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Water Scarcity Analysis, Assessment and Alleviation: New Approach for Arid Environment

Ahmad Danboos [1,]*, Othman Jaafar [2] and Ahmed El-Shafie [3]

[1] *Department of Civil & Structural Engineering Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia.*

[2] *Department of Civil & Structural Engineering Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia.*

[3] *Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Jalan Universiti, Wilayah Persekutuan Kuala Lumpur, Malaysia.*

**Correspondence Author*

[1,] Orcid: 0000-0002-3251-4642*

Abstract

Iraq is one of the riparian countries in the Tigris-Euphrates river basin in the Middle East. This region currently faces water shortage issues because of increased demand and the mounting effects of climate change. Iraq relies heavily on water from the Tigris and Euphrates Rivers; indeed, Iraq was considered rich in water resources until the 1970s, when water scarcity problems began to arise. The water shortage problem is expected to become more serious in the near future. The primary objective of this review is to discover stringent, practical and quick measures that can be implemented to overcome Iraq's water resource problems. The Iraqi authorities must craft a strategic water management vision (including cooperation and coordination), improve the agriculture and sanitation sectors, conduct research and development, and initiate a public awareness program. This paper discusses both current conditions and future expectations to overcome Iraq's water scarcity problem.

Keywords: water resources management, water scarcity in Iraq, Tigris and Euphrates Rivers

INTRODUCTION

Across the Middle East, water shortage became an important issue in the previous century due to rapid climate change and increasing water demand (Issa et al., 2014). From the beginning of human civilization, water has played a prominent role. The first water resource projects began in 5500 BC in the Tigris-Euphrates river system in Mesopotamia. The Sumerians and Babylonians used the water in the Euphrates River to irrigate their cities and fields employing a canal system. For the first time in this long history, Iraq faces a severe water shortage problem (Janabi, 2013) . Water scarcity has become a worldwide occurrence. However, the water crisis in the Middle East region is not only an environmental concern but also a serious problem for political stability (Mulholland, 2011). Rapid annual population growth along with increasing water consumption per capita in southern Iraq have driven water levels below the gauging stations. The water discharge used in the water consumption calculation considers evaporation losses, infiltration, and water used for different purposes (Issa et al., 2014).

Two major problems currently face the river environment: the diversion of massive channels of water and the wastewater discharge of quality water. Additionally, there is a vicious circle between water quality and water quantity (S and Environmental Protection Administration, 2006) . Today, with increasing hydropower construction and exploitation of water resources, water problems have become significant in the discussion and research of the ecological water demand (EWD). EWD is the water demand that meets the requirements of wildlife, fish, entertainment, and other aesthetic values (Ge et al., 2010). In recent years, water scarcity has been considered one of the most critical issues worldwide (Ruijun Zhang et al., 2011) . The following chapter explains water scarcity in Iraq. Water inequality and water availability are issues that have arisen due to the increased attention to water resources.

WATER SCARCITY

The majority of people in Iraq live in either a dry or semi-dry climate, which is defined as having less than 150 mm of rain per year at a high rate of vaporization. Currently, available water in Iraq is estimated at approximately 1435 m^3 per person per year. The water levels in the lakes, reservoirs and rivers of Iraq are decreasing to critical levels; managing minimal aquifers is affecting the quality and quantity of groundwater (IAU, 2012). Iraq depends on exports from nearby countries for more than half of its water. This high dependence makes Iraq vulnerable to climate change and project storage in Syria and Turkey.

The main source of water in Iraq consists of the Tigris and Euphrates Rivers, which have fallen to third standard capacity in recent years (IAU, 2012).. The water scarcity problem is exacerbated by poor water management of the Tigris-Euphrates river basin (Abumoghli, 2015). Water is wasted through poor irrigation practices such as uncovered canals, flood irrigation, evaporation and unlined channels for the reservoirs. Various pesticides and chemical fertilizers are used in farming that affect the water quality of the groundwater and rivers, as shown in Figure 1 and 2. Both domestic and industrial waste in the rivers have increased river pollution, particularly downstream, which may lead to frustration and dissatisfaction, which could lead to conflict (Al-Ansari, 2016).

