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The spatial analysis of Yamama Formation heterogeneity in south of Iraq

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Abstract

This study focuses on determining the heterogeneity of Yamama Formation and its spatial distribution in south of Iraq using three indices namely, Coefficient of Variation, Lorenz Coefficient, and Dykstra – Parsons Coefficient. The porosity and permeability values from eleven wells in south of Iraq (Basra and Maysan oil fields) are used for computing heterogeneity indices. Ordinary kriging technique is used to interpolate the computed indices and to show the spatial distribution of these indices over the study area. Results indicated that the average values of Lorenz and Dykstra – Parsons Indices are 0.73 and 0.86, respectively which refer to the extremely heterogeneity nature of Yamama Formation in the study area.The spatial distribution of the heterogeneity indicates that the heterogeneity of Yamama Formation increases from southeast to northeast and follows the same trend of decreasing formation thickness. Results from this study could be helpful in managing production plans in the southern Iraqi fields and enhance oil recovery project.

Keywords: Heterogeneity, Yamama Formation, Lorenz Coefficient, Iraq

التوزيع المكاني لعدم التجانس في خصائص تكوين اليمامة في جنوب العراق

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الخلاصة

يركز البحث الحالي على تحديد عدم تجانس تكوين اليمامة والتوزيع المكاني لعدم التجانس هذا في جنوب العراق باستخدام ثلاثة أدلة وهي معامل التغاير ومعامل لورنز ومعامل بارسون–ديكسترا. استخدمت بيانات النفاذية والمسامية الماخوذة من احدى عشرة بئراً (في البصرة وميسان) لحساب ادلة عدم التجانس. استخدمت تقنية الاستكمال الداخلي المعروفة باسم كرايجنك لرسم توزيع المعاملات في منطقة الدراسة. بينت النتائج بان معدل معاملي التجانس المحسوبين باستخدام لورنس وبارسون–ديكسترا بحدود 0.73 و 0.86 على التوالي وهذا يشير الى عدم التجانس العالي جدا لتكوين اليمامة في المنطقة المدروسة. التوزيع المكاني لادلة عدم التجانس اشرت الى ان عدم التجانس في تكوين اليمامة يزداد من الجنوب الشرقي باتجاه الشمال الشرقي ويتبع نفس نمط الزيادة في سمك التكوين. ان نتائج هذه الدراسة ممكن ان تكون مفيدة لإدارة خطط الانتاج في الحقول الجنوبية للعراق وتعزيز مشاريع الاستخلاص النفطي.

الكلمات المفتاحية: عدم التجانس، تكوين اليمامة، معامل لورينس، العراق

1. Introduction

The term reservoir heterogeneity is used to describe the geological complexity of a reservoir and the relationship of the complexity to the fluids through it [1]. The heterogeneity may be defined as the complexity or variability of a specific system property in a particular volume of space and/or time [2].

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Reservoir heterogeneity is a function of the porosity/permeability distribution due to lithologic variation during sedimentary deposition which is further complicated by mechanical processes related to deformation and chemical processes associated with diagenesis. Identify of the reservoir heterogeneity is sought to design the most efficient injection – production system for economy of energy and maximization of hydrocarbon production [3]. In addition, quantitative measure of reservoir heterogeneity served as a guide to use homogenous conditions in petroleum reservoir studies. In fact, there is the intrinsic heterogeneity of the property itself (e.g. porosity or mineralogy) and the measured heterogeneity which described by the scale, volume and resolution of the measurement technique. Reservoir heterogeneity can be classified in a variety of ways based on their size of scale. The common categories are wellbore, inter-well and field wide scales of heterogeneity. Table-1 showed the reservoir characteristics that affected by these different scale of heterogeneity. In earth sciences, there are five basic types of heterogeneity [4]: Spatial – lateral, vertical and three – dimensional, (2) Temporal – one point at different times, (3) Functional – taking correlations and flow – paths into account, (4) Structural – either unconformities or tectonic elements, such as fault and penetrative features such as bedding, or alternatively less regularly distributed features, including ripples, hummocky cross – bedding, and bioturbation. The available techniques to quantify reservoir heterogeneity fall into two groups: (1) characterizing the variability in a dataset, and (2) characterizing variability through using heterogeneity measures such as coefficient of variation (C_v), the Lorenz coefficient (L_k), and (3) Dykstra – Parsons coefficient.

In this study, the spatial heterogeneity of Yamamma rocks (reservoir and source rocks) was evaluated, for the first time, in south of Iraq by means of heterogeneity measures and ordinary kriging interpolation technique. Characterizing of heterogeneity for this formation is crucial for developing production plans and efficient management of this important formation.

