Sustainability & Remediation of Groundwater Environment by a (Hydrogeologic Dilution) Against Radon (^{222}Rn) Pollution in Hashyimia, Iraq

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Abstract:

A hydrogeologic 2D model has been built and adopted to solve the problem of a radioactive element (^{222}Rn) conc that exceeds the allowable limit in a subsurface water of Hashyimia Region in the middle of Iraq. Too many injuries of cancers and early death of population behind Contaminant infection. Hashyimia is an agricultural area of 100km^2 at which Hillah river divides it into two parts and contains many streams to supply it with water requirements namely as; Sareaa, Kids, Zabbar and Hashyimia. 20 wells have been randomly drilled to tracing ^{222}Rn concentrations (conc). Sampling process and Laboratorial testing proved that during (3hrs) of continuous pumping, the conc of ^{222}Rn exceeds (103, 104,105, 107, 108, 110, 111, and 113Bq/L) in the wells no. (1, 18, 6, 17, 14, 5, 16 and 12) respectively and it is probably expected that in well no.(17) Radon conc may reach (150Bq/L) if the pumping process is continued more than 3hrs. The entire area is divided into 7 sectors, only sectors (2, 6, &7) were infected with exceedance of ^{222}Rn conc therefore the remediation technique was confined to them.

An annual dilution process for groundwater strategic storage was hydrogeologically achieved to reduce the exceedable Conc to a desired limits. The principle of this technology is represented by replacement of a groundwater by fresh water of Hillah River by injecting process and pumping the same quantity of water from groundwater into local streams to be used for irrigation to avoid water loss. This is a combination processes of groundwater replacement and aeration since ^{222}Rn gas releases into the atmosphere while exposing to fresh air. It is found that a strategic storage of groundwater (44.4, 22.3 & 72.35 mcm) at sectors (2, 6, &7) respectively. It is concluded to reduce ^{222}Rn conc to (90Bq/L), 51, 21, and 78 pumping wells and 28, 25 and 26 injecting wells are needed for sectors (2, 6 and 7) respectively. It is approved that a dilution process is economic, easy, efficient, and natural.

Keywords: Radon **(**^{222}Rn), Concentration (Conc), Dilution Equation, Recharge Capacity (Rc), Safe Yield (Sy)**,** Water Table Level **(**WTL)

Introduction:

^{222}Rn is an element of Uranium ^{238}U decay series which its variation in groundwater needs an extensive field and official work to be quantitatively tested and evaluated. Skepptstrom K. and Olofsson (2007) indicated problems of a natural radioactive elements ^{238}U and ^{222}U of the extracted groundwater on the health of smokers due to halation. The did not solve a problem but constructed a mathematical model to predict future concentration of radioactive elements with a complexity of aquifer non homogeneity, geochemistry, geologic fracture, and ground flow pattern.

Occurrence of Radon in Groundwater

^{222}Rn is a radioactive gas occurring due to ^{238}U decay series as shown in Fig. (1),. Environmental Protection Agency (EPA) indicated that it is of lung cancer in USA (EPA, 1999). Briefly it escapes from groundwater to outside air in low concs which is limited to (0.15 Bq L^{-1}) for inside houses air (EPA, 1986), anyway practical evidences indicate radon transferring rate is about 10^{-4} Bq L^{-1} in air per 1Bq L^{-1} in water, Gesel and Pichard (1975). Usually radon transfer is well evaluated by what is called radon transfer coefficient (*f*) Norris et al. (2004) , where:

$$f = \frac{\Delta C_{air}}{C_{water}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where ΔC_{air} (Bq L^{-1}) is a radon conc change in the space and C_{water} (Bq L^{-1}) is a radon conc water.

Generally, all mathematical models predict the amounts of radon emission into air from surrounding flowing water. It is worth to mention that the emitted radon into open air spaces is of less harmful effects on human health than confined one since conc in open air spaced permanently exposed to natural dilution which in turn is depending on temperature and wind speed and ventilation in confined rooms.

Fig.(2) Uranium Decay Series

After Vincente (1999)

Organization of Radon Study

The current study composed of two parts. The first one includes a spatial and temporal measurement and waterborne of an existing radon and the second part serves a possible hydrogeologic remediation of a measured radon conc in groundwater aquifer.

Field Exploration of Radon (^{222}Rn) and Testing

In order to measure Radon conc in groundwater, many field sampling and testing methods are available in addition to laboratorial testing methods. Among them are:-

1- De-emanation technique by (Lucas 1957).
2- NaI gamma spectroscopy system by (Lucas 1964).
3- Electret ion chamber by (Kotrappa and Jester 1993).
4- Liquid scintillation by (Prichard and Gesell 1977).
5- Lucas cell de-emanation by (Whittaker et al. 1987).
6- liquid scintillation counting by (AWWA 1996).

Radon Occurrence in Rocks

Origination of radon conc varied corresponding to geomorphology of existing rocks (Sloto 2000, Hess et al. 1985). Radon conc may take a wide variation range, i.e. its conc in Maine, USA has identified by type of rocks for instance ^{222}Rn conc of groundwater in granites is (810 Bq L^{-1}) and of (480 Bq L^{-1}) in sillimanites (Brutsaert et al. 1981, Hess et al. 1985). It is found that terrain of high grade metamorphic rock and granites produce high radon concs (Brutsaert et al. 1981). This is returned to high Uranuim conc.

Radon is a member of occurring uranium contains more than 99% ^{238}U by mass (Baum et al. 2002) and radium ^{226}Ra is the intermediate parent of radon, when it is decayed radon nucleus emanates of alpha particle (a helium nucleus) and only radon fraction will be dissolved in confined groundwater or soil. The emanating power of radon is defined as atomic fraction that releases from the total number of solid (Tanner 1980). If Radon atom is close to confined filled pores spaces with water, it dissolved in water. The water media is extremely aided to increase the emanating power of solid knowing that most radon come from an existing radium in shallow surface layers.

Temporal Variation of Radon Emission

Radon gas is chemically not active and its conc do not correlate pH, conc of dissolved ions and other chemicals when it is in water (Senior et al. 1997, Davis and Watson 1990). Natural abstracted groundwater has low radon concs due to high pumping discharge rates from gravel aquifers to satisfying a republic water demand. However small and private capacity water supplies may have radon concs higher by 3 to 20 times (Hess et al.1985).

Many workers in this field have discovered that radon in water offers different concs when separate sampling rather than continuous sampling. (Sloto, 2000) indicated that radon conc changes with time as a result of dilution by a natural recharge. It is also noted there is no seasonal variations in concs but it is directly changed with depths.

Behavior of radon conc during continuous pumping of polluted groundwater was found by Fukui (1985), McHone and Siniscalchi (1992), Hightower and Watson (1995) and Freyer et al. (1997) increases continuously and rapidly during purge as "S" curve and radon conc is depending on recent amounts of pumped groundwater. Briefly, it is agreed by many researchers local geology with a specified pumping conditions during sampling reflects temporal variation. All researchers observed that early hours offered lowest radon concs and in the later day concs increases by about 58%, anyway they agreed to use the stable radon conc periods of radon as a representative values to be evaluated and treated as was undertaken in this research.

Significance of Study

In recent decades, remediation calls for environmental pollution by radon gas (^{222}Rn) in drinking and groundwater of Hashyimia Region were raised up. Since people used to drinking the polluted water with ^{222}Rn there is no wonder a high monthly injuries number with cancer disease is encountered. Field and laboratorial tests proved that Radon gases are emanated during groundwater extraction for different purposes. Anyway radon concs are consequently exceeded the allowable limits according to *world health organization*. Hashyimia Region is a part of Iraq economically depends upon agricultural production, correspondingly, people are always in contact with available water resources category which may be assessed in a rainfall, surface water and groundwater extraction of the unconfined water bearing stratum. Accordingly any environmental contamination by a radio-active elements will reflect a cancer disease.

Purposes of Study

The main purposes of this research are mainly traced the radon conc sources in surface water and groundwater and putting a hydrogeologic dilution technique for reducing its conc below the allowable limits (100Bq/L) corresponding to WHO.

General Description and Location

Hashymia Area of about 100 km^2 is located between longitudes (44º 36′ – 44º 47′) and latitudes (32º 18′- 32º 27′). The area constitutes a network of Hilla River and many local stream i.e. Sarrea, Kids, Khamisya, Awadel, and Zabbar streams. Most a renewable groundwater storage primary comes from the interflow of these existing surface boundaries and secondary from an infiltration recharge resulting from seasonal agricultural activities and a short duration rainstorms. In addition the area constitutes many drains as shown in the location map of Fig. (3).

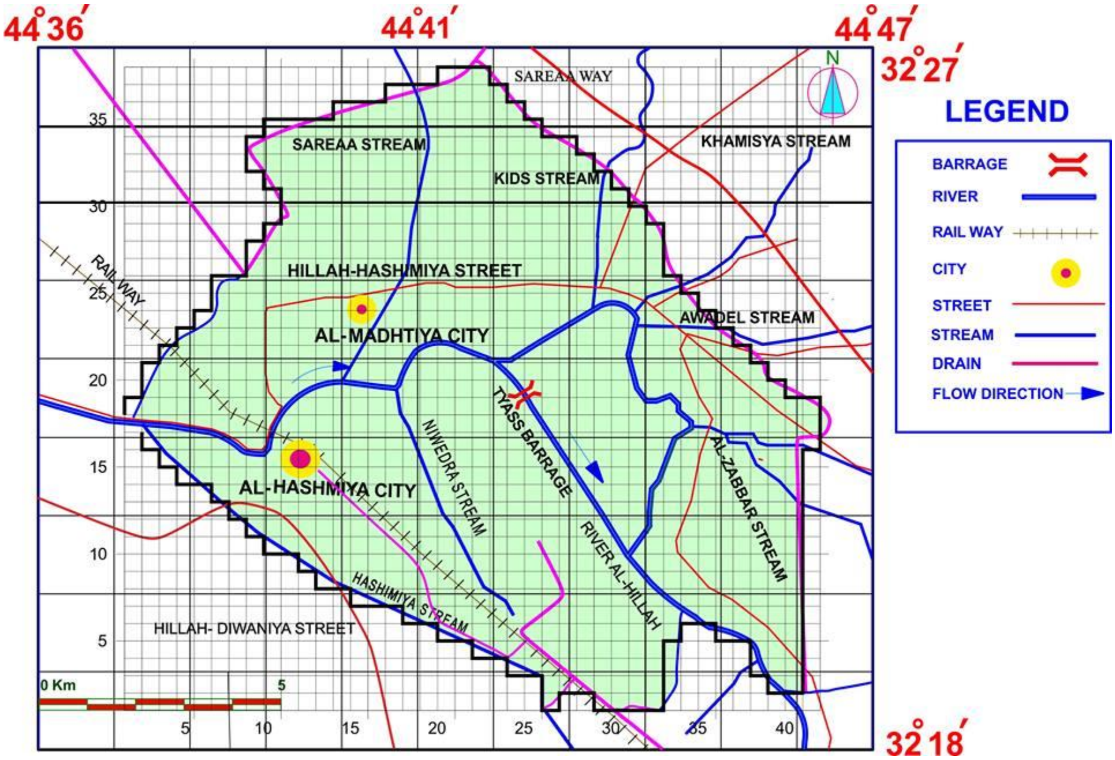


Fig.(3) Geographic Map of Hashymia Area

Geography & Topography

Hashymia area seems to be a flat. The highest part of 27m above sea level in the west whereas the lowest one of 24 m above sea level is located in east. The first glance to the hydrologic system, one concludes that the surface water category is composed of a natural river and streams water ways as shown in the topographic map of Fig.(4).

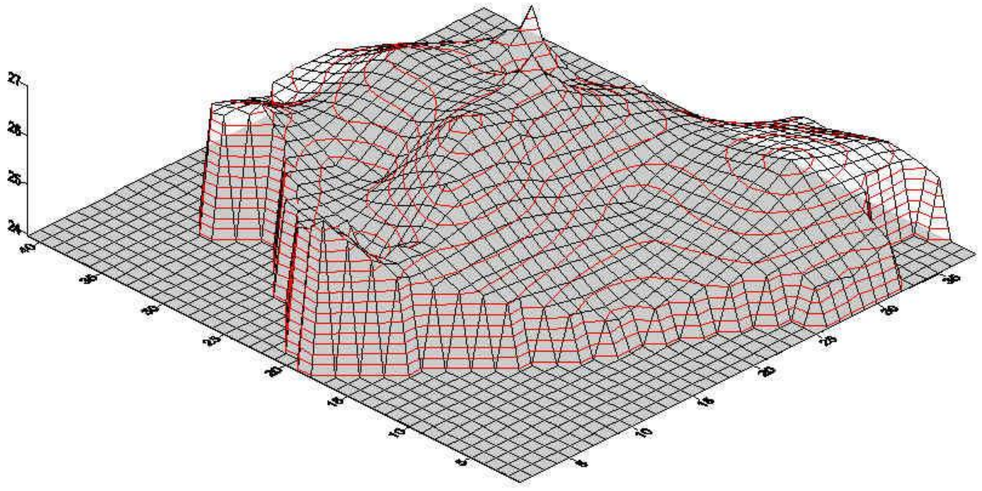


Fig.(4) Topographic Map of Hashyimia

Tracing of Radon in Hashyimia

A short term pumping period has been followed in tracing of radon conc in Hashyimia area by drilling 20 wells which scattered overall the area. The locations of these wells were selected randomly depending on many private and social circumstances such as owner's permission, administration priorities and researcher ability and possibility. Fig.(5) present the wells location.