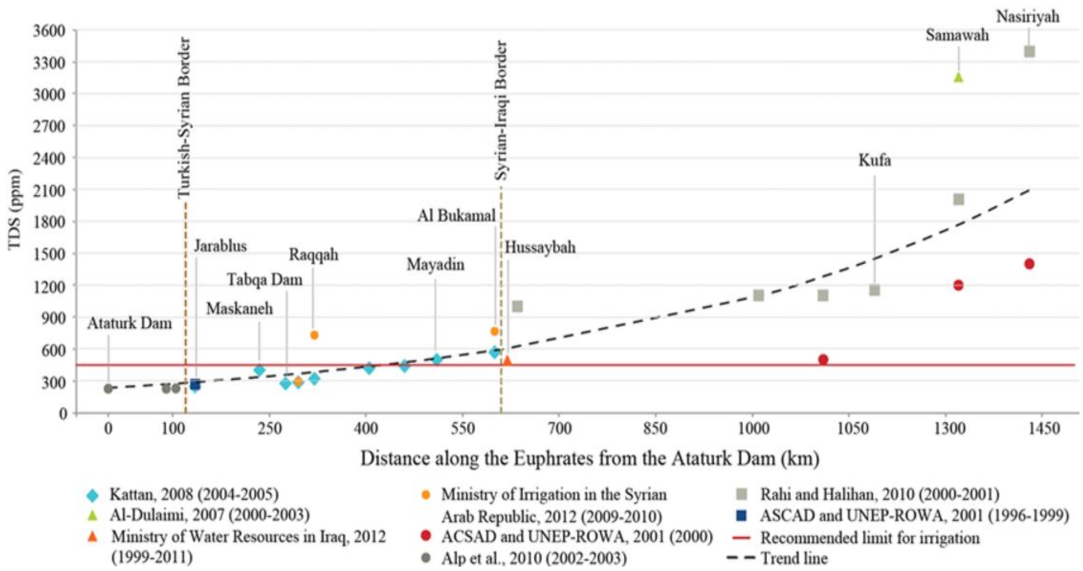

Figure 1: Salinity variation along the Euphrates River since 1996(Abumoghli, 2015).

