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Assessment of underground water reservoirs' vulnerability to pollution in the Ghamka basin in Syria

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Abstract:

Groundwater protection begins with assessing the vulnerability of groundwater to contamination. For this purpose, a vulnerability map must be created to indicate areas that are more susceptible to pollution based on hydrogeological characteristics and conditions.

The research involves applying four computer methodologies within a Geographic Information System (GIS) environment to study geological, hydrogeological, climatic, land use characteristics, and express them as layers used later in creating a contamination vulnerability map.

Groundwater vulnerability maps are a relatively new scientific technique that emerged in the late 1960s and have been used to support land use plans, decision-making,environmental protection measures, and resource management. These maps are considered a standard for groundwater protection.

This process is closely related to administrative aspects, political issues, and forms the basis for subsequent discoveries. There is no fixed method due to variations in data availability between different areas. Some methods require spatial distribution of over 10 pa rameters and very precise data.

The research is expected to provide various benefits by identifying locations most susceptible to contamination in the groundwater reservoirs in the Ghouta basin, then generalizing the results to similar basins in terms of morphological, climatic, hydrological, and hydrogeological aspects. The model will then be applied to other basins in the Syrian coast, selecting suitable locations for drilling wells away from current sources of pollution.

Scientific results of reference studies have shown that using computer mathematical models within the ArcGIS environment saves a significant amount of effort and time in building an accurate groundwater simulation model. The difficulty lies in collecting the data needed for this model, which ranges from aerial images to field data to various details required by the model. It is built on real field data. This research represents new ideas applied in the field of environmental engineering in Syria, even though it is widely used worldwide. It provides a comprehensive view of pollutant distribution in groundwater, if present. The reality of groundwater in Syria requires management to reduce sources of pollution or treat contaminated water and establish administrative plans for its resources.

Key Words: Groundwater Reservoirs, Ghouta Basin, Groundwater Sensitivity Model, Groundwater Pollutants From Sewage, Groundwater Pollutants From Industrial Waste, Groundwater Analysis, Groundwater Level.

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تقييم حساسية خزانات المياه الجوفية للتلوث في حوض الغمقة في سورية

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الملخص:

إن حماية المياه الجوفية تبدأ بتقييم قابلية (حساسية) المياه الجوفية للتلوث، ومن أجل هذا الغرض يتوجب وضع خريطة لقابلية المياه الجوفي للتلوث (Vulnerability map) التي توضح فيها المناطق التي إمكانية تلوثها أكبر من غيرها بالاستناد إلى الخصائص والظروف الهيدروجيولوجية.

يقوم البحث على تطبيق أربع منهجيات حاسوبية ضمن بيئة برنامج نظم المعلومات الجغرافية (GIS) الذي تتم فيه دراسة الخصائص الجيولوجية والهيدروجيولوجية والمناخية وطبيعة الأرض واستخدامها، ويتم التعبير عنها على شكل طبقات (Layer) يعتمد عليها لاحقاً في إنشاء خريطة قابلية التلوث (الحساسية).

خرائط حساسية (قابلية تلوث) المياه الجوفية هي تقنية علمية جديدة نسبياً ظهرت في أواخر الستينات واستخدمت من أجل دعم خطط استخدام الأراضي وصناعة القرار وتدابير حماية البيئة وإدارة الموارد وهي تعتبر معيارية لحماية المياه الجوفية. وهذه العملية لها صلة وثيقة بالنواحي الإدارية والقضايا السياسية وتشكل أساساً لاكتشافات لاحقة، ولا توجد طريقة واحدة ثابتة بسبب اختلاف إمكانية جميع البيانات بين منطقة وأخرى، حيث أن هناك طرق تحتاج للتوزع المكاني لأكثر من 10 بارامترات وبيانات دقيقة جداً. من المتوقع أن يحقق البحث فوائد عديدة من حيث تحديد أكثر الأماكن عرضة للتلوث في الخزانات الجوفية في حوض الغمقة، ثم تعميم النتيجة على الأحواض المشابهة له من حيث المظاهر المورفولوجية والمناخية والهيدرولوجية والهيدروجيولوجية، ثم التوجه لتطبيق النموذج على باقي أحواض الساحل السوري، واختيار المكان الأنسب لحفر الآبار في مواقع بعيدة عن مصادر التلوث الحالية.