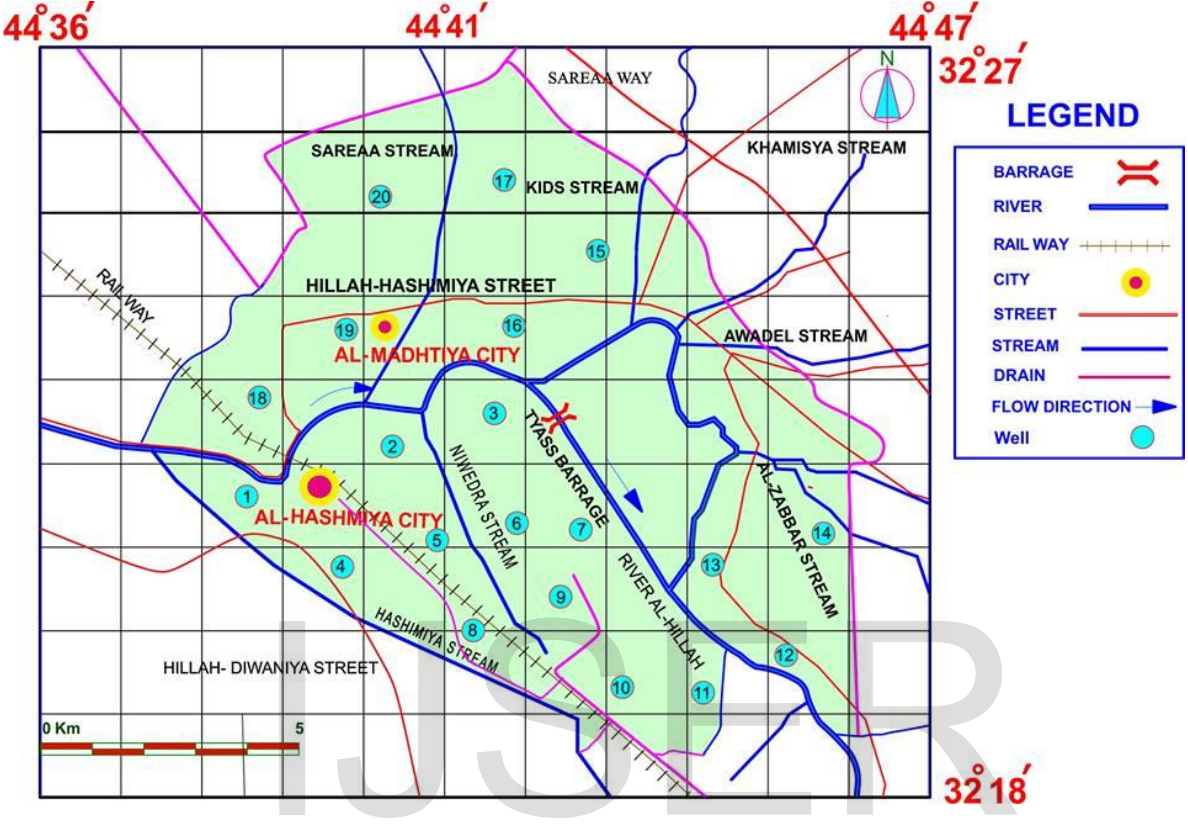


Fig.(5) Wells Locations over Hashyimia Area

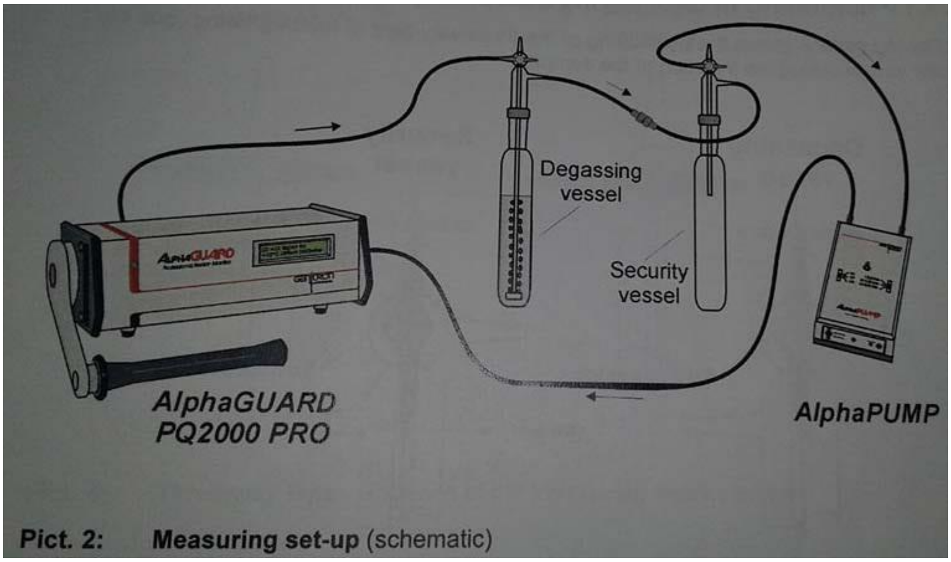
Preliminary testing of polluted groundwater samples with radon which obtained from an open well offered concs less than the dangerous limits, since samples were taken from water exposed to the atmosphere. Water with radon concs of 1000 Bq/L or more are significantly inconvenient for any consuming whereas for conc equals or exceeds 100 Bq/l are of significant importance and can be used for human consumption after some types of remediation.

Anyway, a continuous pumping of (3 hours) duration was carried out and samples were taken from all wells each half an hour. The samples were taken and kept in a closed pockets to prevent releasing of radon into atmosphere in order to test the real concs in a polluted groundwater.

Laboratorial Testing of Radon Conc

A 140 samples of polluted groundwater with radon were collected and brought to the laboratory of *Babylon Environmental Directorate*, each 7 samples for one well of the 20 scattered wells.

The device of *AlphaGUARD PQ2000 PRO* should be setup as shown in Fig.(6). The device is a collection of *AlphaGUARD PQ2000 PRO*, *AquaKIT* and *AlphaPUMP*.



Pict. 2: **Measuring set-up** (schematic)

Fig.(6) Setup of *AlphaGUAR PQ2000 PRO*, *AlphaPUMP* & AquaKIT,
(manual of *AlphaGUAR PQ2000 PRO*)

Standard Steps of Specimen Testing

The manual includes 10 standard steps that had been followed for testing the contaminated water with radon, they are as follow:-

1- Setup the equipment *AlphaGUAR PQ2000 PRO*, *AlphaPUMP* and AquaKIT,
2- Switch on the AlphaGARD monitor and chose a measuring mos of 1 min Flow.
3- Bring the three-way taps at degassing and security vessel into 3 o'clock position foreseen for sampling.
4- Dock the plastic injection with a water sample that to be measured to the vertical connection socket of the degassing vessel.
5- Emptying the plastic injection slowly into the degassing vessel.
6- Bring the three-way taps of the degassing and security vessel immediately into the 6 o'clock position for a measuring mode.
7- Remove the plastic injection of a vertical connection socket of the degassing vessel.
8- Set the AlphaPUMP performance level switch to a flow rate of 0.3 L/min.
9- Bring the operation mode switch of AlphaPUMP in position "ON"
10- After 10 min rotating operation switch mode of AlphaPUMP to position "OFF"

Methodology of ^{222}Rn Conc Determination

Radon conc estimating basically depends upon the indicated radon conc in the monitor. This value is not the required radon conc since some of radon is diluted by air within the measurements setup and small part of it remains diluted in a watery phase. To quantify the diluted radon, the interior volume of the measurement set-up (V_{system}) is required. The remaining quantity of radon can be determined by introducing the coefficient k. Briefly Eq.(1) is the basic form for radon estimation

$$C_{water} = \frac{C_{air}*\left(\frac{V_{system}-V_{sample}}{V_{sample}}+k\right)-C_o}{1000} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: C_{water}: Radon conc in ware sample (Bq L^{-1}), C_{air}: Radon conc in the measuring setup after spelling the radon (Bq m^{-3}), C_o: Initial conc in the measuring setup before sampling (Bq m^{-3}), V_{system}:

Interior volume of the measuring setup (mL), S_{ample}: is the measuring water sample volume (mL), and k: is the radon distribution coefficient.

Calculation of Radon

In order to estimating radon conc the measuring set-up parameters should be known as: V_{system}=1102 ml, V_{sample}=100ml, k=0.26 and C_o=0 Bq m^{-3}. Accordingly Eq. (1) may be abbreviated to:

$$C_{water} = \frac{C_{air} * 10.28}{1000} \qquad \ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Pumping process Technique

An efficient pump was setup at each well separately and the pumping process is exactly continued to (3hrs) with a constant pumping discharge of (5L/s). Seven samples are taken for each well.

Briefly, the radon concs are estimated according to Eq.(2) for the 140 samples and represented graphically in Figs. (7 to 10).

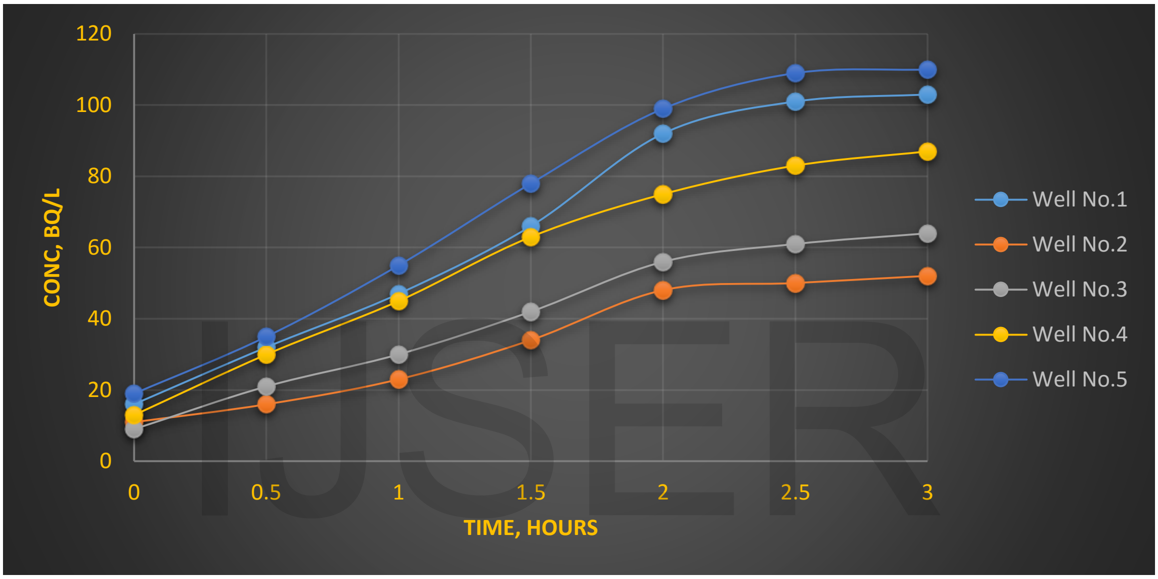


Fig.(7) S-Curve of Radon Conc for Wells (No.1, 2, 3, 4 & 5)

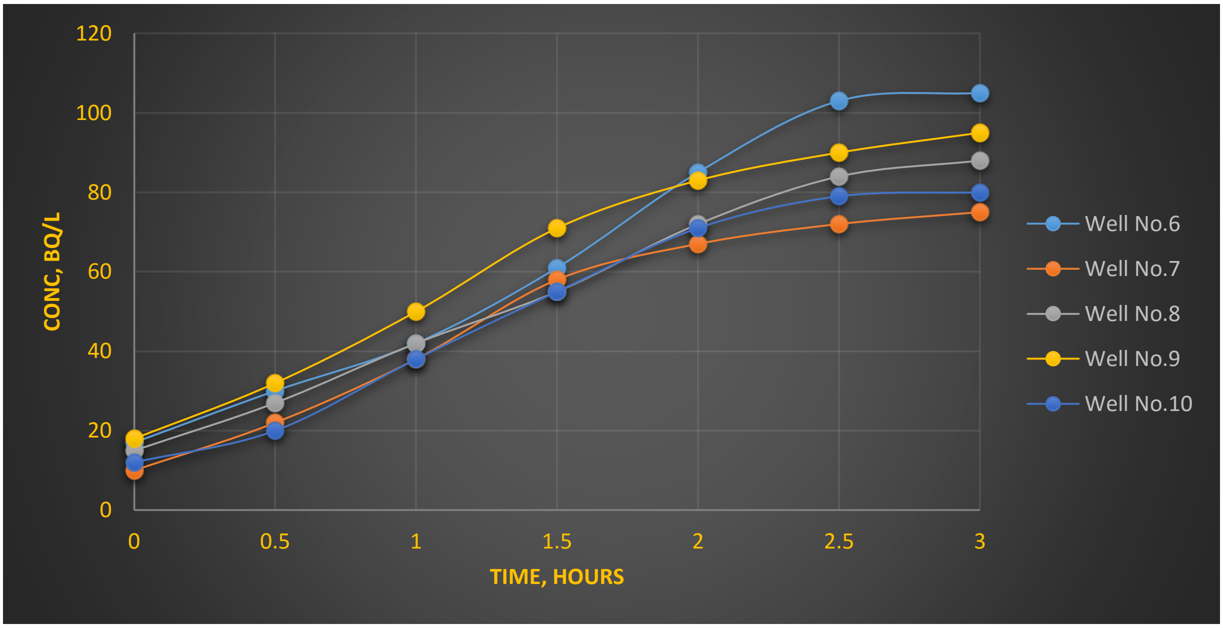


Fig.(8) S-Curve of Radon Conc for Wells (No.6, 7, 8, 9 & 10)

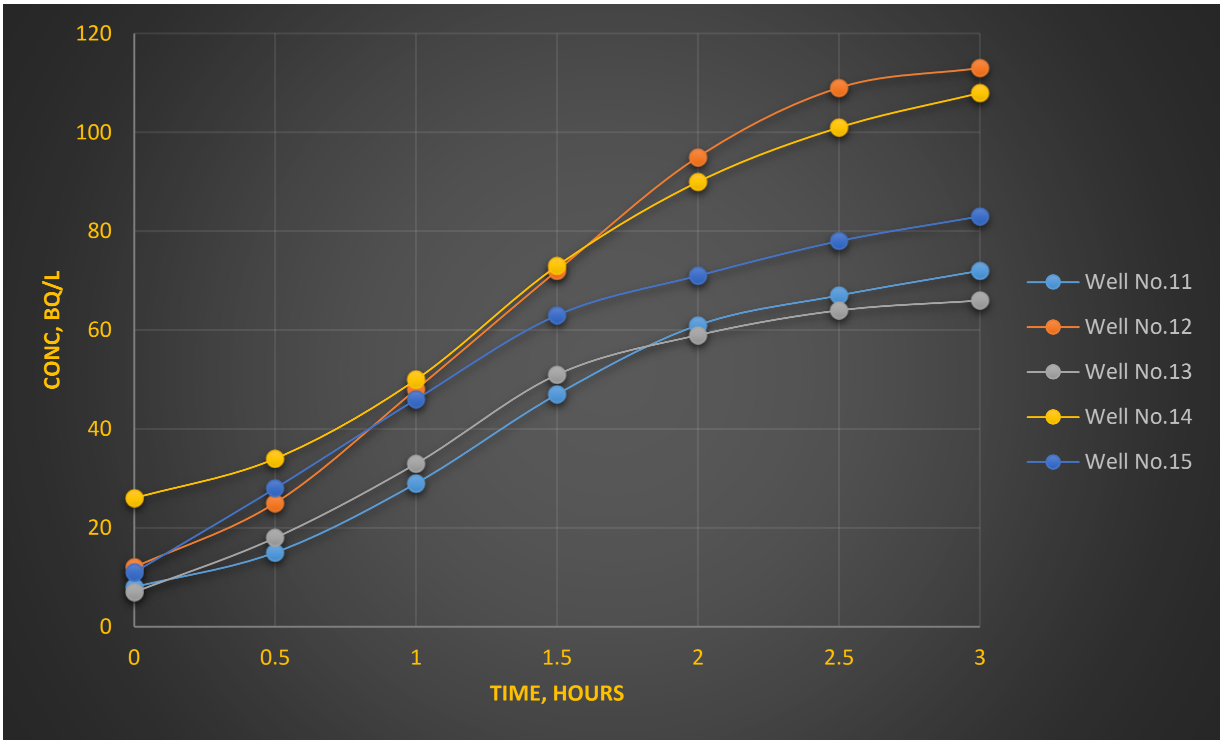


Fig.(9) S-Curve of Radon Conc for Wells (No.16, 17,18, 19 & 20)