Table 1-Affected reservoir characteristic by different categories of heterogeneity (modified after [4])

Scale of heterogeneity	Affected reservoir characteristics
Wellbore	Matrix permeability Distribution of residual oil Directional of flow fluids Potential fluid-rock interactions Formation damage
Inter-well	Fluid flow patterns Drainage efficiency of the reservoir Vertical and lateral sweep efficiency Secondary and tertiary recovery properties
Field-wide	In – place hydrocarbon volume In – place hydrocarbon areal distribution Trend of hydrocarbon production

2. The Yamama Formation

The carbonate – dominated Yamama Formation is one of the main Lower Cretaceous carbonate promising reservoir in the Mesopotamian Basin, southern Iraq. It is up to 360 m thick in the southeast of Iraq [5]. The Yamama Formation in south Iraq comprises outer shelf argillaceous limestone and oolitice, pelloidal, pelletal and pseudo – oolitic shoal limestones [5]. Oolitic reservoir units are present in several northwest – southeast trending depocentres [6]. The formation of Berriasian – Valanginian age [7]. Two variants of the Yamama Formation are the “Garagu” and “Zangura” formations. The first one, Garagu, comprises oolitic sandy limestones with marl and sandstone in its upper and lower parts with organic detrial limestones in the middle [7].

The second formation, Zangura, comprises pseduoolitic limestones argillaceous limestones and calcareous mudstones. According to Sadooni [6] the Yamama Formation was deposited in alternating oolitic shoal and deep inner shelf environments, probably controlled by subtle structural highs within a carbonate ramp. The isopach map of the Yamama Formation is presented in Figure-1, in which the greatest thickness of the formation is in the Basrah area. The correlation between units of Yamama Formation in southern Iraq is shown in Figure-2.

3. Heterogeneity Measures and interpolation technique used

3.1 Coefficient of variation (C_v)

The C_v is defined as a statistical measure of the dispersion of data points in a data series around the mean, and is calculated as: [8]

$$C_v = \frac{s}{\bar{x}} \tag{1}$$

where, C_v is the coefficient of variation, s is the standard deviation, and $\bar{x}$ is the mean.

The C_v is a useful measure for comparing the degree of variation from one data series to another, even if the means area drastically different from each other. A homogenous formation will have a C_v of zero, with the value increasing with heterogeneity in the dataset [9].

3.2 Lorenz Coefficient (L_k)

The Lorenz heterogeneity coefficient is a static measure of heterogeneity which is taking into consideration the statistic nature of the porosity and the permeability of a stratified reservoir. This coefficient was firstly developed as a measure of degree of inequality in the distribution of wealth across a population [10]. The measure was modified by [11] for use in petroleum engineering through plot which relate cumulative flow capacity – defined as the product of average permeability and thickness of an interval - to cumulative storage capacity – defined as the product of average porosity and thickness of the same interval**.** The value of L_k ranges from zero to one. The L_k is null for homogeneous reservoirs and one for heterogeneous ones. The L_k can be computed with a good accuracy for any oil filed if the thickness, porosity, and permeability are correctly determined.

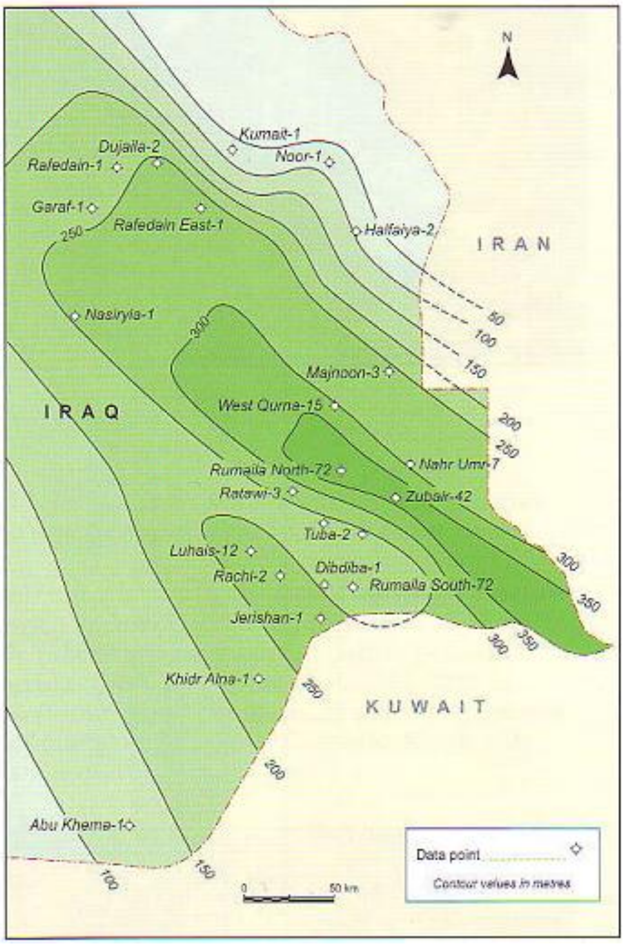

Figure 1-Isopach map of the Yamama Formation (After [6])