أثبتت النتائج العلمية للدراسات المرجعية أن استخدام النماذج الرياضية الحاسوبية ضمن بيئة برنامج ArcGIS يوفر جهداً ووقتاً طويلاً لبناء نموذج محاكاة لواقع المياه الجوفية، بصورة دقيقة، حيث أن الصعوبة تكمن في جمع البيانات التي تخص هذه النموذج من صور جوية الى بيانات حقلية الى الكثير من التفاصيل التي يحتاجها هذا النموذج، فهو يُبنى على بيانات حقلية حقيقة، البحث يعتبر من الأفكار الجديدة التي تطبق في مجال الهندسة البيئية في سورية رغم أنه منتشر في دول العالم بصورة كبيرة، حيث أنه يعطي تصور كبير عن انتشار الملوثات في المياه الجوفية ان وُجد، وواقع المياه الجوفية في سورية يحتاج الى ادارة من حيث الحد من مصادر التلوث أو معالجة المياه الملوثة ووضع خطط ادارية لمواردها.

الكلمات المفتاحية: خزانات المياه الجوفية – الحوض الساكب – نموذج حساسية المياه الجوفية – ملوثات المياه الجوفية الناتجة عن الصرف الصحي – ملوثات المياه الجوفية الناتجة عن المخلفات الصناعية– تحليل المياه الجوفية – منسوب المياه الجوفية .

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Introduction:

Water resources are considered essential for sustainable development, and the problem of water pollution is one of the most serious problems facing modern societies, especially after the industrial and agricultural development of these societies. The increase in the number of people and the increase in activities related to it has led to a number of environmental problems related to the limited natural resources of water, which requires strategies to rationalize use and reduce its pollution.

Rivers and lakes are polluted from point sources represented by sewage or industrial water, and non-point sources represented by rainwater and the fertilizers, pesticides and others it carries with it in the phenomenon of surface runoff on the surface of the earth, and both of them necessarily lead to groundwater pollution over time, as the leakage of these materials into groundwater leads to an increase in salts, nitrates, nitrogen and phosphorus compounds, pathogenic microorganisms, and many heavy metals. Some studies have indicated a strong relationship between the use of agricultural land and the quality of groundwater in the areas surrounding it.

The pollutants dumped into the water source, depending on their quantity and quality, affect the qualities and characteristics of this source, as they may lead to a change in taste, smell and color (physical changes), and the appearance of floating materials on the surface and placement Sediments at the bottom. These changes together lead to the unsuitability of the water source, whether for drinking, agriculture or industry. Groundwater protection begins with an assessment of the susceptibility (sensitivity) of groundwater to pollution. For this purpose, a vulnerability map must be developed that shows the areas that are more likely to be polluted than others based on hydrogeological characteristics and conditions.

Reference studies:

The process of modeling the sensitivity of groundwater to pollution is considered a complex matter due to the difficulty of obtaining field measurements due to the many indicators related to the properties of groundwater reservoirs, soil properties, and the unsaturated zone. There are many proposed models that can be used to predict the sensitivity of groundwater to pollution, which depend on analyzing the elements affecting the transfer of pollutants from the soil surface until they reach the groundwater reservoir, and also depend on the properties of the groundwater-bearing layer that help in their spread, the most important of which is permeability. Despite the availability of groundwater reservoir data in developed countries, which may be sufficient to model the movement of groundwater, the processes of feeding these reservoirs, and the movement of pollutants, this data is scarce in developing countries, which calls for considering the use of some models that do not require a lot of data (often unavailable). Wang and CHEN classified the models used in predicting the sensitivity of groundwater pollution into three types in 2012, namely statistical models, mathematical or physical models, and spatial matching index models; Statistical models depend on collecting data on actual pollutants in a specific groundwater reservoir and linking them to the properties of the groundwater reservoir, the unsaturated zone, soil properties, and land uses. Then, the model relationships are determined and tested with the experimental data available for a particular area, and then used to predict the extent of pollution. The most important of these models is the model (Helsel and Hirsch, 1992). The use of these models requires a huge amount of accurate data about the conditions surrounding the groundwater reservoir, which makes their use impractical (Martin, 2000) [1]. While mathematical models depend on the quantitative study of the movement of water and pollutants from the soil surface until they reach the groundwater, the most important of these models is the (SAAT/SWAT) model, in addition to the fact that there are a number of numerical analysis programs, including (DHI Software), (MODFLOW), and (Butscher) [2].