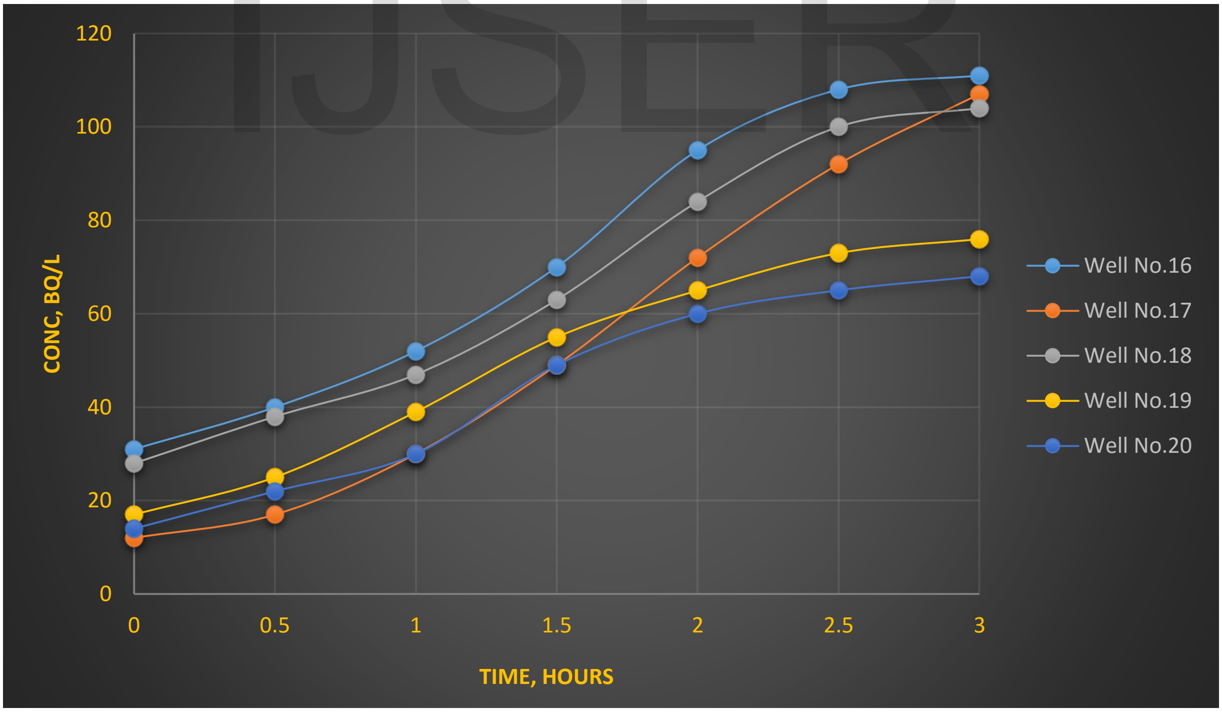


Fig.(10) S-Curve of Radon Conc for Wells (No.16, 17, 18, 19 & 20)

Temporal Variation of Radon Concs in Hashyimia

The results of a short period continuous pumping for the twenty scattered wells in the study area are shown Figs.(7 to 10). Some of these wells, namely as (well No.1, 5, 6, 12, 14, 16, 17 and 18) as included in Table (1) exceeds the allowable limits of radon conc [100 Bq L^{-1}] at the end of pumping period (3hrs) in groundwater as it is recommended by WHO.

The physical interpretation for the ascending concs of radon with time during pumping process is returned to a releasing process of radon into atmosphere when the concentrated water with radon is exposed to air. Figs.(7 to 10) reveals that around the vicinity of the pumping wells the initial concs are in their minimum values since the polluted water lost most of it radon conc due to the exposure of the aquifer storage to the atmosphere. But as a pumping process is continued, the confined groundwater in deep water bearing stratums and fractures flowing toward the centers of the pumping wells and immediately the tested specimens were taken corresponding to a standard process before groundwater releasing its natural radon conc into atmosphere. This is interpreted why radon concs increased with time to exceed [100 Bq L^{-1}]. A good inspection of Figs (7 to 10) one observes the followings:-

1- Some wells reach a constant radon conc such as (Wells No.1, 5, 6, 10 and 16) after (3hrs).
2- Other wells still show increasing in radon conc after (3hrs) of pumping process.
3- It is observed that (Well No. 17) which is indicated in Fig.(10) still reflects a sharp increasing in radon conc and its conc is probably exceeding (140 or even 150 Bq L^{-1}) after 4hrs of continuous pumping process.
4- It is expected that radon concs are exceeded the presenting values in Figs.(7 to 10) if the roof of pumping discharges increase to (10 or 20L/s).

Note: The mathematical model reveals that the safe yield of the unconfined aquifer of Hashymia is (6.5L/s).

Table (1) Maximum Concs of Radon

Well No.	Cartesian Coordinates		Conc (Bq L^{-1})
	X	Y	
1	8	15	103
2	15	18	52
3	21	19	64
4	14	11	87
5	18	13	110
6	21	14	105
7	25	14	75
8	21	7	88
9	24	10	95
10	28	5	80
11	31	5	72
12	37	8	113
13	38	12	66
14	32	12	108
15	25	29	83
16	21	24	111
17	20	32	107
18	7	20	104
19	12	25	76
20	14	32	68

Spatial Variation of Radon Concs in Hashyimia

Experimental and field applications of modeling processes and environmental remediation usually requires to draw a clear figure about a spatial distribution of any pollutant in surface and subsurface water alike. Accordingly, a spatial distribution contour map of extreme radon concs in Hashyimia aquifer is shown by the contour map of Figs. (11 and 12).

Fig.(11) indicates that a radon concs exceed the allowable limits [100 BqL^{-1}] is occurring in three positions overall the study domain.

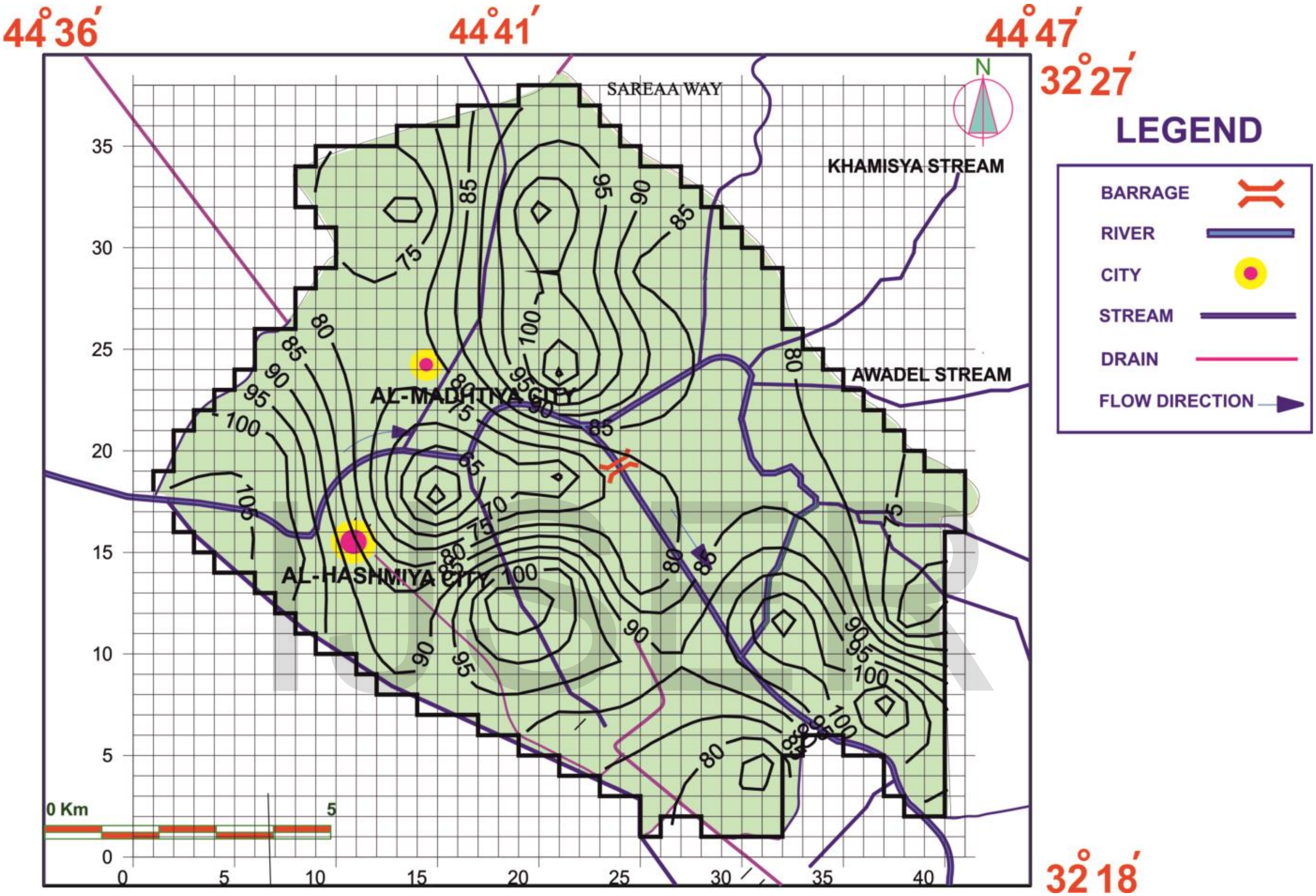


Fig.(11) Spatial Distribution of Radon in Hashyimia Aquifer,[Bq L^{-1}]

Preparation of Hashymia Aquifer to environmental Remediation

A preliminary preparations and requirements should be achieved before any environmental remediation, they are;

I) Assessment of the polluted aquifer extents.

II) Evaluation of the aquifer groundwater storage within the polluted quifer.

III) Development of a groundwater mathematical model.

I) Assessment of the Polluted Aquifer Extents

Since Hashymia is a wide aquifer in horizontal extent and is too shallow, it is decided to assigning a significant divisions for many logical reasons, among them are;

1- Some parts are polluted with radon whereas another are not.

2- The area is naturally divided by a natural and artificial streams.

3- A division into smaller parts eases the remediation process.

Subsequently, the area of the aquifer is divided into seven sectors namely as; (sector 1, 2, 3……, 7). The division model is shown in Fig.(13).

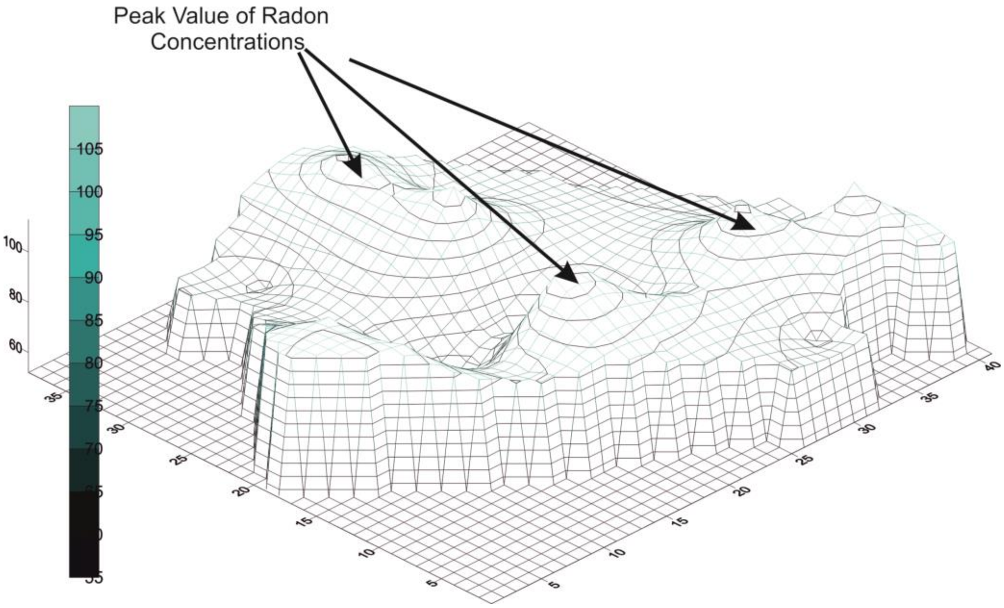


Fig.(12) Spatial 3D Radon Distribution

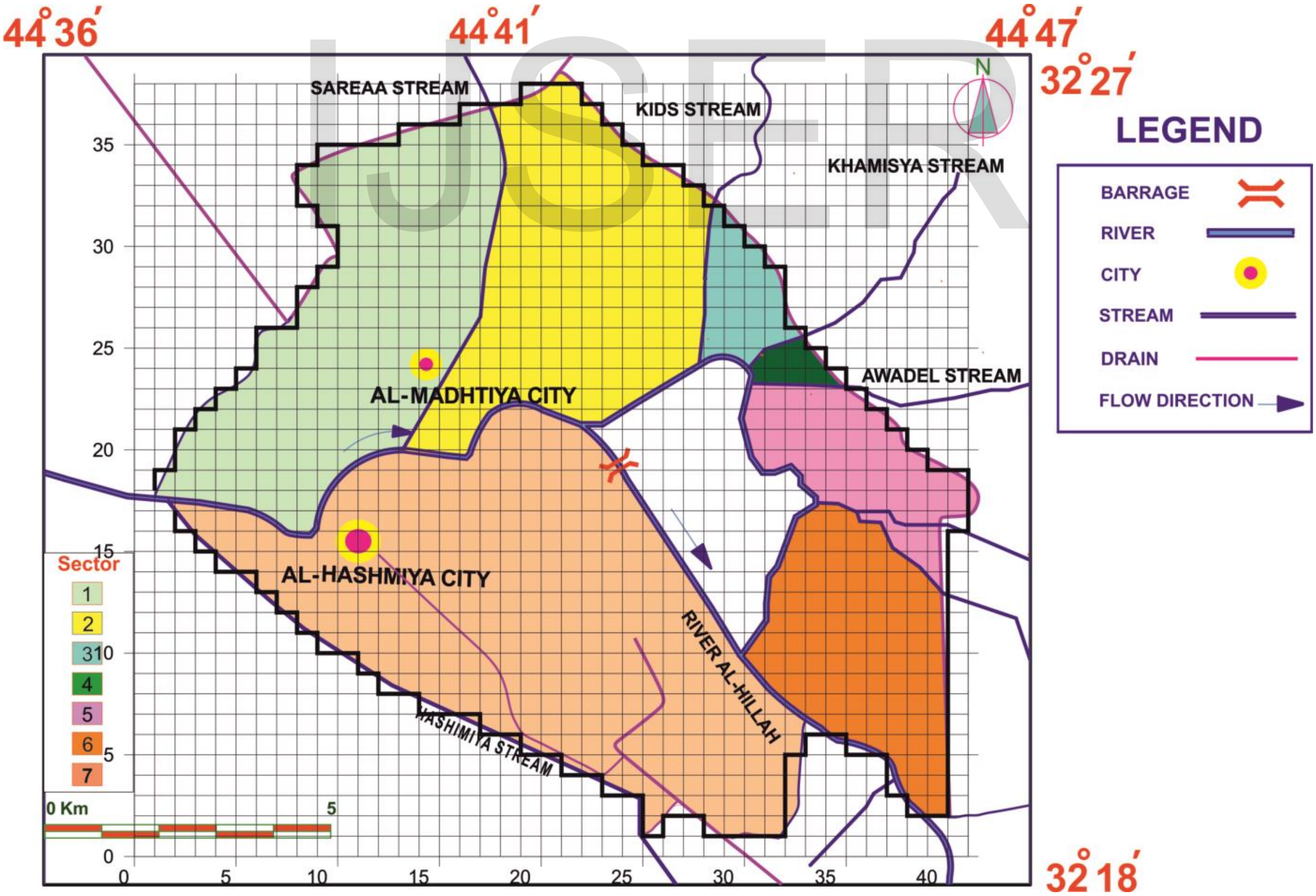


Fig.(13) Divisions of Hashymia Aquifer

Referring to Fig.(14), one observes that only aquifer sectors (2, 6, and 7) are infected by radon conc exceeding the allowable limits, therefore the next environmental and Hydrogeologic remediation will be focused to these sectors and in any other sector may be infected in the future.