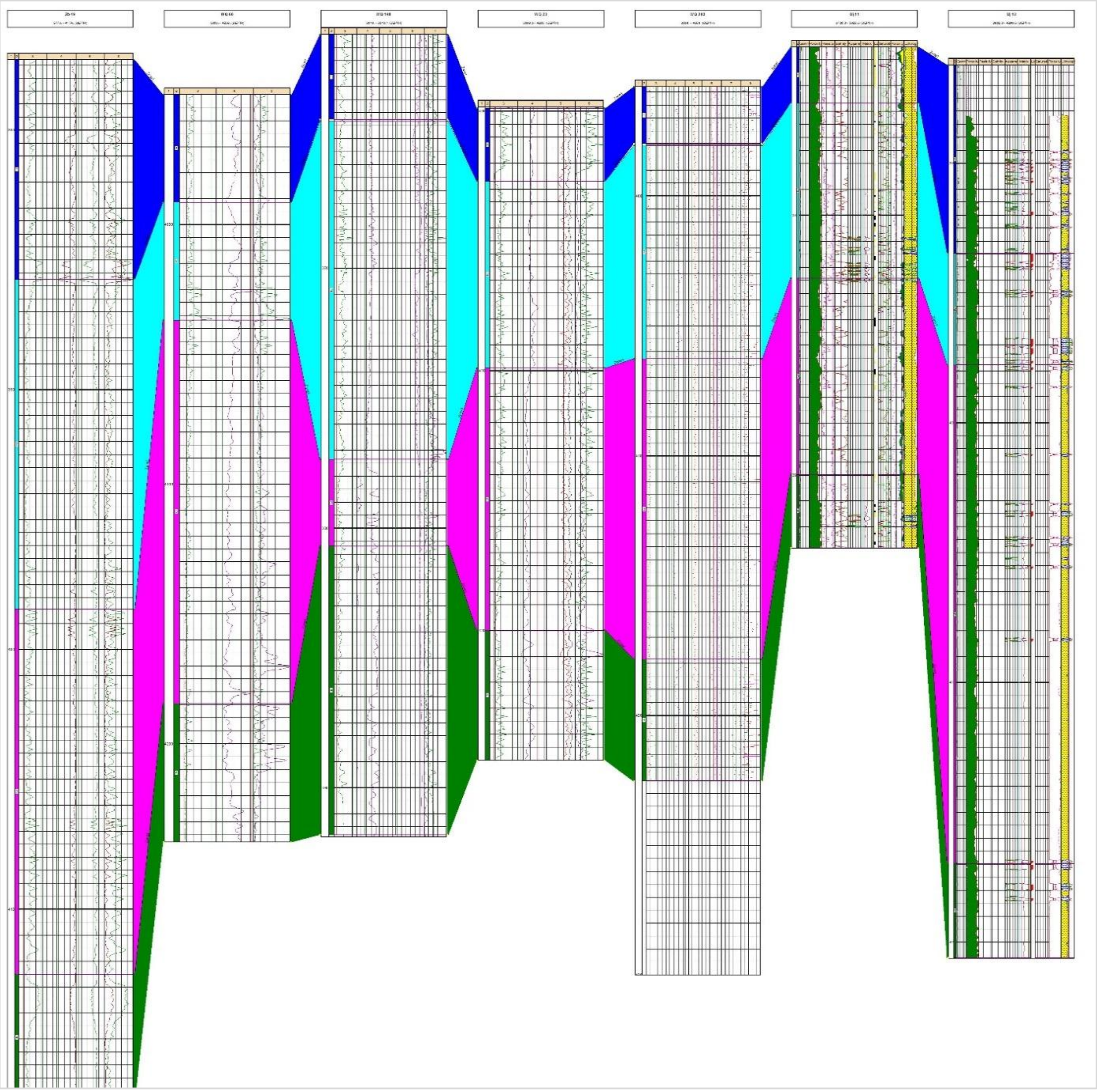

Figure 2- Correlation between wells in the study area for Yamama Formation

3.3 Dykstra – Parsons Coefficient (DP_c)

The Dykstra – Parsons Coefficient is commonly used in the quantification of permeability variation [2]. The DP_c is an excellent tool for characterizing the degree of reservoir heterogeneity. The DP_c of permeability variation, V_k, can be obtained graphically by plotting permeability values of log-probability paper. The following equation is used to quantify V_k as follows [12]:

$$V_k = \frac{k_{50} - k_{84.1}}{k_{50}} \quad \textbf{(2)}$$

Where, k_{50} is the permeability value with 50% probability, $K_{84.1}$ is the permeability at 84.1% of the cumulative sample. The range of this heterogeneity measure is $0 < V_k < 1$. Table-2 the relation between value of this measure and the degree of heterogeneity with other useful information.