• A reference study entitled: ((Sensitivity of surface groundwater reservoirs to pollution using the DRASTIC model in the Jfara Plain region, Libya)) [3] A group of scientists studied the sensitivity of surface groundwater reservoirs to pollution using the DRASTIC model in the Jfara Plain region, Libya, where the region is famous for agricultural and industrial activity and the frequent exposure of surface soil to many pollutants and waste, which may expose the surface groundwater reserve to pollution, so it was In this study, the DRASTIC model was used in a GIS environment to produce spatial maps to predict the sensitivity of surface groundwater to pollution, determine the degrees of sensitivity of these reservoirs to pollution, and develop spatial distribution maps for all the characteristics of the DRASTIC model by applying the inverse weighted distance method (IDW) in a GIS environment. Results: It was shown that when using the inverse weighted distance method, it was possible to obtain spatial maps for all the characteristics of the DRASTIC model, and it was shown that the spatial distribution maps of these characteristics can be trusted (Figure (1)), by obtaining the values of the root mean square error (RMSE) as one of the measures to evaluate the quality of the predicted values; where it was found that the RMSE values are close to zero, and that the slight variation between the RMSE values of the characteristics of the DRASTIC model is due to the variation in the number of samples used in this model.

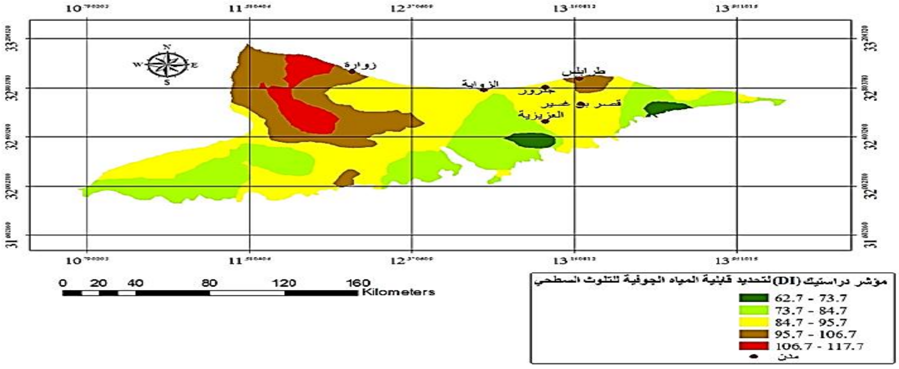

Figure (1): DRASTIC index map of the Jufra Plain region.

The results also indicated that most parts of the region were classified as moderately sensitive, with the exception of some northwestern regions of the study area, which were more sensitive to pollution compared to other regions. To ensure the validity of the DRASTIC model, it was calibrated with 9 well water samples in the quaternary reservoir located in the irrigated areas, in which the nitrate concentration was estimated. It was found that there is a strong linear correlation between the DRASTIC index and the change in nitrate concentration in the study area. The linear correlation coefficient reached 0.84, indicating the validity of the results obtained from this study. Therefore, this study recommends protecting surface groundwater and reducing the risk of pollution in order to sustain groundwater resources in the region.

Benefits from the research: After reviewing this study and its results, it became clear that there is a similarity between the Jafra Plain region and the study area in this research, considering that the groundwater aquifer in the two regions is free water, and considering the average permeability coefficient for each aquifer.

• Reference study entitled: ((Studying the estimation of the sources and availability of groundwater in the Al-Hussain Basin, Syria)) [4]

A group of researchers at the University of Damascus, Faculty of Science, Department of Geology, conducted a study to estimate the sources and availability of groundwater in the Al-Hussain Basin, Syria, where rainfall, springs and groundwater are abundant in the Al-Hussain Basin with karst rocky outcrops and with the increase in population and reliance on agriculture mainly and the weakness of the infrastructure of sewage networks represented by the lack of stations Sewage treatment and the large number of technical drillings, in addition to the spread of olive presses, it was necessary to anticipate the possibility of groundwater pollution. This study aims to assess the susceptibility of groundwater layers to pollution in the Al-Hussain Basin, and to identify the areas exposed to groundwater pollution. To achieve this, the (DRASTIC) model and the (EPIK) model were used through the Geographic Information System (GIS). Both methods require identifying many geological, hydrogeological and tectonic factors that play a role in water pollution.