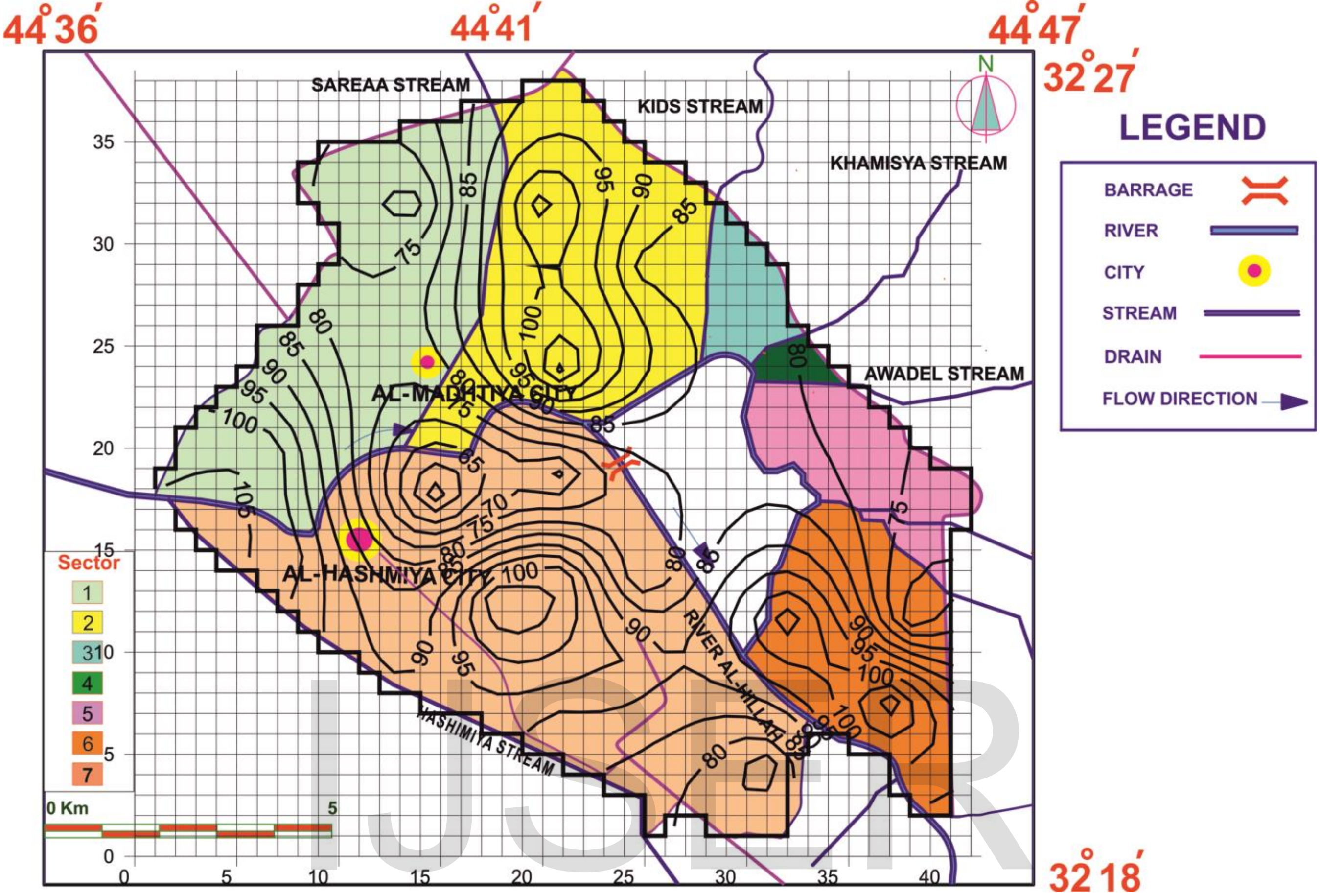


Fig.(14) Radon Conc Distribution over Sectors

II) Evaluation of aquifer groundwater storage

Groundwater storage may be defined as the amount of water saturated the pores of the full zone of the existing bearing layer via a geologic formation. The strategic storage of groundwater can be defined by the following equation.

$$V = A * n * d * Nm \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where : V: is a strategic storage of groundwater (m^3), A: is the area of each mesh which equals ($111111m^2$), n is an average porosity of the bearing layer, d: is a thickness of the bearing layer at each individual mesh and Nm: is a number of meshes per individual sector.

1- Determination of Porosity

In order to find out the porosity of the bearing layer easily, let us consider a cross sectional control volume in the geologic formation of Fig.(15) and start with porosity definition (n).

$$n = \frac{v_v}{v} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where:v_v: is a volume of voids, (m^3) and v is a total control volume (m^3), and

$$G_s = \frac{w_s}{v_s \gamma_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where G_s: is a specific gravity of solids,w_s: is a weight of solids (KN),v_s: is a volume of solids (m^3) and γ_w is a unit weight of water (KN/m^3).

Eq.(4) can be written in the following form:

$$n = \frac{v - v_s}{v} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Eq. (5) may be reformed as:-

$$v_s = \frac{w_s}{G_s \gamma_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Combining Eq. (6) and Eq.(7) to obtain;

$$n = \frac{1 - \frac{w_s}{G_s \gamma_w}}{v} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Further simplification of Eq. (8) offers:-

$n = \frac{1}{v} - \frac{\frac{w_s}{v}}{G_s \gamma_w}$ Which leads to

$$n = 1 - \frac{\gamma_d}{G_s \gamma_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

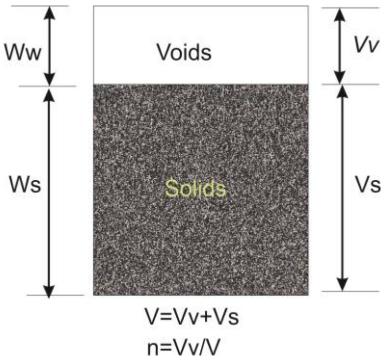


Fig.(15) Cross Section of a Geologic Formation

Where γ_d: is a dry density of natural soil sample in (KN/m^3), if the water density is approximated to be (9.81KN/m^3) therefore Eq.(9) may be written in a final form of:

$$n = 1 - \frac{\gamma_d}{9.81 G_s} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

2- Experimental work

During the digging of the wells in Hashyimia aquifer, a soil samples were carefully taken and sent to the laboratory for different depth within the geologic formation of the aquifer to find out the *dry density* and *specific gravity*. The dry unit weight and specific gravity were tested experimentally at each well and Eq.(10) was used to calculated the average porosity at each well. The porosity values were calculated at each sector in Table (2) and represented graphically in the contour map of Fig.(16).

Table (2) Porosity Algorithm

Sector	Cartesian Coordinates , km		Ave. Dry Density (γ_d) KN/m^3	Ave. Specific Gravity (G_s)	Ave. Porosity (n)
	x	y			
1	12	26	17.6423	2.610	0.310958
2	22	29	17.34899	2.624	0.326029
3	30	27	17.14003	2.664	0.344144
4	33	25	16.68877	2.610	0.348199
5	35	20	17.05076	2.639	0.341379
6	36	11	17.54519	2.601	0.31238
7	18	13	16.55143	2.625	0.357257

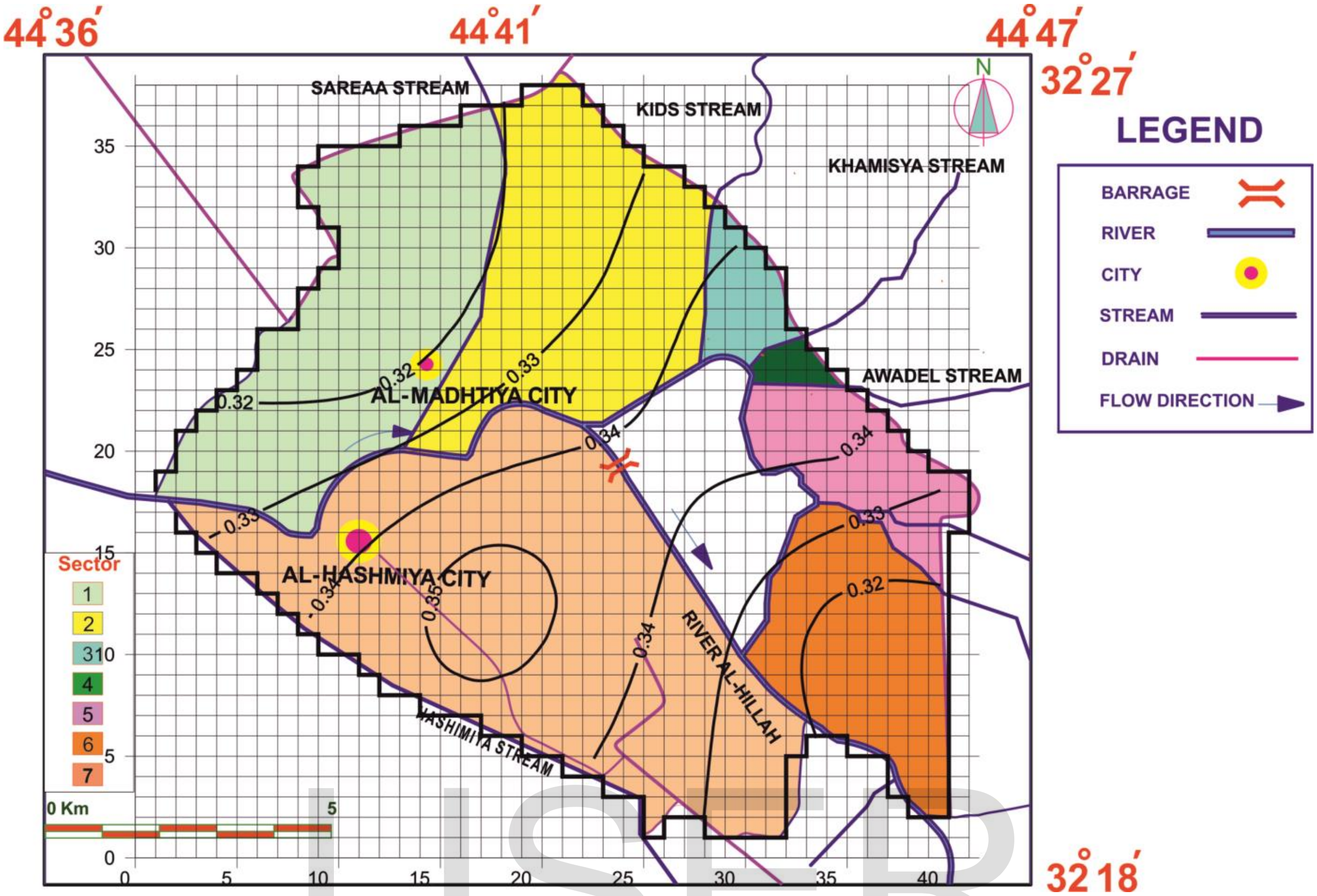


Fig.(16) Porosity Distribution over Hashymia Aquifer

3- Evaluation of Strategic Aquifer Storage

A computer 2D model has been designed for algorithm of strategic storage on the basis of Eq. (3). The structure of the model is illustrated in the flowchart of Fig.(17). The model is basically used a Fortran Language (Micro Soft Developer Studio). After the porosity values were extrapolated overall meshes within the polluted sectors. The model read the input data files of a natural water levels [WL (i, j)], a natural bed levels of the aquifer [(Bot (i, j)] and the interpolated porosity [n (i, j)] and then the aquifer storage is estimated as illustrated in the flowchart.

The model program was run for Sectors 2, 6, and 7 then the resulted strategic storage is shown graphically in the histogram of Fig.(18)

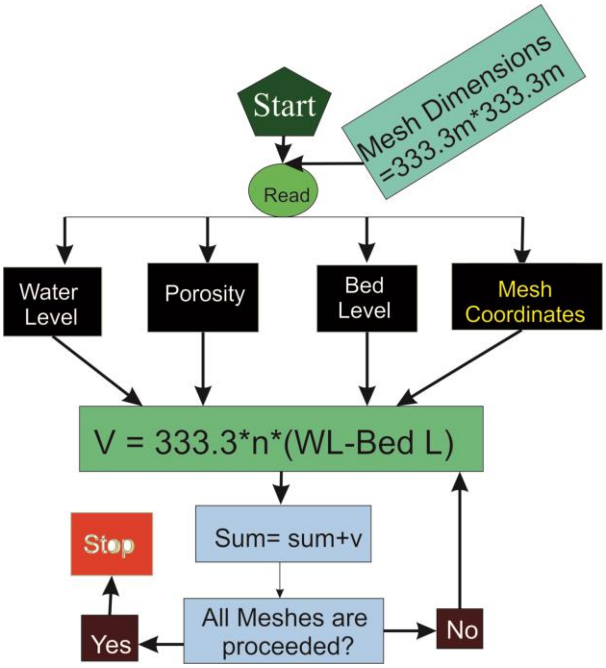


Fig.(17) Flowchart of Strategic Groundwater Storage

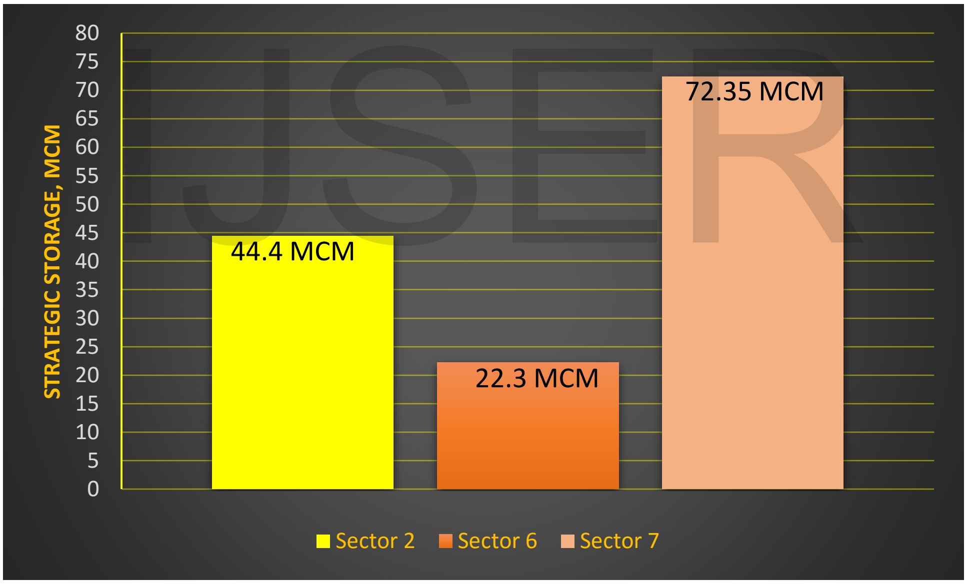


Fig.(18) Strategic Groundwater Storage of a Polluted Sectors

III) Conceptualization of 2D Groundwater Model

A mathematical 2D groundwater model was designed by using a combination between the technology of *FORTRAN LANGUAGE* and *SURFER 12* software. The model is basically based on a finite difference approach which originally represents a numerical solution of a two dimensional partial differential equation of Laplace.