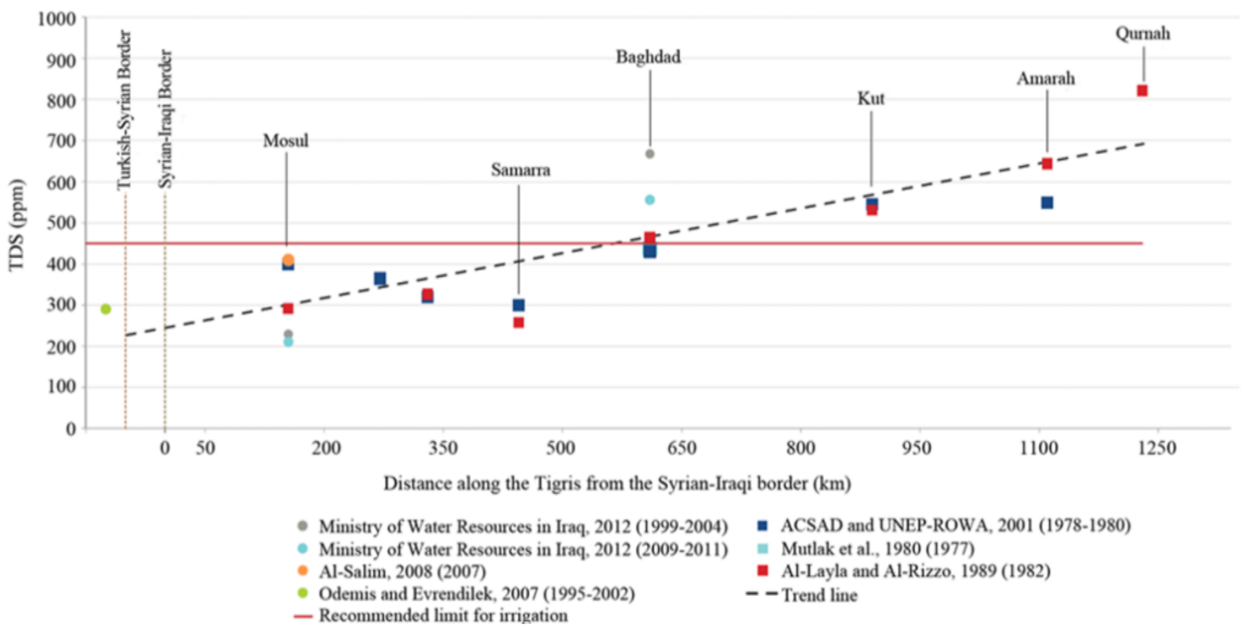

Figure 2: Salinity variation along the Tigris River before 1983 and after 1995 (Abumoghli, 2015).

WATER RESOURCES

Iraq covers approximately 433,970 square kilometers and has a population of approximately 35 million people **(**United Nations WPP, 2015 Revision). Iraq relies heavily on the water resources of the Tigris and Euphrates Rivers and currently faces a wide range of water shortage problems due to both internal and external factors. The external factors include global warming and the water resources policies of neighboring countries, whereas the internal factors include the mismanagement of water resources. The Iraq water demand and supply are predicted to be approximately 66.8 and 43 BCM in 2015 and are expected to reach 77 and 17.6 BCM in 2025, respectively (Al-Ansari et al., 2015). In summer, water demand is the highest when the supply is the lowest. Therefore, water structures capture water before it is consumed to store the excess discharge in the wet season so that this water can be used in the dry season. In addition, Iraq has developed a water system over time (Janabi, 2013).

The Tigris and Euphrates Rivers are the two greatest and most important rivers in western Asia (Issa et al., 2014); Figure 3 shows these rivers and their basin. These rivers start in Turkey approximately 30 km apart. The basins have deep gorges and high mountains with a humid and cold climate. The flow of the two rivers is drained poorly every day. The upper basin streams are categorized as the high plateaus of Syria, the mountain gorges of Anatolia and the rocks in Iraq. The climate of the area is similar to that of the Mediterranean, excluding the differences due to the mountainous regions in Turkey. The climate in these mountainous regions features a cold, rainy winter, a hot, dry summer, and occasional snowfall. Precipitation in the Mesopotamian basin occurs between October and May.

Figure 3: The Tigris-Euphrates river basin(Yalcinkaya, 2010).

The annual rainfall of the Tigris-Euphrates river basin varies from 100 to 1000 mm (Al-Ansari and Knutsson, 2011) . The average monthly water temperature ranges from 6˚C in January to 34˚C in July, and the temperature decreases further north (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). The discharge flow is approximately ten times greater during the flood season, which occurs during winter and spring due to rain and snow melt, than during the dry periods of summer and early autumn. Tables 1 and 2 show the river lengths and distribution of the basin area.

Table 1: River lengths in the basin by country (in km).

River	Turkey		Syria		Iraq		Iran		Total
Euphrates	1230	41%	710	24%	1060	35%	0	0%	3000
Tigris	400	22%	44	2%	1418	76%	0	0%	1862

Source: (Yalcinkaya, 2010)

Table 2: Distribution of the basin area by country (in km^2).