Results: Using the EPIK model showed that the potential for pollution is high and covers an area of 175 km2, or 49.6% of the basin area, Figure (2), while the potential for high pollution using the DRASTIC model covered an area of the basin of 57 km2, or 16.2% of the basin area, Figure (3). This difference between the results of the two methods is due to the fact that the parameters of each model differ from the other, as the DRASTIC model depends on seven parameters, while the EPIK model depends on only four parameters, two of which are E, K, which express karst openings and the development of the karst network. Therefore, the main difference between the two methods is the method's ability to describe the development of karst, and this is logical when knowing that the study area has many karst features.

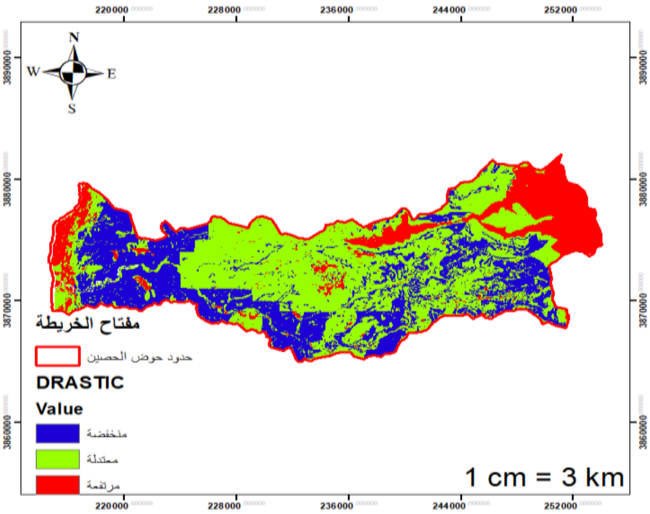

Figure (2): DRASTIC model map of the hippocampus.

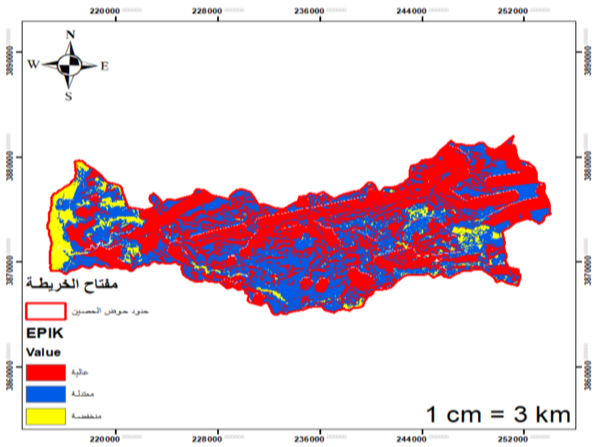

Figure (3): Groundwater pollution susceptibility map according to EPIK

Benefit from the research: After reviewing this study and its results, we note the similarity of the hydrological and hydrogeological conditions of the Al-Hussain Basin with the study area, as the type and nature of the groundwater-bearing layers in Tartous Governorate are similar, in addition to the type of soil and the nature of the ventilation area, and it differs from it that the Al-Ghamqa Basin is topographically higher than the Al-Hussain Basin, and the research will use all models for studying the sensitivity of groundwater within the Arc GIS environment.

• A reference study entitled: ((A study to evaluate the susceptibility of groundwater to pollution in the western aquifer using the DRASTIC model)) [5]

A group of researchers in Morocco studied the assessment of the susceptibility of groundwater to pollution in the western aquifer using the DRASTIC model, as this article aims to study the susceptibility of groundwater to pollution in the western aquifer using the extreme model, based on the hydrological characteristics of the

region regardless of the type of pollutant, which can be used for future planning, and taking measures that limit groundwater pollution from surface activities. The West Water Table is an important source of drinking and irrigation water in the Gharb Plain. Population growth, industrial and agricultural activities have led to the impacts of pollutants that have contributed to the deterioration of water quality. The results showed the vulnerability of groundwater in the West Aquifer using the root model, where most areas were classified as low to medium vulnerability to pollution, except for the coastal and southern groundwater areas as the most vulnerable areas to pollution.
Results: By using this model, the results showed that most areas were classified from weak to medium pollution susceptibility, with the exception of the coastal and southern areas, which were classified as areas most susceptible to pollution, Figure (4). To verify the validity of these results, they were compared with a number of well samples in which the nitrate concentration was estimated. It was found that there is a medium correlation between the DRSIC index and the use of nitrate, Figure (5). This is evidence of the necessity of disposing of liquid and solid waste through sound means, and not throwing it into waterways, which may lead to its transfer with rainwater or irrigation water to groundwater reservoirs, in addition to not overusing pesticides and fertilizers, which may lead to the pollution of agricultural soil and the leakage of these pollutants into groundwater.