The initial (i.e. No. of iterations and time steps) and the boundary conditions (i.e. initial groundwater levels, constant head boundaries (Hillah river) and the existing drains) data files were lunched into the model. Geometrical data files such as; extents and bed levels of the aquifer, and the physical properties files of the aquifer namely as; specific storage and hydraulic conductivity.

Error term and default data files are the most important files in the modeling process. ***Error term*** *is defined as the summation of all differences between a successive water levels per single iteration.* ***Default file*** *may be defined as a preliminary file prepared to include most necessary constant values of geometrical, physical, and even the error term.*

The first step in the modeling process is the discretization of a model domain into a finite difference meshes to construct the matrix dimension. In this research, the maximum number of columns and rows are denoted by NC and NR which taken as 41 and 38 respectively. The discretization of the domain is shown in Fig.(13)

Briefly, the model was calibrated by comparing the output data of water table levels (simulated WTL) with the observed (measured WTL) as shown in Fig.(19) and verified by comparing its output data files with a theoretical solution of Theis (1935).

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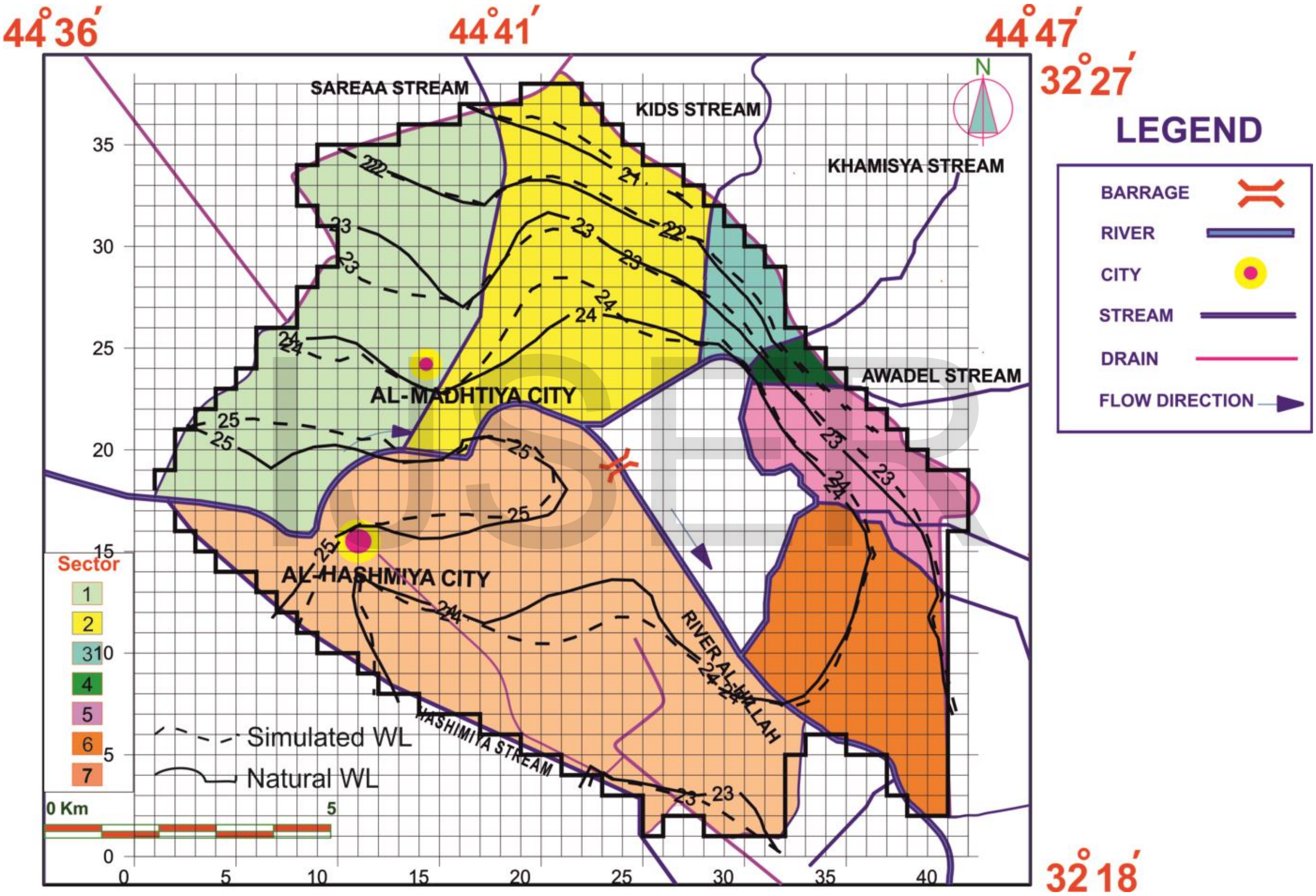

Fig.(19) Comparison between Natural and Natural Water Table Levels

A verification process has been achieved by an arbitrary pumping well which had been chosen at a mesh (24, 30). A pumping process is starting with 100m^3/day up to 900 to observe the response of the unconfined aquifer to the effect of pumping as presented in Fig.(20). It is found that a maximum drawdown has been occurred at the center of the well of (3.4m). The resulting WTL is indicated in Fig.(21) whereas the extents of the resulting drawdown is shown graphically in the contour map of Fig.(22).

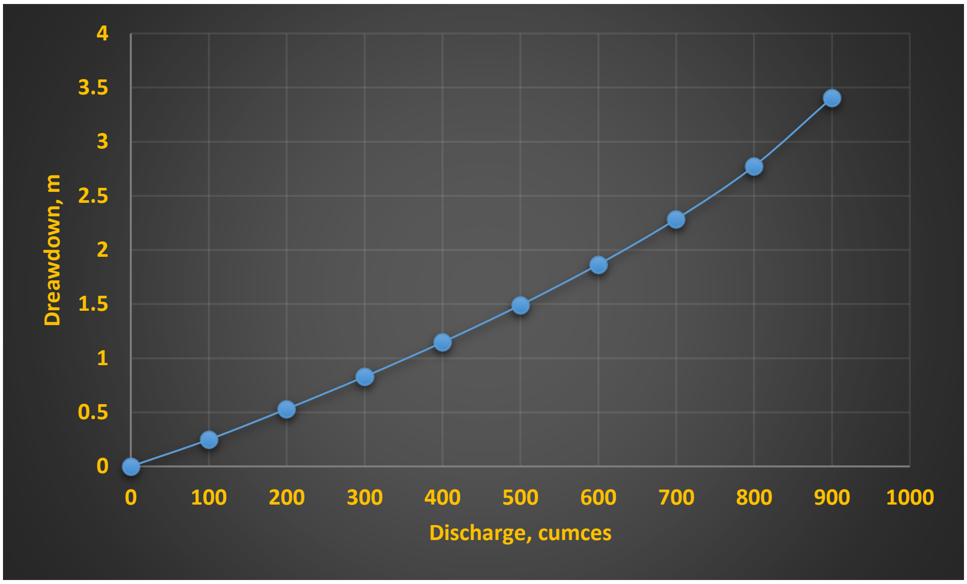

Fig.(20) Discharge Drawdown Curve

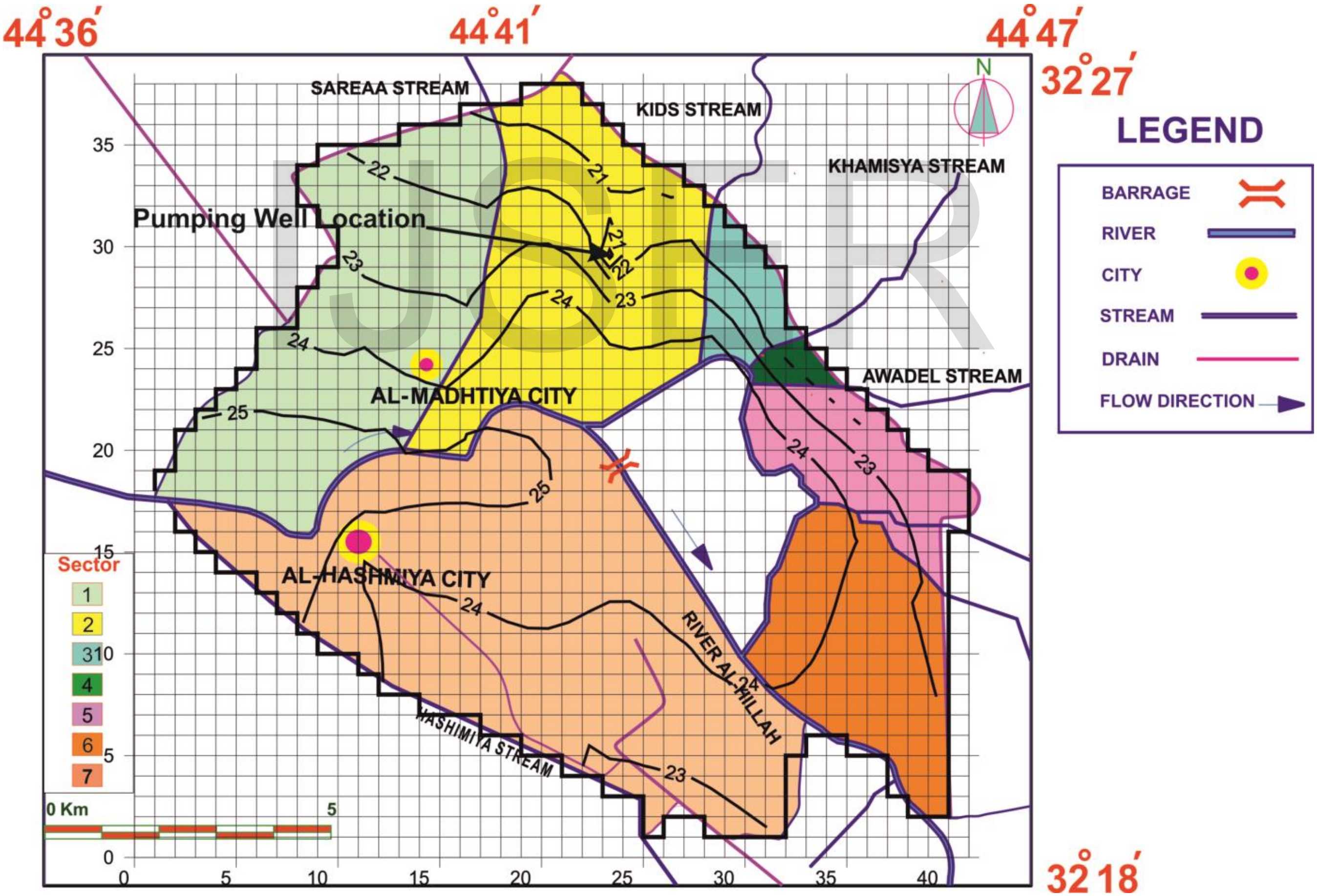

Fig.(21) Resulting WTL Due to Pumping Effect of (900 m^3/day) at Well Location

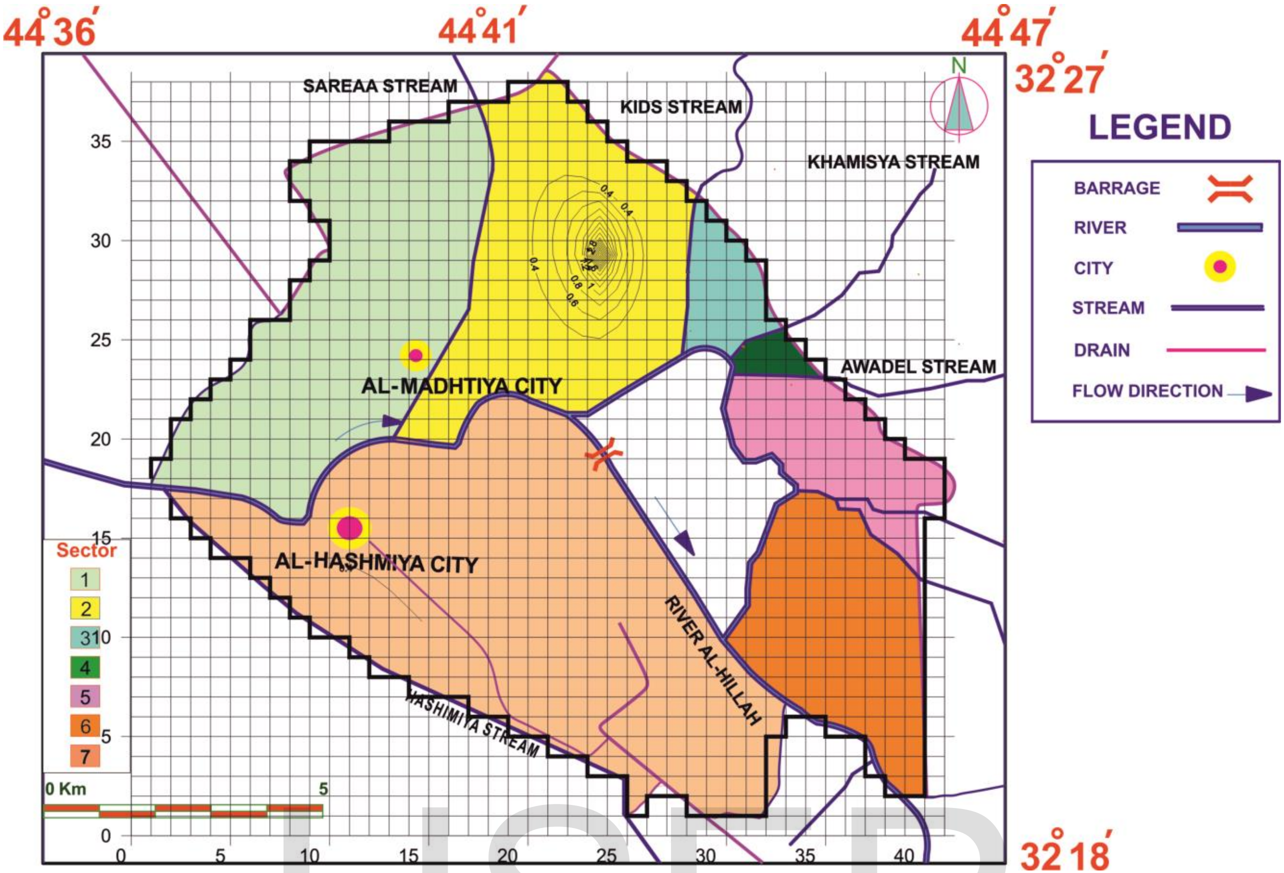

Fig.(22) Responded Drawdown Due to pumping (900m^3/day) at Well Location

Two comparisons have been done to verify the current model, they are:-

1- Time-drawdown relationship has been evaluated between the resulting simulated drawdown curve and theoretical drawdown of Theis solution at 333.3m distance from the pumping well. An acceptable matching has been obtained as presented in Fig.(23).

