.* (2017) using the Modflow platform on similar water interventions but with slightly different assumptions, the groundwater condition under the existing practices scenario (II) refers to a depression that will reach −24 m MSL by 2040 in the southern area of the Gaza Strip and shows a change of +4 m compared with scenario (I). However, under similar conditions of scenario (III), the restoration in the groundwater will be by +10 m and the water table level will be −18 m MSL by 2040. The findings of this study are compatible with the numerical model results.

CONCLUSION

The data-driven stochastic and artificial intelligence models are robust and accurate tools to simulate the interconnective relationships between the different physical parameters and groundwater tables to enable water
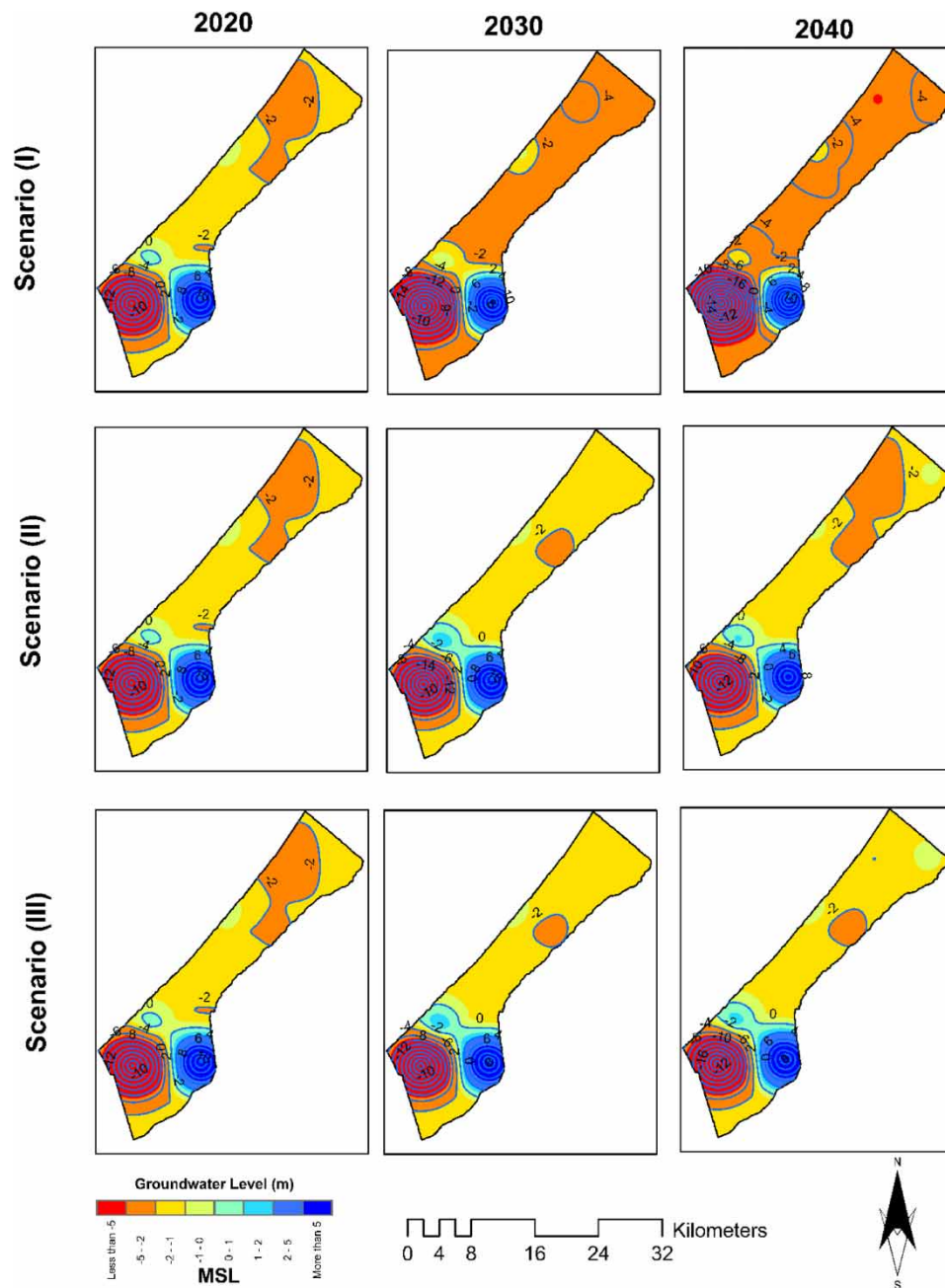
Figure 10 | Groundwater levels of the GCA under three different scenarios.

managers from assessing the efficiency of water management plans. The adopted water intervention management plan for the sustainable recovery of GCA by PWA that was investigated over the timeframe of 2020–2040 indicates that the groundwater condition exhibits a restoration manner in response to the taken mitigation measures throughout the water management plans. Specifically, the current condition of the groundwater level is reported to undergo a serious depression of about −18.5 m below MSL which is expected to continue to decline to reach −28 m below MSL by 2040. The intervention of seawater desalination introduces considerable contribution in ceasing the depletion in the groundwater if the contribution rate will be lifted from about 28% in 2020 to nearly 54% by 2040. Furthermore, the wastewater reuse forms about 49% of the total unconventional water resources with a capacity of 22.5 million cubic meters per year and is projected to be doubled by 2040. The implications of climate change and drought in the Gaza Strip make the practicing of stormwater harvesting inefficient because of the low precipitation levels. In general, the unconventional water resources intervention plan under scenario (II) reveals significant restoration in the status of the GCA within the 2020–2030 but

beyond this period the new water resources become insufficient to supply the water system needs and therefore the abstraction from the groundwater will be practiced again. However, the water intervention under scenario (III) will continue supplying the water requirements without the need to extract water from the groundwater wells. In conclusion, the emergence of the new water resources and stopping groundwater pumping will enhance the GCA balance and will cease the deterioration in the water table for which the expectations show that the groundwater level will be restored by 47% in the case of scenario (III) compared with scenario (I).

DATA AVAILABILITY STATEMENT

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

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