Table 2- Relation between V_k and degree of heterogeneity (summarized after [12])

V_k range	Degree of heterogeneity	Additional notes
$V_k = 0$	Ideal homogeneous	Ideal homogeneous reservoir
$0 < V_k < 0.25$	Slightly heterogeneous	Can be approximated by homogeneous model in reservoir simulation with minimum error
$0.25 < V_k < 0.50$	Heterogeneous	Geometric averaging technique is applicable. If the index is closer to 0.5 run the numerical simulator with the heterogeneous condition
$0.50 < V_k < 0.75$	Very heterogeneous	A combination of geometric and harmonic averaging technique is necessary
$0.75 < V_k < 1$	Extremely heterogeneous	None of the conventional averaging techniques are applicable in this range
$V_k = 1$	Perfectly heterogeneous	It is unlikely that such reservoir exists

3.4 Ordinary Kriging technique

Kriging is a group of geostatistical techniques to interpolate the value of a random filed at an unobserved location from observation of neighboring values. Kriging is built on the assumption that things that are close to each other are more similar than those farther away. The detail description of Kriging theory and its application is found in [13]. In general, four main steps are required to build Ordinary Kriging (OK) model: (1) constructing a variogram from available point data. The variogram determine the spatial continuity of a data set. Variogram analysis consists of the experimental variogram and the variogram model fitted to the data. (2) fit a model. This is done by defining a line that provides the best fit through the points in the experimental variogram cloud graph [14] (3) The third step involve computing the weights in the kriging equations and make a prediction. The OK estimator can be written mathematically as [15]:

$$\hat{Z}(x_\circ) - \mu = \sum_{i=1}^{n} \lambda_i \left[Z(x_i) - \mu(x_\circ) \right] \qquad \textbf{(3)}$$

where μ is an known stationary mean, assumed to be constant over the whole domain and computed as the average of the data, λ_i is kriging weight, n is the number of available point to be interpolated, and $\mu(\chi_o)$ is the mean of data point within the search window.

4. Results and Discussion

The porosity and permeability data for this study came from the conventional core analysis acquired from eleven wells in Basrah and Maysan Governorates. The statistical summary of the data was presented in Table-2. The higher values of coefficient of variation values for porosity and permeability indicate the heterogeneous nature of the studied formation. The calculated heterogeneity using L_k and V_k indices are summarized in Table-3 and Figure-3 and -4, respectively. The minimum, maximum, and average values of V_k index for the studied wells are 0.72, 0.95, and 0.86, respectively. These figures indicate that Yammama Formation is very heterogeneous to extremely heterogeneous. If we exclude Mj-11 which has V_k equal to 0.72, the remaining V_k figures are higher than 0.75 which indicate that Yamama Formation can be regarded as extremely heterogeneous. This employs that none of the conventional averaging methods are applicable to quantify average values of this formation. The same results are gotten using L_k index where the minimum, maximum, and average are 0.60, 0.85, and 0.73, respectively. All figures of L_k are higher than 0.5 which indicate the heterogeneous nature of the formation. The spatial distribution of computed heterogeneous indices is shown in Figure-5 and 6. It is clear from these Figures that the Yamama heterogeneity decrease from northwest to southeast corresponding with decrease formation thickness in the same direction. The interpolated fields of heterogeneity produced using both indices require more points (wells) to be smoother and more accurate. In addition, the getting interpolated field could be more helpful where enhanced recovery processing or drilling horizontal wells are necessary to be used and have to know the nature of formation heterogeneity.

5. Conclusions

In this study, three indices are used to investigate the heterogeneity condition of Yamama Formation at southern Iraq, namely Coefficient of Variation, Lorenz Coefficient, and Dykstra – Parsons Coefficient. The porosity and permeability values gotten from eleven wells randomly distributed in south of Iraq are used to compute these indices and investigate the spatial distribution of these indices. Results indicate that Yamama Formation is extremely heterogeneous (average values of

Lorenz and Dykstra-Parsons indices are 0.73 and 0.86, respectively) which infer that averaging methods could not be used to simplify calculation of reservoir storage, mass balance, and constructing numerical simulation models until enough wells are drilled. The spatial distribution of the Lorenz and Dykstra-Parson indices refer that the heterogeneity of Yamama Formation increases from southeast to northeast and follows the same trend of decreasing of formation thickness. The resulted picture of heterogeneity distribution could be helpful for manage this formation in the future when more wells are drilled to develop oil field in the south of Iraq.