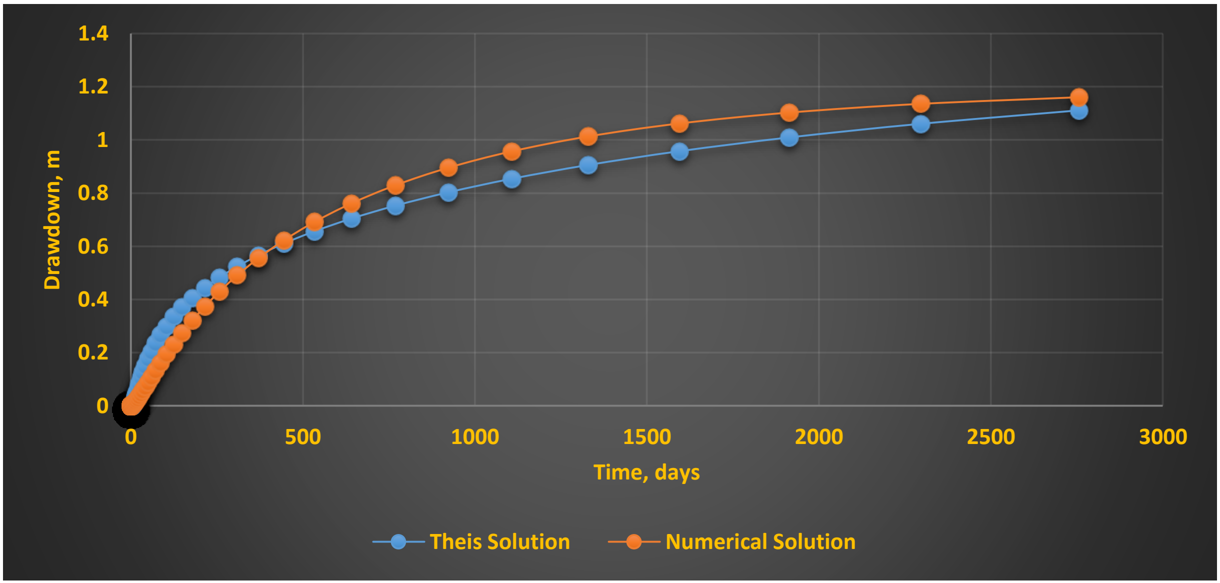

Fig.(23) Time Drawdown Curves Due to Pumping 900m^3/day at Distance 333.3m from Pumping Well Location

2- A distance- drawdown relationship are also compared between Theis solution and the resulting simulated results, this is shown in a cone of depression of Fig.(24).

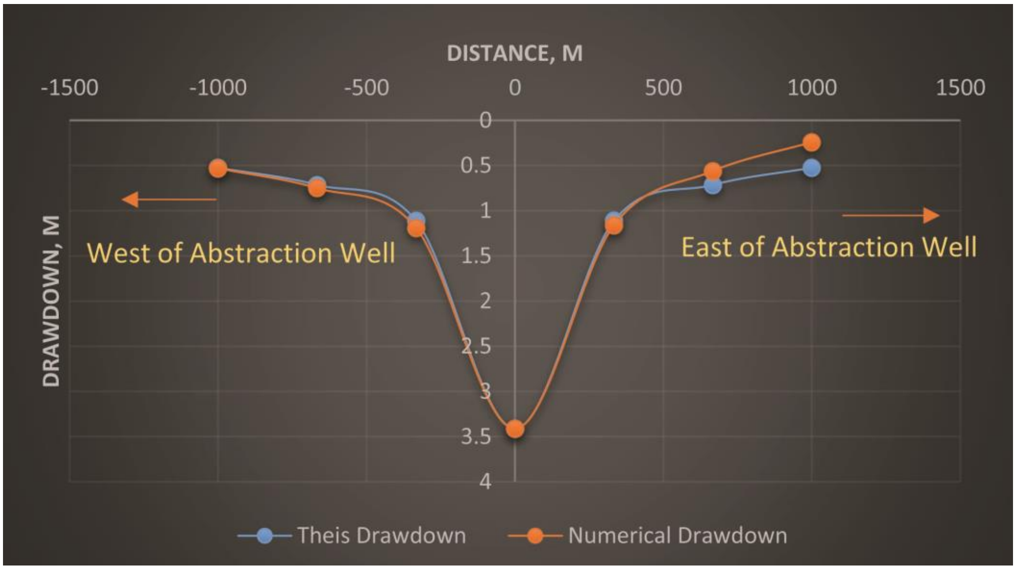

Fig.(24) Resulting Cone of Depression Due to Pumping Effect of (900m^3/day)

Environmental Remediation of Infected Sectors & Conceptualization

A hydrogeologic Remediation of an infected aquifer requires a good understanding of a mechanism of groundwater flow regime. Anyhow, the remediation process is composed of several basic rules, they are as follows:-

- I) Construction a flow net of Hashymia Aquifer.
- II) Determination of :-
  - a- Aquifer safe yield.
  - b- Injection capacity (Ic) of the aquifer.
- III) Estimation of strategic storage (*achieved previously*).
- IV) Dilution of the aquifer.

I) Construction a Flownet of Hashymia Aquifer

The construction of Hashymia flownet was confined to the polluted sectors (2, 6, and 7) in order to develop the remediation policy. Anyway, the flownet of the considered sectors is shown in Fig.(25). Fig.(25) also reveals that sector (2) of an area of (17.3km^2) is bounded between Sareaa and Kids streams from west and east respectively, whereas it is bounded by a drain and Hillah River at north and south respectively.

In general Fig.(23) shows at groundwater flow lines are toward the north and parallel to Sareaa and Kids streams.

Sector (6) of and area equals (10.6km^2) is also bounded by Hillah River from two sides and by Zabbar stream at the north and the groundwater flow lines are toward the east.

Sector (7) of (35.3km^2) is also bounded by Hillah and Hashymia stream with flow lines are directed toward the south.

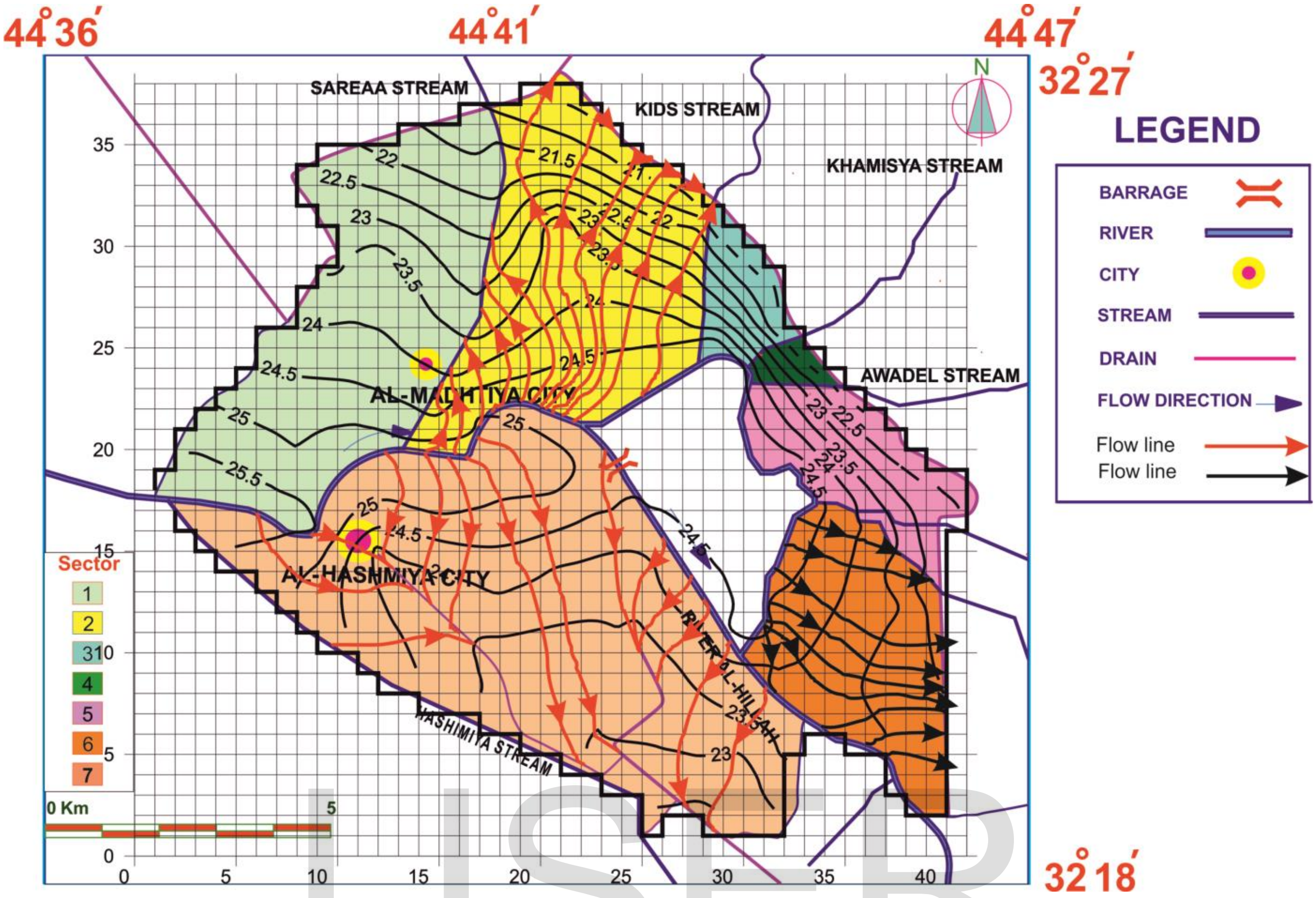

Fig.(25) Flownet of the Polluted Sectors of Hashiymia Region

II) Evaluation of a Safe Yield & Injection Capacity

A- Safe Yield Evaluation

The safe yield of an aquifer may be defined as a maximum discharge that can be drawn from an aquifer provided that the resulting drawdown should be no more than (30%) of the bearing layer thickness.

Subsequently, three pumping wells were arbitrary selected for evaluating the amount of a safe yield that will be used for dilution processes and remediation. The Cartesian coordinates and locations of these wells are included in Table (3) and indicated in Fig.(26) respectively. The model was run for a long period of (2755 days) to evaluate the safe yield of the aquifer. A pumping processes were initialized with discharge of (1L/s) and the resulting drawdowns were immediately observed and recorded.

The safe yield results of the three selected wells at a steady state condition as indicated in Table (3) and the transient drawdown variations are shown in Figs (27 to 29).

Drawdown results discussion

Figs.(27 to 29) show that the drawdown is obtained in a steady state for each a specified discharge and it is increased proportionally with increasing of the discharge. The figures reveal that the simulated WTL reduces successively with increasing of discharge. The pumping process and discharge increasing are stopped when the drawdown percentage converges to 30% of a bearing layer thickness. Figs.(27, 28, and 29) also show that the drawdown% converges to 30% with a safe yields of 6.5, 8.8 and 6.5 l/s and corresponding drawdowns of 1.75, 2.137, and 1.977m at the centers of the pumping wells of the sectors (2, 6 and 7) respectively. This also indicated in Table (3) and the resulting cones of depression are shown in Fig.(30).

Table (3) Injection and Discharging Well Location

Sector No.	Area (km^2)	Injection Wells				Discharging Wells			
		Cartesian Coordinates		Cartesian Coordinates	WTL Rise (m)	Cartesian Coordinates		Safe Yield, (L/s)	Drawdown (m)
		X	X			X	Y		
2	17.323	20	20	11.65	-1.61	25	29	6.5	1.75
6	10.664	33	12	7.1	-1.23	37	9	8.8	2.137
7	35.3262	20	25	11.1	-1.3588	20	12	6.5	1.977