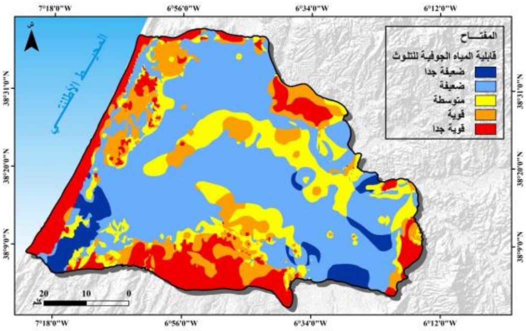

Figure (4): Groundwater susceptibility to pollution, a study model for the western aquifer.

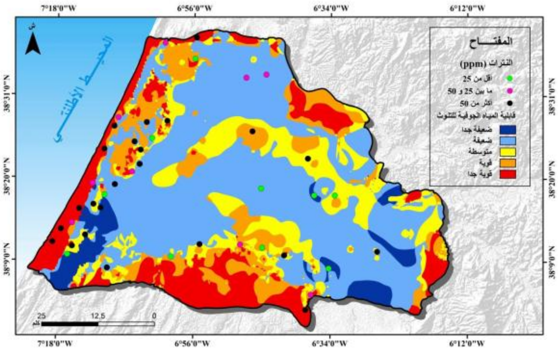

Figure (5): Comparison between the study model and the nitrate concentration in the western brush.

Benefit from the research: After reviewing this study and its results, all groundwater sensitivity study models will be used within the Arc GIS environment and their suitability will be studied by comparing them with field measurements taken from groundwater in the study area.
A reference study entitled: ((Evaluating the susceptibility of groundwater to pollution in the Difa spring)) [6]
Researchers at Tishreen University, Department of Environmental Engineering, evaluated the susceptibility of groundwater to pollution in the Difa spring, as this area is an agricultural area that suffers from many environmental problems, hence the importance of evaluating the susceptibility of the Difa spring to pollution using the DRASTIC method and developing a groundwater susceptibility map using GIS.
Results: The groundwater susceptibility map at the end of the research showed that most of the water feeding the Difa spring has a high and moderate susceptibility to pollution. Figure No. (6).

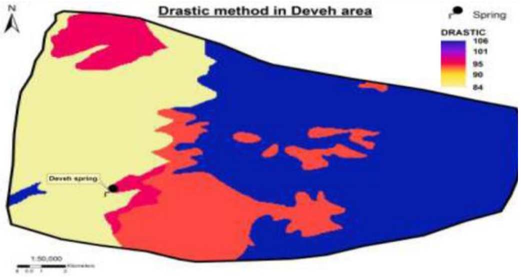

Figure (6): Groundwater susceptibility to pollution, a study model for the Difa spring.

The area of the area with highly polluted groundwater was estimated at about 82 km², which constitutes about 48% of the total area of the study area, which is 170 km², while the area of the area with moderately polluted groundwater was about 40 km², which constitutes about 23% of the total area of the study area. Therefore, measures must be taken to protect water from pollution through integrated management of groundwater resources.

Benefits from the research: After reviewing this study and its results, we see that the DRASTIC model is the most widely used around the world, but a comparison will be made between the different models to obtain the best map that represents the sensitivity of groundwater to pollution in the study area.

Materials and methods:

There are several methods for developing vulnerability maps, which are:

The choice of the appropriate method is related to a number of factors taken into account in the evaluation in addition to the map scale, the availability of spatial data and information, and the purpose of the map.

Table (1) shows the methods for analyzing the susceptibility of groundwater pollution and its parameters.

Place of Use	Methodology
Used in the US, it is suitable for areas where data is scarce and is simpler than other .models	DRASTIC
And its amendments, including the (PI) method used .in Germany	GLA
.User in Switzerland	EPIK
Used in Oria, especially in .karst areas	COP

The selection of the appropriate approach is linked to a number of factors taken into account in the evaluation, in addition to the scale of the map, the availability of spatial data and information, and the purpose of the map. Table (1) shows the approaches to analyzing the susceptibility of groundwater pollution and its parameters.

Table (1): Methods for analyzing the susceptibility of groundwater pollution and its parameters.