River	Turkey		Syria		Iraq		Iran		Total
Euphrates	124320	28%	75480	17%	177600	40%	0	0	444000
Tigris	46512	12%	776	0.20%	209304	54%	131784	34%	387600
Total Basin	170832	22%	76256	10%	386904	51%	131784	17%	765600

Source: (Yalcinkaya, 2010)

Tigris River

The Tigris River originates in Turkey and enters Iraq from the north after flowing through Syria. Specifically, 77% of the total river length flows through Iraq (1418 km). The Tigris River has five tributaries in Iraq: Feesh-Khabour, Greater Zab, Lesser Zab, Al-Udhaim, and Diyala. The total catchment areas are shared by Turkey, Syria, Iraq and Iran (Al-Ansari et al., 2012; Al-Shahrabaly, 2008) . The Tigris River discharge at Mosul before 1984 was 701 m^3/s but has decreased to 596 m^3/s at present, representing a 15% decrease in river discharge.

The Tigris River is the second-largest river in western Asia. The primary water source for this river is Hazar Lake in the southeastern region of Turkey. Hazar Lake is enclosed by the Taurus mountain chain region, which has a height of approximately 3500 m. The head of the Tigris River is the small mountain lake region of Jazar Golu in Turkey, 30 km away from the Euphrates. The Tigris River flows along the mountainous regions that are located in southeastern Turkey, Iran and Iraq. The Tigris River flows in a straight line through Iraq and the Mesopotamian plain to its smaller length that is parallel to the Syrian border. The river crosses the border of Iraq at Faish-Khabur village, which is located 400 km from the primary sources (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013) . Eight major tributaries feed the Tigris River from the left bank, three of which are in Turkey (the Batman, Garzan and Botan rivers) and five of which are in Iraq (the Feesh-Khabur, Greater Zab, Lesser Zab, Al-Udhaim, and Diyala rivers).

The Iraqi branches flow from northeast Iraq and join the main stream in Baghdad (Al-Ansari and Knutsson, 2011; Najib, 1980). The river drains an area of approximately 375,000 km^2 that is shared by Turkey, Syria, Iraq and Iran. The total river length is approximately 1862 km, 21% of which lies in Turkey while the rest is in Iraq. According to earlier studies, the annual flow of the Tigris River from Turkey to Iraq ranges from 20 to 23 BCM. The river receives water from all the branches mentioned above, and the water flow varies from 25 to 29 BCM through Iraq (Al-Ansari and Knutsson, 2011; Biedler, 2004).

The monthly discharge of the Tigris River at Mosul Dam from 1931 to 2011 is shown in Figure 4 for October to September. The greatest discharge occurs during April, while the smallest discharge occurs in September.

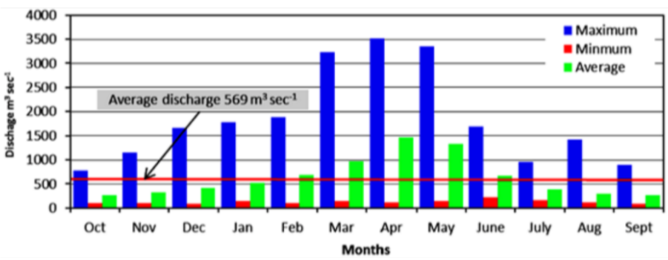

Figure 4: Monthly discharge of the Tigris River at Mosul Dam from 1931 to 2011 (Issa et al., 2014)

Euphrates River

The Euphrates River originates in Turkey and enters Iraq from the northwest after flowing through Syria. This river has no tributaries inside Iraq except for small, seasonal wadies from the west. The catchment areas are distributed among the countries of Syria, Iraq, Turkey and Saudi Arabia (Al-Ansari and Knutsson, 2011; Holmes, 2010). The daily discharge of the Euphrates River in the cities of Hit and Haditha has decreased from 967 m^3/s to 553 m^3/s, representing a 43% reduction.

The Euphrates River is the longest river in western Asia, and most of its water resources are located in the Turkish territories of Anatolia. The River rises near Mount Ararat at heights of around 4500 m near Lake Van. Moreover, the two tributaries of Kara-Sue and Murat-Su merge to form the Euphrates. The river flows southward toward the Mediterranean for approximately 160 km with an average slope of approximately 2 meters per km before it turns left into Syria and flows southeast, almost directly towards the Shatt Al-Arab River (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013; Altinbilek, 2004; Biedler, 2004). Consequently, this river enters Syria at Jarablis; within Syria, two small branches, Balikh and Khabur, join the Euphrates, adding a small amount of water to it. The Euphrates River enters Iraq at Hasaibah with a water flow of approximately 28 to 30 BCM (Al-Ansari et al., 1981, 1988) .