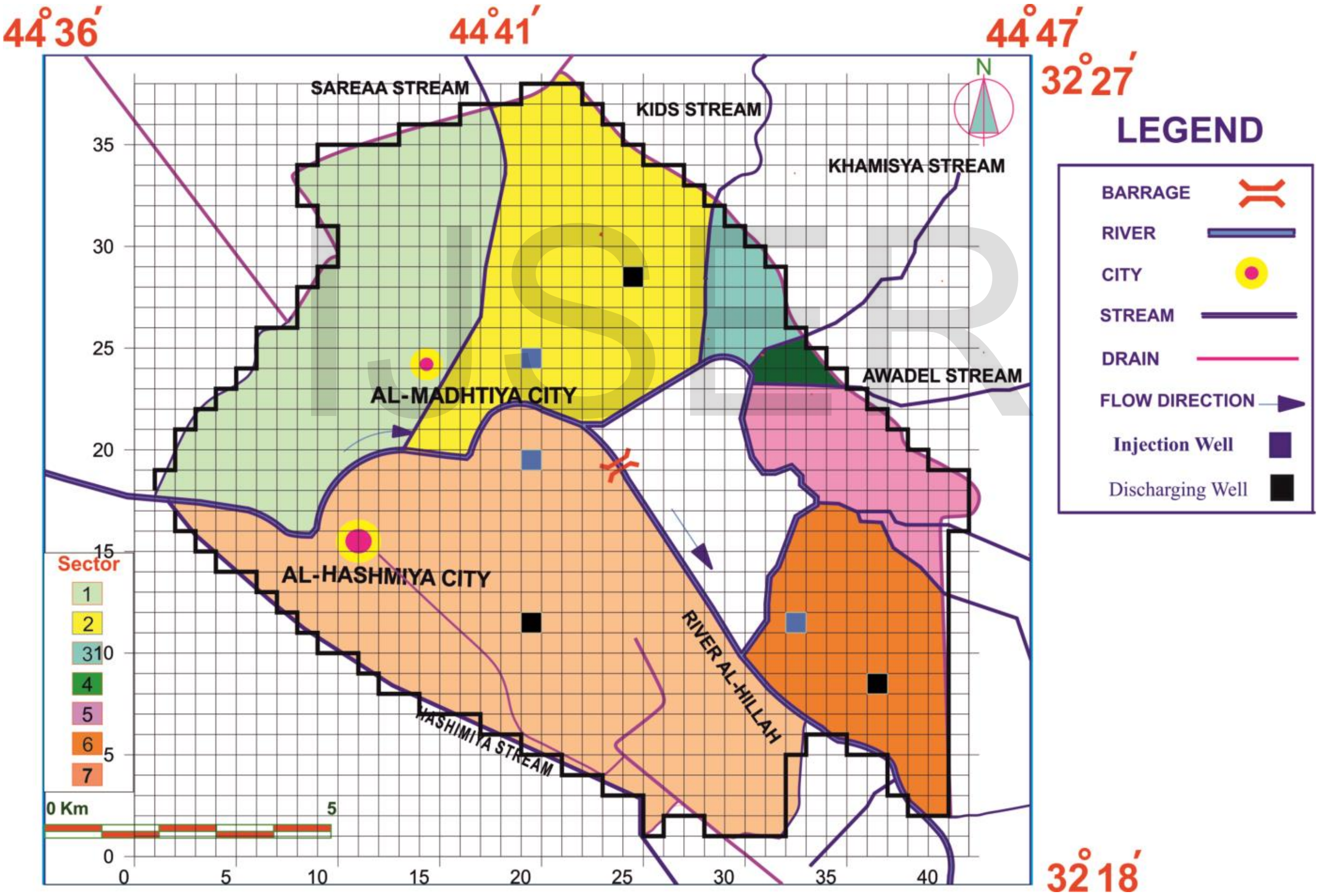

Fig.(26) Distribution of Injection and Discharging Wells

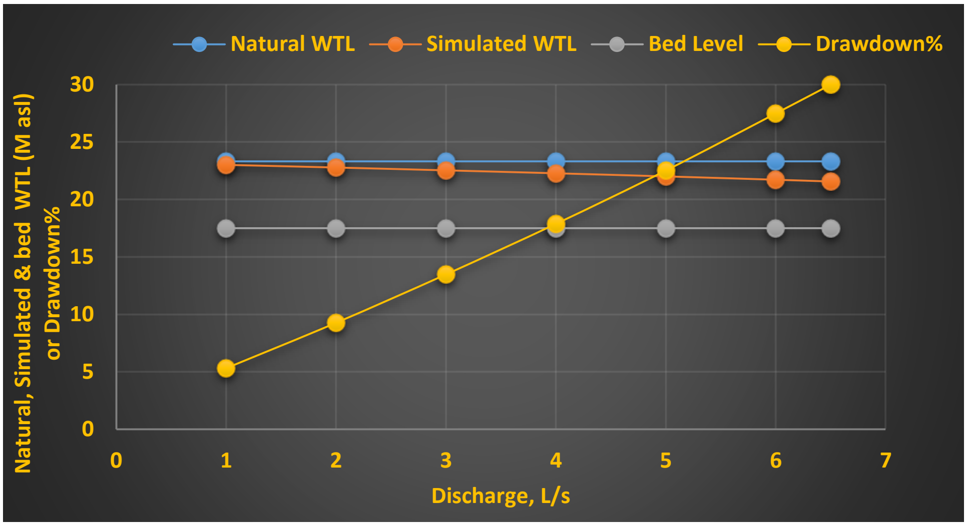

Fig.(27) Drawdown-Discharge Stages Curve of Sector (2) at Well Location

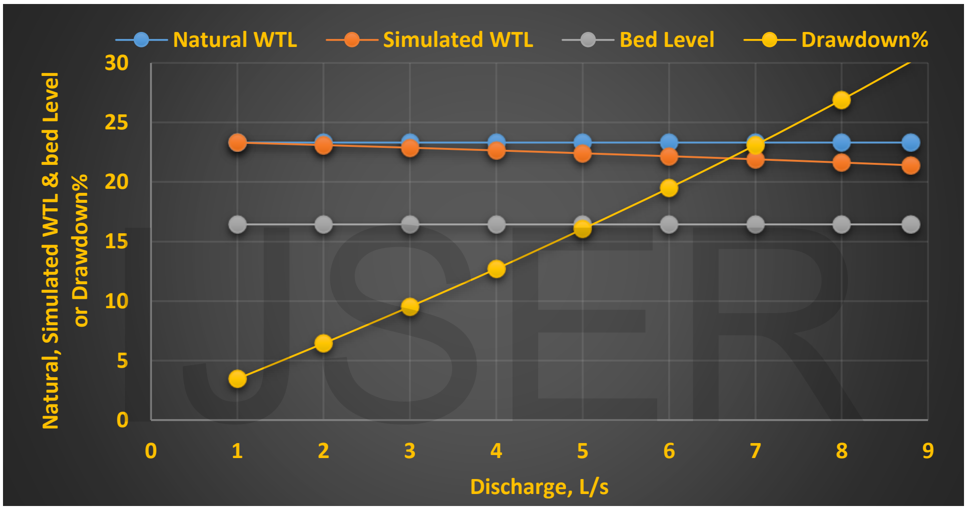

Fig.(28) Drawdown-Discharge Stages Curve of Sector (6) at Well Location

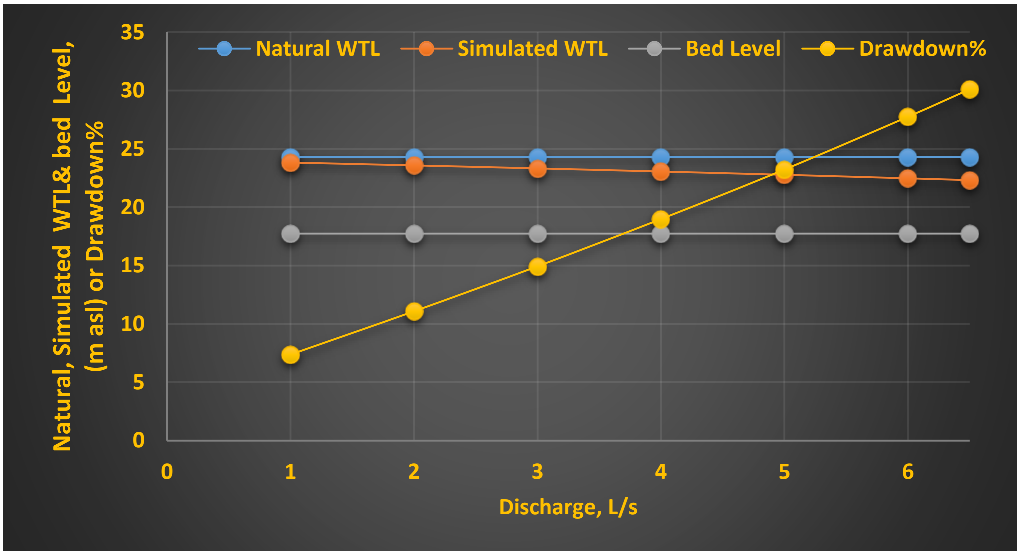

Fig.(29) Drawdown-Discharge stages Curve of Sector (7) at Well Location

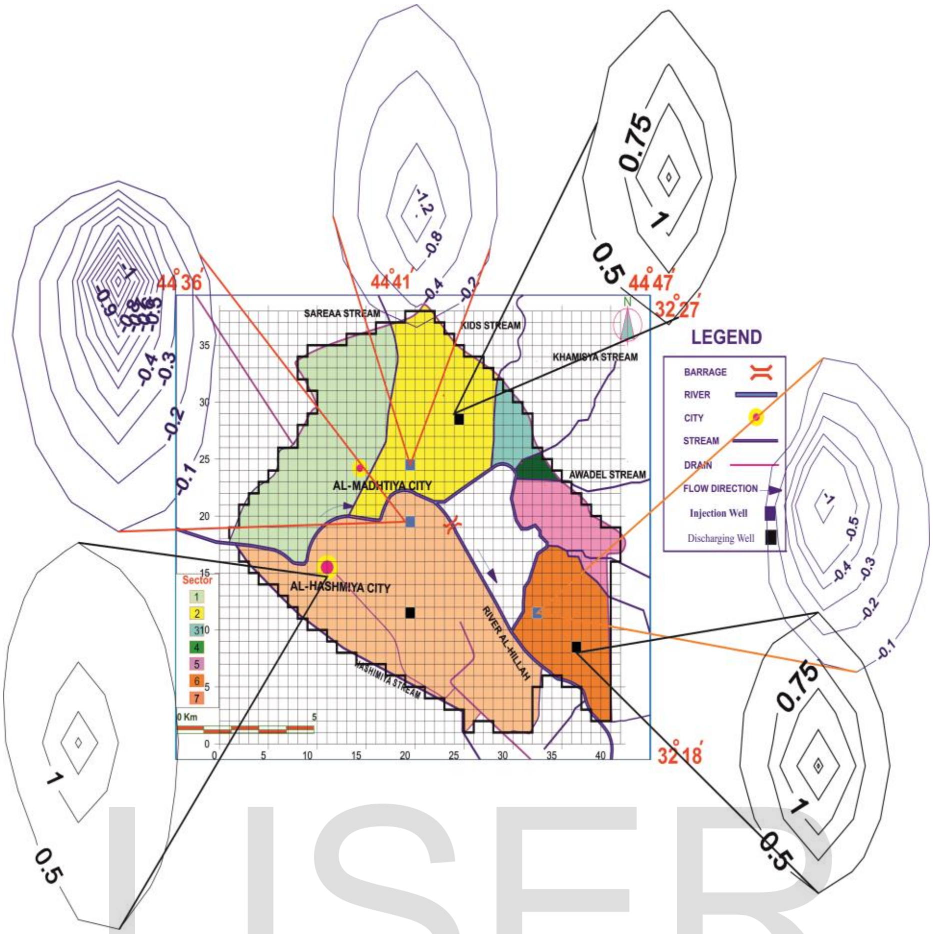

Fig.(30) Drawdown and WTL Rise Contour Maps of the Polluted Sectors

B- Injected Recharge Evaluation

Similarly, an injection process is achieved by the same methodology to evaluate the injection capacity of the aquifer and during the injection process the simulated WTL reflects a subsequent rise as a discharge values increase. The constraint in the technology is completely different. In this situation the increasing in the injected recharge is immediately stopped as the WTL converges to a ground surface level (GSL) to avoid a flooding of ground surface. This limitation is clearly illustrated in Figs (31, 32 and 33). The Figures show the natural WTL begins to rise gradually with recharge increasing at the center of the injecting well and immediately stopped when it is converged to GSL.

Briefly, Figs (31, 32 and 33) shows that the maximum injected recharge (Recharge Capacity) of 11.65, 7.1, and 11.1 L/s with subsequent rise in WTL of 1.61, 1.23, and 1.3588m at sectors (2, 6, and 7) respectively.

The figures also include a linear relationship between the rise of WTL and the injected recharge with an acceptable correlation coefficient.

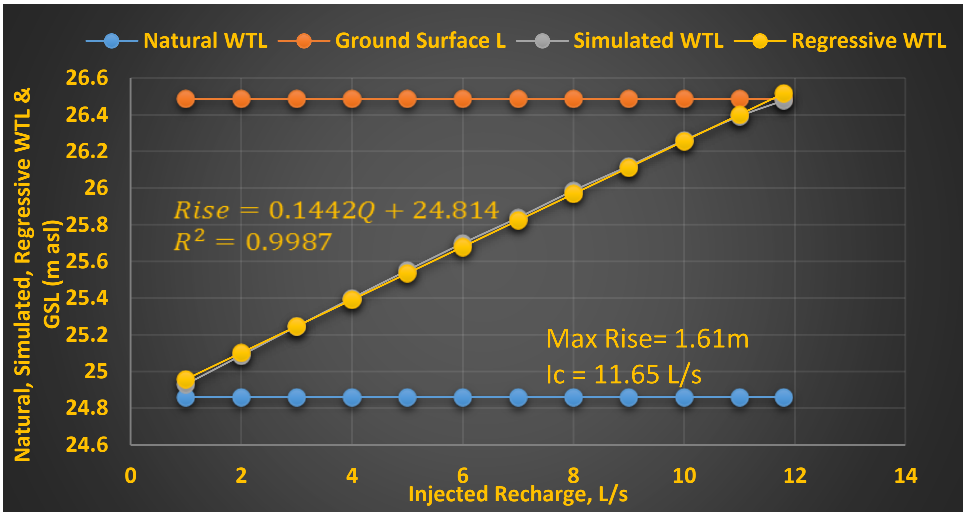

Fig.(31) Groundwater Rise due to Injected Recharge at Well Location, Sector(2)

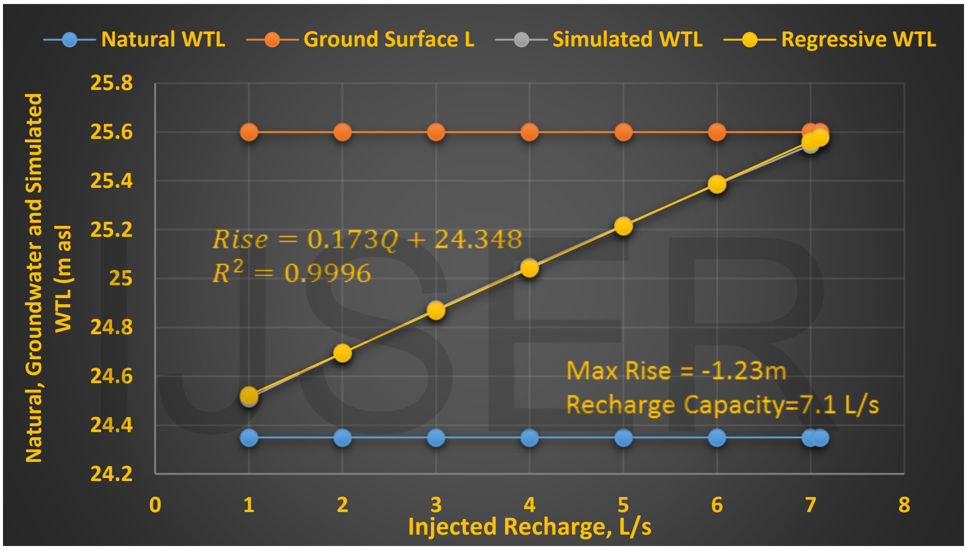

Fig.(32) Groundwater Rise due to Injected Recharge at Well Location, Sector(6)

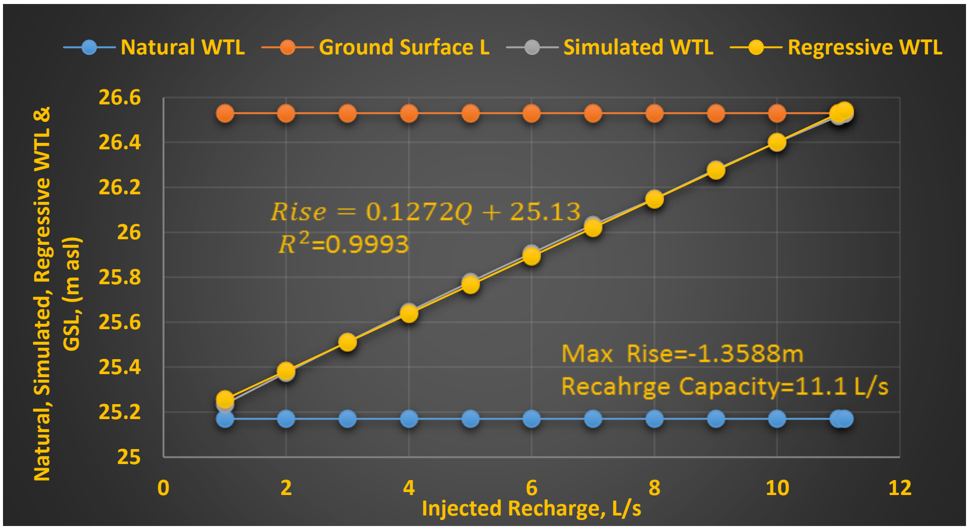

Fig.(33) Groundwater Rise due to Injected Recharge at Well Location, Sector(7)

Concs Exchangeable Theory and Dilution Equation

Conc exchanging of a solute in solution depends mainly upon a volumetric variation of strategic storage of an aquifer. Anyhow, the concept begins among considering a storage volume of Fig.(32). Let the initial volume of a liquid is $V_1$with a pollutant conc C_1 is increased to V_2 with pure or with a little conc liquid , therefore the resulting conc of the volume V_2 is certainly reduced to C_2.