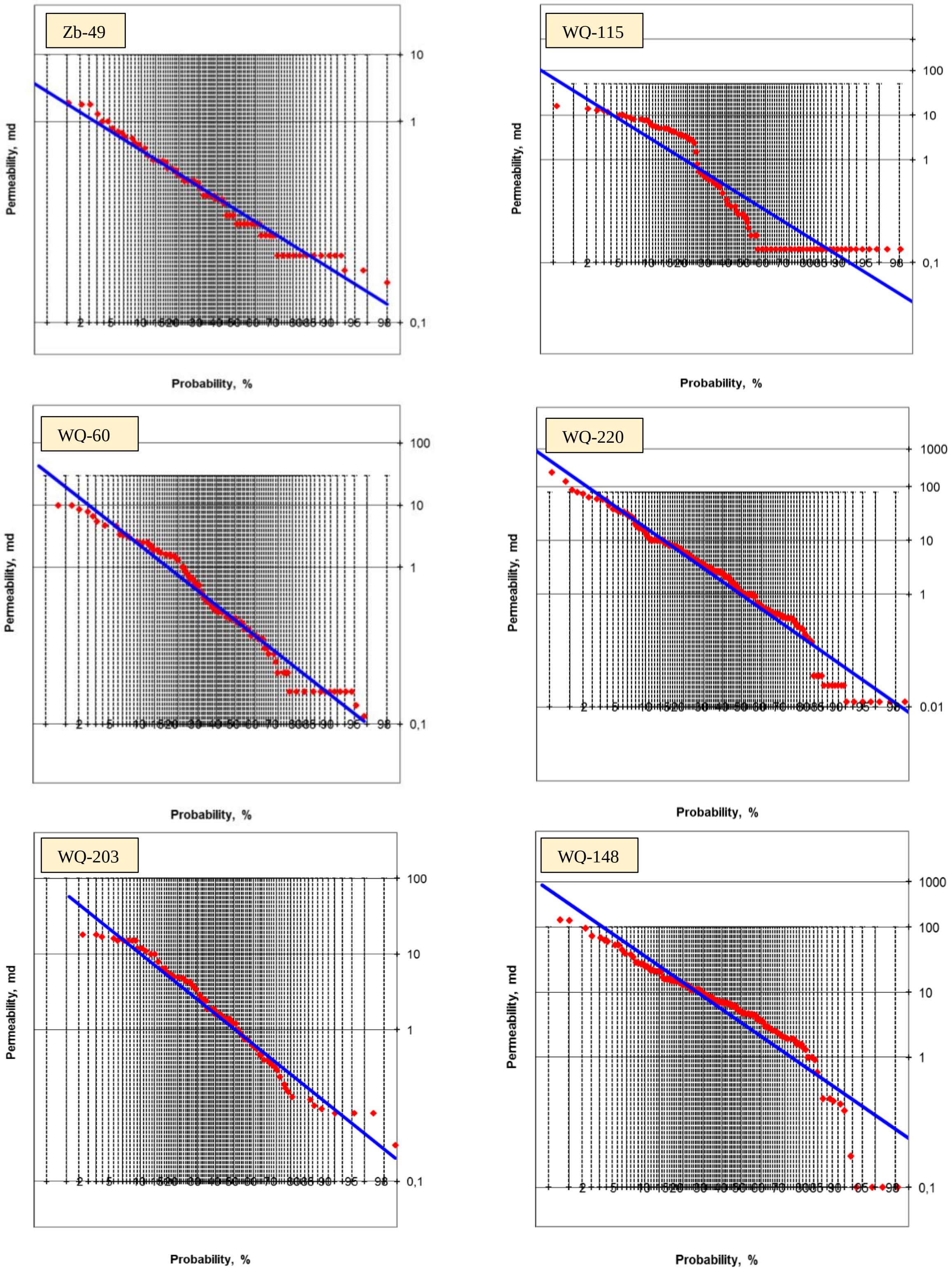

Figure 3- V_k index for the studied wells

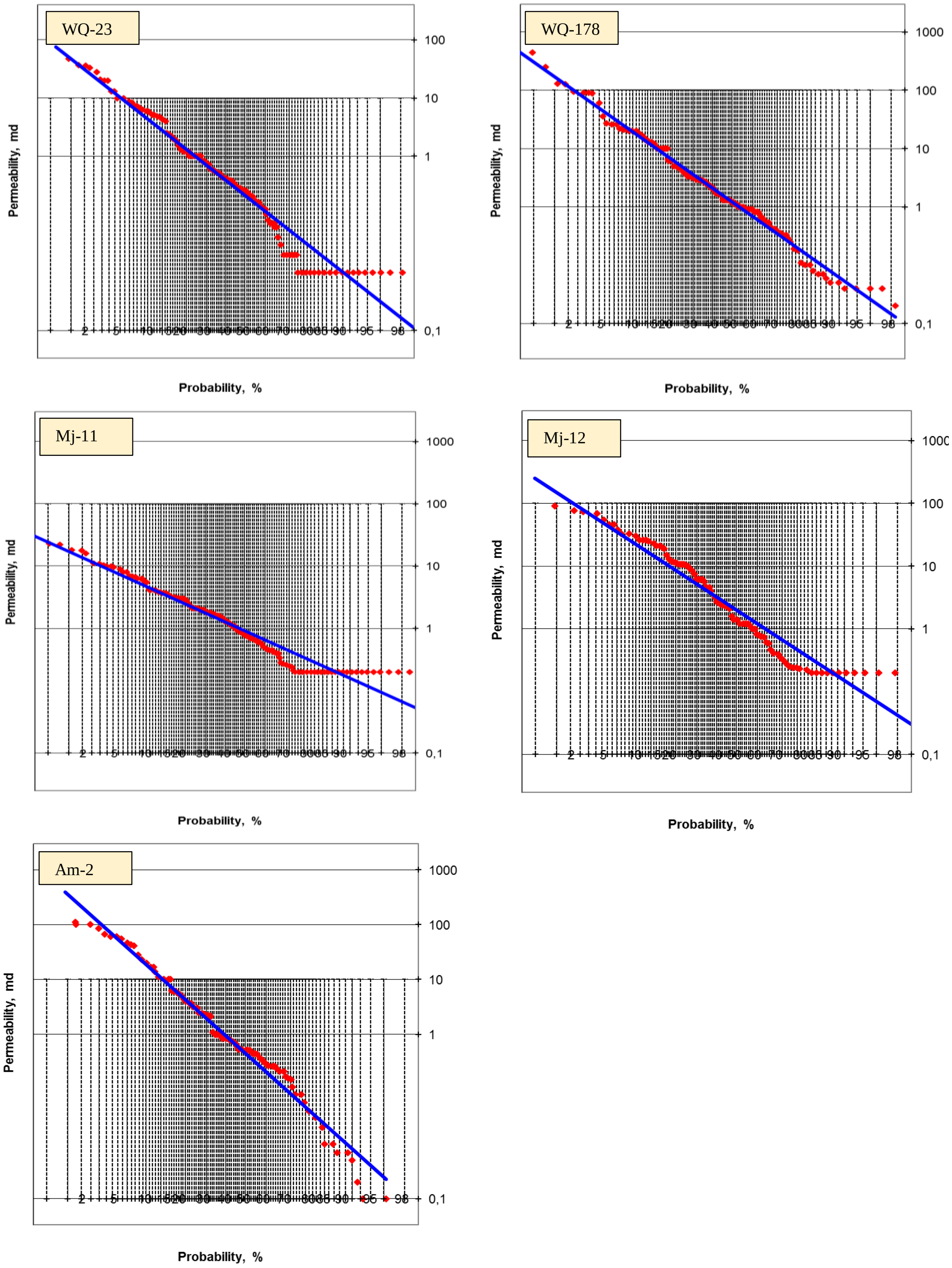

Figure 3- *continue …*

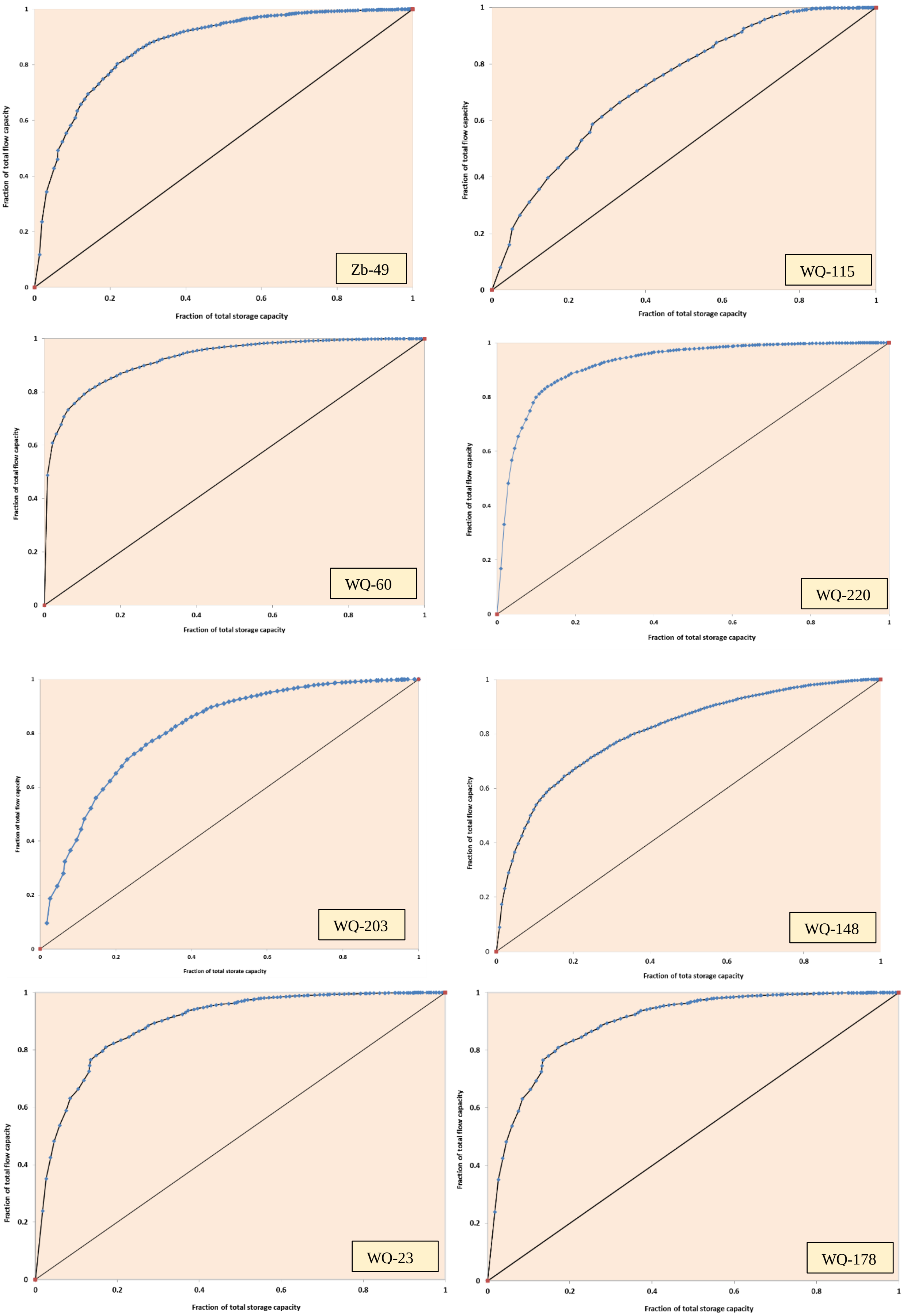

Figure 4- L_k index for the studied wells

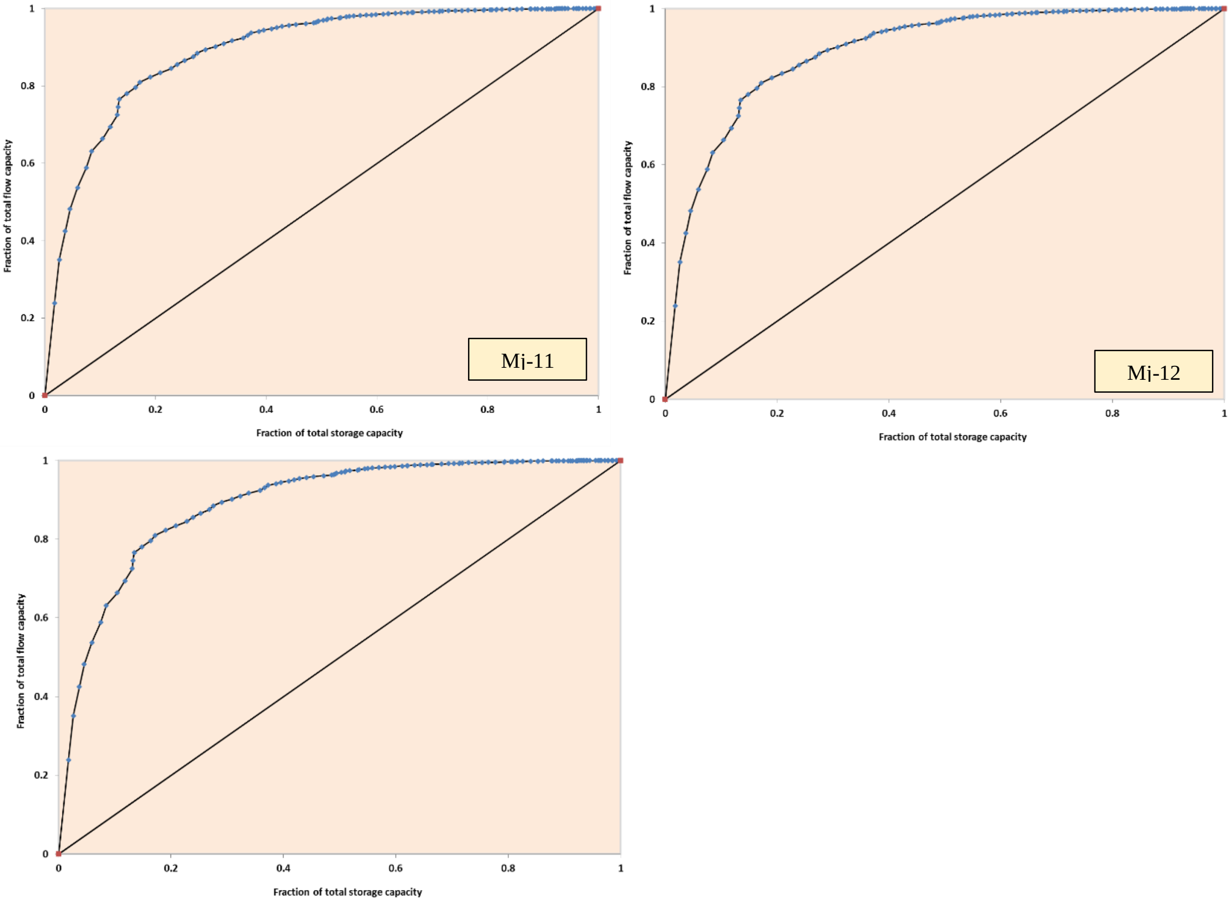

Figure 4- *... continue*

Table 2- Statistical summary of porosity and permeability values of selected wells

Well Name	**Depth (m)**	**Parameters**	**Min**	**Max**	**Mean**	**Stadev**	**C_v**
Zb-49	3776 – 3908	ϕ	0.600	24.70	8.46	5.003	***59.15***