Because of the 360 km limit, the river spreads across a vast alluvial delta at Ramadi towards Iraq, where the elevation is 53 m a.s.1. From here, the river crosses the empty areas of Iraq, depositing some of its waters into a sequence of desert tributaries and distributaries, both man-made and natural. The Euphrates has some insignificant branches in southern and central Iraq that are used for irrigation. No sector underwrites the river water within the Iraqi territories. The Euphrates River has a very moderate incline in Iraq (Issa et al., 2014). The annual hydrograph for the Euphrates River from October to September is shown in figure 5. The highest mean scheduled discharge occurs in May, and the driest month is September.

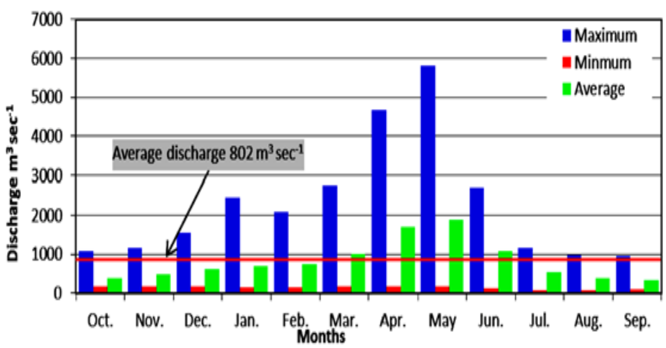

Figure 5: Monthly discharge of the Euphrates River at Hit from 1932 to 1997 (Issa et al., 2014).

Water Demand

Water demand is increasing due to population growth, environmental considerations, and economic development. To overcome its water shortage issues, Iraq must concentrate on reducing poverty, investing in agriculture, and improving the economy to achieve self-sufficiency and improve agriculture, irrigation and water management, in addition to ensuring a sustainable supply of high-quality water. All the methods used to estimate water demand have rather high uncertainty. This study considers current efficient water use and effective management measures for future needs in Iraq by concentrating on the Tigris and Euphrates Rivers and their successive flows at the gauging stations. Then, this study successively estimates the error in demand due to the loss of discharge among the station positions. In addition, precipitation and penetration in the sub-area zones are included by using the human water consumption and the annual discharge records at two gauging stations.

THEORETICAL SIGNIFICANCE/IMPORTANCE

In water-rich nations, people have difficulty visualizing living without a seemingly endless supply of water. However, approximately 1.1 billion people around the world do not have access to clean drinking water (Unicef, 2015). Approximately 1.6 billion people face water stresses or shortages, and 1.2 billion people live in areas characterized by water scarcity (United Nations, 2016) . Specifically, the United States water supply per capita in 2008 was more than 9000 cubic meters per year (World Bank, 2016). Iraq is currently experiencing both the economic and physical effects of water shortages, and the country continues to add to its mounting deficits using infrastructure to extract water from its insufficient resources. In Iraq, the water supply is categorized into mineralized, poor quality and high salinity, which can lead to health and soil degradation issues (Gulflink, 2016). If the substructure and water treatment equipment are not maintained, the water supply in Iraq and the population's health, especially children's health, will be at a higher risk (Nagy, 2001).

Several studies have been previously conducted to address the water shortage problem. Some studies focused on an irrigation management system (Al-Ansari et al., 2015; Al-Murib, 2014; Daming et al., 1999; Ma et al., 2010) , and a few concentrated on environmental conditions (Dariush Fooladivanda and Taylor, 2015; Fang-yun et al., 2011; Guo et al., 2011; Ponte et al., 2013; Qiuxia and Minjian, 2011; Wanliang Wang et al., 2013). These studies are discussed below.