The conservation of mass requires that:

$$M_1 = M_2 \qquad \text{.........(11)}$$

Where M is a mass of pollutant

But,

$$M = Cv \qquad \text{.........(12)}$$

Where C and V are conc and volume of pollutant, therefore, by substitution in EQ.(11) we obtain,

$$C_1 v_1 = C_2 v_2 \qquad \text{.........(13)}$$

Where C_1 and C_2 are concs of volumes V_1 and V_2 respectively.

Eq.(13) may be modified to be:

$$v_2 = \frac{C_1}{C_2} v_1 \qquad \text{................(14)}$$

But delta storage equals

$$\Delta v = v_2 - v_1 \qquad \text{................(15)}$$

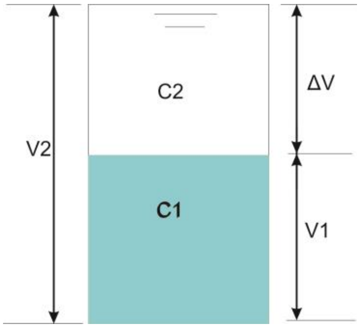

Fig.(32) Conc Variation in Solvent

Where: Δv is a volumetric change in the storage volume and can simply be defined as the fresh or less concentration water volume required to dilute or reduce the pollutant conc of the strategic groundwater storage to a desired limit.

Eq.(15) may be reformed as:-

$$v_2 = v_1 + \Delta v \qquad \text{...................(16)}$$

By combining Eq. (14) and Eq. (16) one obtains:-

$$v_1 + \Delta v = \frac{C_1}{C_2} v_1 \qquad \text{...................(17)}$$

Which can be simplified to be

$$\Delta v = v_1 (\frac{C_1}{C_2} - 1) \qquad \text{...................(18)}$$

Eq. (18) may be called a "*Dilution Equation*" and was used to estimate the exchangeable storage (Δv) corresponding to a desired conc (C_2) if the initial storage volume (v_1) and initial concentration (C_1) are known.

The dilution water volume (exchangeable storage) Δv is estimated on the basis of Eq.(18) as included in the algorithm of Table (4), Col (9).

Fig.(34) presents that an exponential relation between a volumetric exchange and conc variation of the ^{222}Rn with a correlation coefficient exceeding 0.98 for sectors (2, 6, and 7).

Method of Calculation of Table (4)

$$Col\ 9 = Col\ 2 * (\frac{Col\ 7}{Col\ 8} - 1) \qquad \text{................(19)}$$

$$Col\ 10 = \frac{Col\ 9}{Col\ 3} \qquad \text{................(20)}$$

$$Col\ 11 = \frac{Col\ 9}{Col\ 5} \qquad \text{................(21)}$$

Other columns values were brought from Table (3).

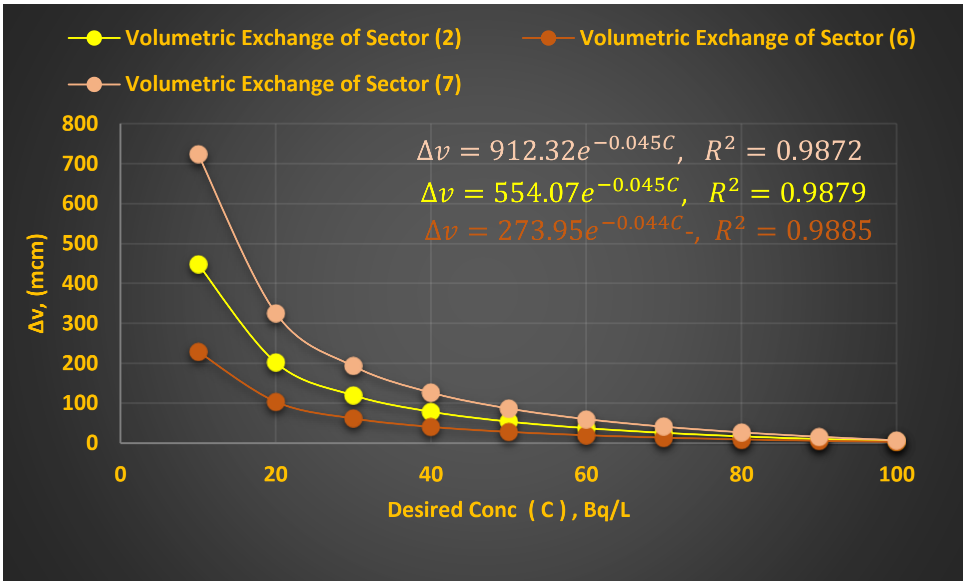

Fig.(34) Volumetric Exchange Corresponding to a desired Conc Level of ^{222}Rn

Table (4) Algorithm of Discharging and Injecting Wells No.

Sector No	Storage, (mcm)	Well Productivity /year (mcm)	Safe Yield, (L/s)	Injected Volume,/year (mcm)	Injected Capacity (L/s)	Extreme ^{222}R Conc (Bq/L)	Desired Conc (Bq/L)	Δv (mcm)	Discharging Wells No. Estimation	Injecting Wells No. Estimation
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
2	44.4	0.205	6.5	0.37	11.65	111	100	4.88	24	13
							90	10.36	51	28
							80	17.2	84	46
							70	26	127	70
6	22.3	0.2775	8.8	0.224	7.1	113	100	2.9	10	13
							90	5.7	21	25
							80	9.2	33	41
							70	13.7	49	61
7	72.35	0.205	6.5	0.35	11.1	110	100	7.23	35	21
							90	16	78	46
							80	27.13	132	78
							70	41.34	202	118

Strategic Planning and Groundwater Environmental Remediation

The main strategy in this research requires to reduce the conc of ^{222}Rn within the infected sectors (2, 6 & 7) below the recommended limit of (100%) according to the WHO. This task can well be achieved by the following sequential steps:-

1- Consulting Table (4) Col (8) to select the desired radon conc and the corresponding number of the pumping wells at each sector. Alternatively, Fig.(34) can be consulted to find the corresponding (Δv) and then Eq.(20) should be used for estimation of the number of pumping wells. The obtained number of pumping wells must be distributed on the banks of the local streams namely as; (Sareaa, Kids, Zabbar and Hashymia) as shown in Fig.(35). After a setting up the required No. of pumping wells, the discharging polluted groundwater should be poured into the adjacent streams to releasing the gas of radon into the atmosphere (by an aeration process) and reducing its conc to a minimum limits .

2- Consulting again Table (4) to obtain the corresponding number of injection wells and also should be distributed along the banks of Hillah River as shown in Fig.(35), since the higher WTL is adjacent the river as illustrated in the flow net of Fig.(25) . The fresh surface water of the river are injected into the specified injecting wells by a syphon technology to canceling the coasts of manual operations.

3- The specifying pumping and injecting wells may be operated immediately together to a subsequent flow-rates of Col (4) and Col (6) respectively. The continuous process of injecting and pumping will reduce the conc of all chemicals in groundwater including radon.

4- After one year of operation the strategic aquifer storage will be diluted to a degree enough that the required ^{222}Rn conc is inevitable fulfilled.

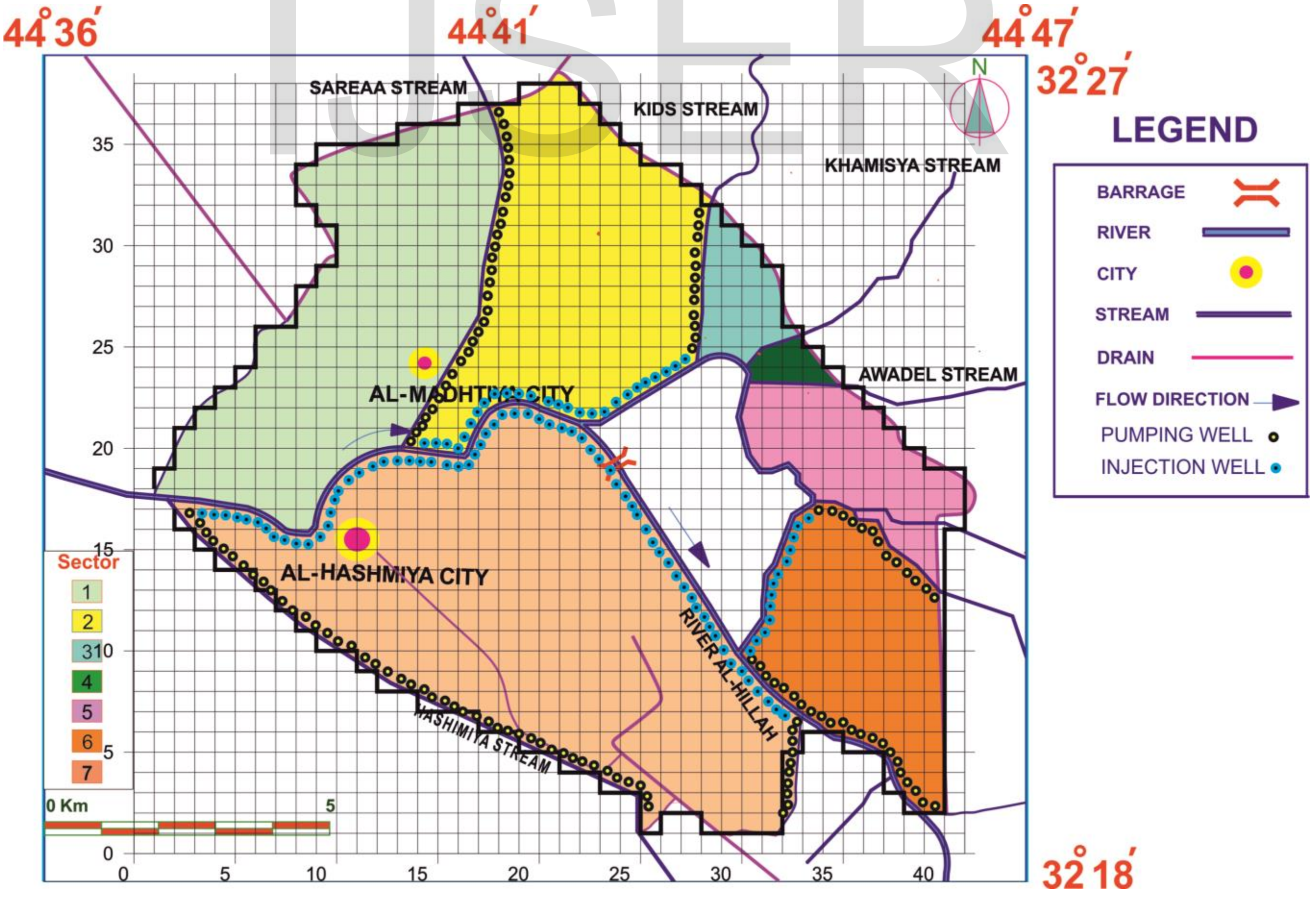

Fig.(35) Distribution of Pumping and Injecting Wells over the Polluted Sectors

Characterization of Strategic Visibility and Facilities

The whole dilution concept is characterized with following headlines:-

1- The continuous process of injecting-pumping process will reduce radon conc to *a* ***desired*** and to ***minimum*** limits in groundwater and surface water of the stream respectively.
2- Since the surface water of Hillah River is higher than the maximum WTL within the polluted sectors, a syphon injection process is recommended to avoid the excessive coasts.
3- An operation time for pumping wells can be reduced to 12 or 6 hrs/day by increasing the discharge values to double or four times respectively. Whereas, the injection operation by syphon should continue (24hr/day) since the injection capacity cannot be exceeded to avoid ground surface flooding.
4- The dilution process will activate and rehabilitate the unconfined aquifer by increasing the hydraulic conductivity, reducing the undesired chemicals, sweetening groundwater and sequentially reducing soil salinity.
5- The real used number of injecting and pumping wells is much less than the estimated one of Col (10) and Col (11), Table (4) since the polluted sectors contains a high number of wells scattered over the area which are used for agricultural and drinking purposes.
6- The current policy is confined to disposing the discharging water into the local streams to a void the loss in the aquatic wealth.
7- The pumping wells number along the streams can be reduced if the farmer accept to use pumping water to satisfy their irrigation needs.

Table (5) Usual & Current Releases of Streams

Sectors	Storage (mcm)	Total Pumping or injecting water Cumces	Streams	Usual Releases cumces	Current Releases cumces
2	44.4	1.407915	Sareaa	0.35	0
			Kids	0.523	0
6	22.3	0.707128	Zabbar	1.25	0.9
			Hillah River	150	150
7	72.35	2.294203	Hashymia	0.97	0

8- The total pumping and injection water should be detected Col (3) Table (5) from the usual releases to obtain the current releases of local streams. Table (5) indicates that under the light of dilution strategy Sareaa, Kids and Hahymia streams have no surface water allocations, since their water allocations are satisfied by the discharging water.

Conclusions

The followings may be concluded:

1- The hydrogeologic solution is proved to be a strong tool for aquifer remediation and rehabilitation against the infection by ^{222}Rn and other chemicals.
2- Dilution Equation is a special simple mathematical form to reduce concs of polluted liquids by pure or partially pure liquids.
3- Not all of Hashymia aquifer is polluted by ^{222}Rn with a conc exceeding 100 Bq/L. The pollutant exceedance is confined to Sectors (2, 6 and 7).
4- Sareaa, Kids, and Hashymia water requirements should be satisfied by the pumping water particularly during the year of remediation.

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