Name	D	R	A	S	U	O
DRASTIC	*	*	*		*	*
COP	*				*	*
EPIK	*				*	*
PI	*	*	*		*	*

•D :(Depth of water) Depth of groundwater.

•R: (Recharge) Recharge.

•A: (Aquifer Characteristics) Characteristics of the aquifer.

•S: (Saturated Zone Characteristics) Characteristics of the saturated layer.

Research limitations: The Ghamqa River basin is located to the north of the Abrash River basin. The Ghamqa River is formed at an altitude of (1069m) from the western slopes of the coastal mountain range. The area of its spillway basin is (199.69km2) up to the Beit Nasser measurement center (the approved basin outlet), with a length of (29.49km) and an average width of (5.02km). The Ghamqa River basin expands with an elongation coefficient of (0.54), and its area decreases at the expense of increasing its length (approaching elongation), and a surface runoff with a low peak is expected to form. The water flows in the upper part of the river within a deep riverbed with a width of up to (20m). The river is known in its upper part as the Ain al-Kabir Canal, and is fed from the north by the Tishur River (an extension of the Fawar River) with a basin area of (51.76 km2). The river flows in the last (5 km) of its valley in a flat land and towards the west. Stagnant water is observed in the course at the lower levels in this section due to the inundation of sea water. It flows into the sea within the borders of the city of Tartous from its southern end. Springs are spread on the left shoulder of the basin in the upper southern part, the most important of which are: Al-Ghamqa Spring, Al-Ain Al-Kabir, Obin Spring, Al-Hawiziya Spring, and Al-Shamamis Spring (fully invested for drinking water). The average topographic ratio of the basin is (0.035), with an average height of (327.7m) and an intermediate height of (288m) with an average longitudinal slope of (0.25). Hills and plateaus with heights ranging between (100m) and (750m) are prevalent over the entire area of the basin, at a rate of (94.46%) of the area of the basin, while the plain areas do not exceed (1.85%). A sharp slope is observed in the area of the mouth of the Beit Nasser measurement center. Figure (7) shows the topography of the Al-Ghamqa River basin and the partial basins according to the water measurement centers on the course, which number (5 centers), from which we can notice that The Ghamqa River Basin is characterised by a coarse drainage texture and the right slope (3GH) of the basin is flatter and lower than the left slope, with a high topography ratio in the source and outlet basins (5GH, 1GH).

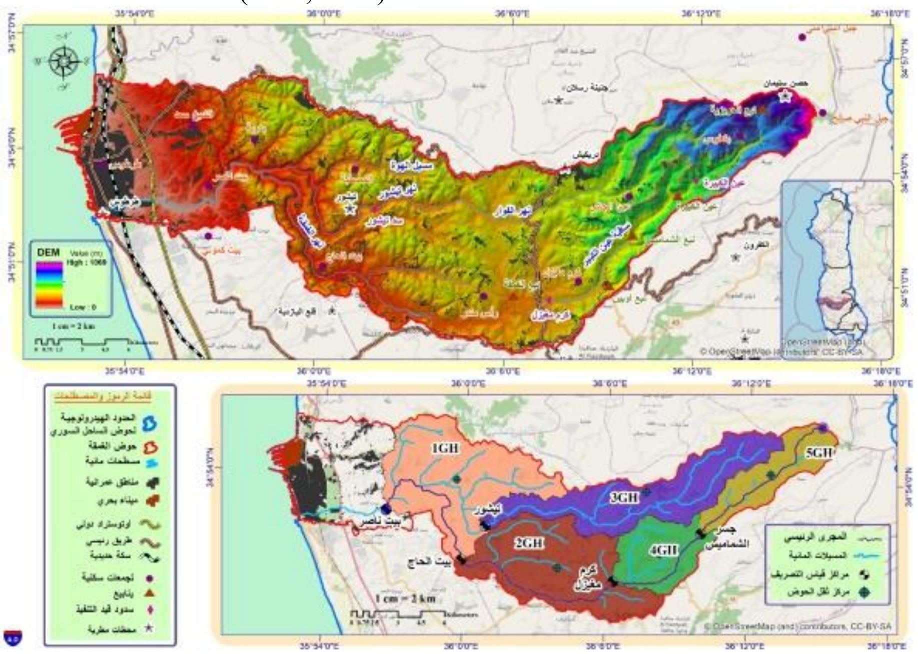

Figure (7): Al-Ghamqa River Basin: (a) Topographic map; (b) Sub-basins.