Daming et al. (1999) determined a strategy for planning an irrigation management system. They used the Penman method and focused on a synthetic study involving basic project situations, water requirement calculations, relevant data, and irrigation scheduling; they also discussed methods for optimizing water use efficiency in irrigated crop production ecosystems with selective use of tabular displays to facilitate the interpretation and analysis of the results. Their research showed a high potential of water resources for improving Ningxia's irrigation management. Irrigation scheduling was found to be reasonable, and the results have been used to improve water management decisions in northwestern China.

Yang and Zhang [36] evaluated and analyzed water resource capacity based on sustainable water use to understand the potential development of a country. These authors applied a quantitative assessment on the effect of sustainable water resources in Tianjin using principle component analysis. In addition, their study offered some consistent measures and suggestions based on the realistic situation and analysis.

Ge et al. [5] explored issues related to the minimum ecological water demand (MEWD) in the mountainous area of China to protect the river hydro-biology and to progress scientific operations toward a hydropower station. Their study used the wetted perimeter method to estimate the MEWD of the Mao Jia He Reservoir Dam. The study findings showed that the wetted perimeter and tenant methods have good agreement. In addition, the study analyzed whether the ancient method is rational and calculated the river MEWD as equal to 0.22 m^3/s.

Ma et al. [29] proposed a fuzzy cluster model to identify the real time evapotranspiration (ET) of demand water. Their study then proposed a model that could be used for irrigation in the Qucun area along the Yellow River. The study findings showed that the proposed method is feasible and reasonable, and this method has been widely used in un-surveyed irrigation areas.

Guo et al. [30] analyzed the water environment of the Wei River considering the water quality and quantity based on data collection from 2000 to 2008. Additionally, their study analyzed the correlation between the COD concentrations, runoff, NH_3–N concentrations and the hydrological areas of the Wei River. The proposed method showed the run off of the Wei River more clearly than COD and NH_3-N.

Fang-yun et al. [32] analyzed the causes of the water pollution unique to Beijing and Tianjin. These authors analyzed the water supply conditions required to maintain sustainable development in areas such as Tianjin and Beijing. In addition, their study found that biodiesel plays a major role in protecting water resources when biodiesel is used in a specific environmental wetland, river source, or environmental protection area. Replacing petroleum diesel with biodiesel in the water system around Beijing changes the oil waste, extensively greens the land and safeguards the capital. The study findings showed that the distribution of water demand in Beijing is irregular and that this demand fails to provide a guarantee for sustainable development.

Qiuxia and Minjian[31] analyzed the eco-environmental problems resulting from water development and the relationship between the Xialio River and the surrounding ecosystem. Their study found that the major problem in the Xialio River is related to eco-environmental failure. However, their study failed to consider different groundwater developments such as range, farmland, and dune grass.

Masia and Erasmus [37] developed water demand management/water conservation (WDM/WC) methods. In addition, these authors evaluated whether these policies can be implemented successfully and whether they could result in non-revenue water (NRW) reduction. The data were collected via structured questionnaires that were collected by engineers and managers. The findings showed that the policies and strategies for WDM/WC can be used only in small areas due to the high requirements of non-revenue water (NRW) resources. In the future, they recommended increasing the awareness of municipal water problems that are faced using the capabilities of smart meter technology within the industry.

Wanliang et al. [34] proposed an improved particle swarm optimization (PSO) along with the dynamic topologies that occur in a neighborhood when a connection is established among the particles in the dynamic zonal particle structure. Their study combined generation scheduling and ecological operations that encompass maximum energy productivity with constraints such as the balance of reservoir water, water environmental factors, output restrictions, and discharge restriction volumes; they used the improved PSO model to solve the optimization problem. Their study results revealed a rapid global search ability that solves the problems of multiple constraints and non-linearity in scheduling hydropower stations.

Ponte et al. [33] proposed modern artificial intelligence techniques to address resource scarcity. The variables were forecasted with fewer resources. These authors developed a multi-agent system specifically to manage decision making. In addition, the results identify the optimal hourly quantity of water pumped to minimize costs, and the study findings showed that the present research structure is based on sophisticated forecasting methods – such as neural networks and ARIMA – that are coordinated with intelligent agents.

Sakamoto et al. [38] determined the allocation of water effectiveness of the Tigris and Euphrates Rivers in Iraq based on the behavior of farmers and operators. Their study addressed the use of the river for agriculture in Iraq and farmers' dependence on the water supply through irrigation. The decision-making process among the operators' reservoir and the farmers' basin was analyzed using non-cooperative game theory. The study findings included the interactive structure of the decision-making process and the advantages of the stockholders' basin. In the future, this study can be extended to an institutional design for better governance.

Salah et al. [39] developed a decision support system (DSS) for water pollution in the Tigris basin based on a mathematical model. The proposed framework comprises the real value of the parameters to determine the infection type and to provide standard values for the parameters, and it offers suggestions for water treatment. Based on the indicators, the DSS estimation procedure suggests strategic plans or instruments that are well-defined principles of water pollution management found in the water framework. The study findings revealed that the initial decision is intended for an emergency and provides suggestions for appropriate water treatment methods.

Villa et al. [40] analyzed the potential use of remotely sensed data to study the process surface in terms of hydrology and vegetation. The dataset was collected from 2007 to 2009 in the Middle East, and these authors found that the surface performance depends on the downstream flow inferred by the dynamic support vegetation. Based on the water reserve surfaces from radar satellites, this study found that agricultural activities in southern Turkey increase the water surfaces.

Sakamoto et al. [41] focused on information transparency and identified the effects of decision making using a case study of the Tigris and Euphrates Rivers in Iraq. Their study discussed transparency and concepts related to transparency such as indeterminacy, uncertainty, players' decision instability within the framework of a theoretical game and the impact of decision making.

Al-Murib [27] used the CE-QUAL-W2 model to simulate the flow, temperature, and total dissolved solids of the Tigris River. The W2 model simulated a study area from Mosul Dam to Kut Barrage (880 km). The salinity of the Tigris River in Iraq dramatically increases from Mosul Dam to Kut Barrage due to the quantity of regulated from Turkey. The salinity increased significantly to the point that the river water is no longer safe for either human consumption or irrigation purposes, which is particularly true after the Greater Anatolia Project (GAP), in the flow from Tharthar Lake to the Tigris and irrigation flow return through Iraq, downstream of Baghdad.

Gomes et al. [42] provided an in-depth examination of the decision-making processes of the reservoir farmers and operators. In addition, their study designed a Soft System Methodology (SSM) to address complex problematic situations involving human activities in structured scenarios. They developed SSM to resolve the conflict of water resources and stated that SSM is adequate for solving the water scarcity problem. However, in the future, their study should be re-examined and extended to the payoff function of the reservoir operator.

Al-Ansari et al. [10] analyzed sensible water management policies that have yet to be implemented for the water shortage problem because of the internal and external factors in Iraq, including a Strategic Water Management Vision, use of unconventional water resources, reducing water losses, research development planning, and developing irrigation techniques. Their study discusses the water scarcity problem and suggests ways to overcome the water crisis in Iraq.

Karpatne and Kumar [43] developed predictive models to estimate whether a particular location on Earth is water or land using remote sensing data. This would facilitate mapping the entire history of global water dynamics by applying predictive models over test instances across all locations and time periods.

Thus, the data-driven approaches for learning predictive models requires the use of training instances, where every training instance has an associated class label indicating whether the case belongs to the water class or the land class. They plan to extend their study by developing local learning methods that capture different notions of the locality at varying spatial scales, e.g., at the level of the county, district, and country, and at varying time periods, e.g., seasonal and decadal.