Using GIS to map groundwater contamination: In the environmental field, the Multi Criteria Analysis approach has become one of the most widespread applications in the world. This program is useful in converting maps from paper to digital format, in addition to the use of spatial analysis tools in the (GIS) program that provides answers to various details of spatial relationships between pollution sources and groundwater reservoirs.

• The four previous models mentioned depend on a specific number of parameters mentioned in Table No. (3):
• Whereas the DRASTIC model depends on both the depth of groundwater, recharge, groundwater reservoir properties, unsaturated layer properties, and other properties such as the geology of the area.
• While the COP model depends on all groundwater depth, unsaturated layer properties, and the geology of the area.
• While the EPIK model depends only on the depth of groundwater, unsaturated layer properties, and the geology of the area,
• The PI model depends on all parameters except for the saturated layer properties as is the case in the DRASTIC model.
• All models depend in their equation on weighting these parameters by multiplying the weighting factor, which is known as the degree of danger, Table (4) By the value of the parameter to obtain the sensitivity degree.
• All the above-mentioned parameters will be collected from the directorates, institutions and sites concerned and then entered into the program to produce groundwater sensitivity maps according to the four-model. This data will be collected in the following order:
• Information about the geology of the region and climatic conditions.
• Information about the morphometric and morphological properties of the river network and its spatial distribution within the Ghamqa basin, by drawing the basin and the river network within the Arcgis program environment.
• Information about the sewage network for each residential community, the treatment mechanism, the service ratio and its final discharge points.
• Information about the water sources for each residential community, the coverage ratio of the network and the sufficiency ratio.
• Information about olive presses (type of press, production capacity, number of working days, number of daily working hours, distance from waterways), economic facilities (restaurants, hotels, rest houses...), and industrial facilities in terms of facility size (small, large), and type of activity (chemical, bacterial), The drainage network, the type of treatment, the methods of disposing of liquid and solid waste, and the final discharge points.
• A map of the distribution of wells in the study area, which includes level measuring wells to determine the depths of the aquifer layer, and sampling wells (physical, chemical, bacterial), aiming to evaluate the results of the adopted model.
• Information about pumping wells in the area (water conductivity, permeability, abundance).
• A digital elevation model (DEM) of the type (SRTM 30m) that is characterized by accuracy in representing elevations, slopes, watercourses and pouring basins, and can be downloaded for free according to the geographical projection system (WGS84; UTM; Zone 36-37) through the US Geological Survey (USGS) Earth Explorer website.
• High-resolution satellite images, which help in obtaining the latest data on the one hand and covering some places whose land uses have not been obtained.
• Topographic maps at a scale of (1:25000), which help in obtaining geographical names and leveling lines...etc. through the digitization process within the (ArcGIS) environment.
• Soil Texture map, which was prepared by merging several maps from the General Authority for Remote Sensing in Damascus and global data, its spatial accuracy ranges between (100m) to (250m).

• Available land use map for the year (2021), which aims to determine the contribution of different regions to water pollution, and prepare a map of agricultural pollution of fertilizers and pesticides according to the degree of A certain weighting is linked to the amount of chemical fertilizers and the amount of pesticides for each agricultural type, in addition to introducing the rain factor and distance from surface water sources.
• The effect of surface runoff represented by the Ghamqa River and rainfall in the Ghamqa Basin will also be studied as a new parameter in the equations of the previous models in order to know the extent of the effect of surface runoff on groundwater pollution.
• Field measurements will be taken by extracting samples of groundwater once a month for a full year, from wells that cover the entire study area and as much of it as possible.
• After the analysis, more than one pollutant will be identified in this water to build a distribution map of E. coli and nitrates within the GIS environment using the nearest neighbor method for spatial interpolation, which gives a spatial prediction of these pollutants through the relationship between the points with known data and the points with unknown data and the weighting of the distance between them.
• After obtaining a map specific to the pollutants (E. coli and nitrates), the result We have chemical analysis of water using the nearest neighbor method, comparison will be made with the maps resulting from the four models of groundwater sensitivity.
• Choosing the best method to represent this sensitivity and building the necessary solutions to reduce this pollution and giving proposals for the management of groundwater resources in this basin, which can be generalized to the rest of the basins similar in terms of all characteristics, or changing the parameters to suit the rest of the basins.

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