Fooladivanda and Taylor [35] studied the vulnerability of thermoelectric power plants to high river temperatures and low water availability. More precisely, they considered constraints on the amount of water that can be consumed by the power plants and constraints on the amount of heat that can be transferred to the environment. They then proposed a general optimal power flow framework that allows the system operator to compute optimal control flows while ensuring that the heat and water flow constraints are satisfied. Finally, they developed numerical techniques to compute sub-optimal solutions to the proposed problem and showed the impact of water availability and heat constraints on electricity generation.

DISCUSSION AND CONCLUSION

From the above literature, the problem statement is identified and discussed as follows:

Masia and Erasmus [37] suggested that municipalities must focus on awareness of water issues in the industry and implement Smart Metering Technology (SMT). Gomes et al. [42] should re-examine and extend their study to the payoff function of the reservoir operator. Remotely estimating the surface water temperature and turbidity of the Tigris River is a helpful tool for obtaining data regarding this work. Because water surface temperature data are currently unavailable in Iraq, remote sensing should be utilized. Furthermore, the river depth and width should be estimated at each cross section as a function of flow rate by implementing Leopold’s approach. In addition, one of the reasons for the water shortage is that the river water can no longer be used due to pollution. The increases in population and economic development have increased wastewater; however, if the wastewater is recycled, this resource will not run out. Some studies concentrated on the Tigris River, while some focused on the combination of the Tigris and Euphrates Rivers. The total available water in Iraq from these two rivers is 70.92 km^3 $year^{-1}$, of which the Tigris River contributes 45.4 km^3year^{-1} and the Euphrates River contributes 25.52 km^3 $year^{-1}$. The reduction rate of the Tigris River is 0.294% (0.1335 km^3year^{-1}), while that of the Euphrates River is 0.961% (0.245 km^3 $year^{-1}$). The rate of annual water demand increases by approximately 1.002 km^3year^{-1}; that of the Tigris river basin is 0.5271 km^3year^{-1}, while that of the Euphrates river basin is 0.475 km^3year^{-1}. In addition, the water inflow in the year 2020 will decrease by approximately 63.46 km^3year^{-1}, and demand will increase by approximately 72.069 km^3year^{-1}, highlighting the water shortage problem in Iraq. Therefore, action must be taken; a few recommendations for addressing these issues are suggested below.

In everyday life, the water resources in the Middle East are insufficient to meet the needs of the population. Water demand will continue to increase due the increasing population and increasing consumption per capita. Specifically, Iraq is experiencing physical and economic water shortages because the country lacks the infrastructure development to extract water from its insufficient water resources. Iraq depends on the Tigris and Euphrates Rivers to supply industrial water, irrigation water and drinking water. In addition, the literature review reported that the Tigris and Euphrates Rivers will entirely dry up by 2040. Therefore, the Iraqi government must take prudent, quick and firm action to resolve its water scarcity problem, possibly through the natural merging of interests to obtain extensive rights to the water of downstream countries.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

RECOMMENDATIONS:

- An integrated long-term “national water master plan” is designed and must be implemented immediately.
- The effective irrigation method is more suitable for the local conditions of water, soil, and crops based on water availability and quality. The irrigation technique increases the natural water supply due to wastewater. Drip irrigation is suitable for agricultural estates. Using salty water through the sprinkler irrigation method is more appropriate for grains and traditional crops than surface irrigation.
- To develop and maintain the water system transmission, losses must be reduced and efficiency must be increased. Closed channels are a conveying system that reduces vaporization and infiltration losses. Additionally, this method is traditional and protects irrigation water from contact with the saline water table.
- To reduce water losses and pollution, effective projects must be implemented.
- This research aims to import advanced technologies in agriculture and water resources that could be suitable for the Iraqi environment.
- More programs must be arranged for public awareness of agricultural activities and water usage.
- The groundwater resources have not yet been drained; significant attempts should be devoted to achieving practical use of groundwater and to protect it from pollution.

- The Community participation and awareness of the need to conserve water resources and the need for proper environmentally friendly practices are important contributions to water sanitation and maintainability. Hygienic and clean environmental requirements can be integrated into the future curriculum of teachers who are trained to promote environmentally friendly villages and towns.

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