		k (md)	0.004	12.00	0.68	1.872	***273.89***
WQ-115	3610 – 3800	ϕ	0.007	0.282	0.110	0.094	***85.41***
		k (md)	0.010	23.00	3.015	4.828	***160.14***
WQ-60	3950 – 4238	ϕ	0.0076	0.196	0.115	0.045	***39.215***
		k (md)	0.004	142	3.093	15.043	***486.24***
WQ-220	3834 – 4117	ϕ	0.020	0.302	0.155	0.049	***31.682***
		k (md)	0.020	497	23.744	77.882	***327.99***
WQ-203	3958 – 4300	ϕ	0.016	0.204	0.135	0.045	***33.290***
		k (md)	0.03	37	5.072	7.323	***144.38***
WQ-148	3610 – 3919	ϕ	0.02	0.351	0.212	0.066	***30.931***
		k (md)	0.01	198	17.078	30.865	***180.73***
WQ-23	3998 – 4250	ϕ	0.003	0.205	0.0845	0.056	***64.696***
		k (md)	0.01	155	5.457	17.239	***315.93***
WQ-178	4032 – 4330	ϕ	0.020	0.302	0.155	0.049	***31.682***
		k (md)	0.02	497	23.744	77.882	***327.99***
Mj-11	3735 – 3928	ϕ	0.002	0.253	0.137	0.065	***47.942***
		k (md)	0.16	68	3.536	7.435	***210.22***
Mj-12	3862 – 4206	ϕ	0.022	0.266	0.147	0.063	***42.648***
		k (md)	0.2	209	14.62	29.04	***198.58***
Am-2	4402 -	ϕ	0.011	0.27	0.142	0.054	***38.324***
		k (md)	0.001	47	4.470	9.049	***202.42***

Table 3- Calculated heterogeneity indices values

Well Name	**Geographic location**		**Heterogeneity index**	
	Easting	**Northing**	L_k	V_k
Zb-49	743200	3387050	0.79	0.73
WQ-115	722500	3410200	0.91	0.64
WQ-60	714121	3427578	0.88	0.85
WQ-220	715200	3438500	0.89	0.84
WQ-203	714500	3448750	0.83	0.63
WQ-148	719854	3434818	0.84	0.62
WQ – 23	725781	3438728	0.90	0.77
WQ-178	720000	3448500	0.88	0.83
Mj-11	748000	3452000	0.72	0.60
Mj-12	747940	3436300	0.85	0.65
Am-2	700063	3517517	0.95	0.83
		Min.	0.72	0.60
		Max.	0.95	0.85
		Average	0.86	0.73

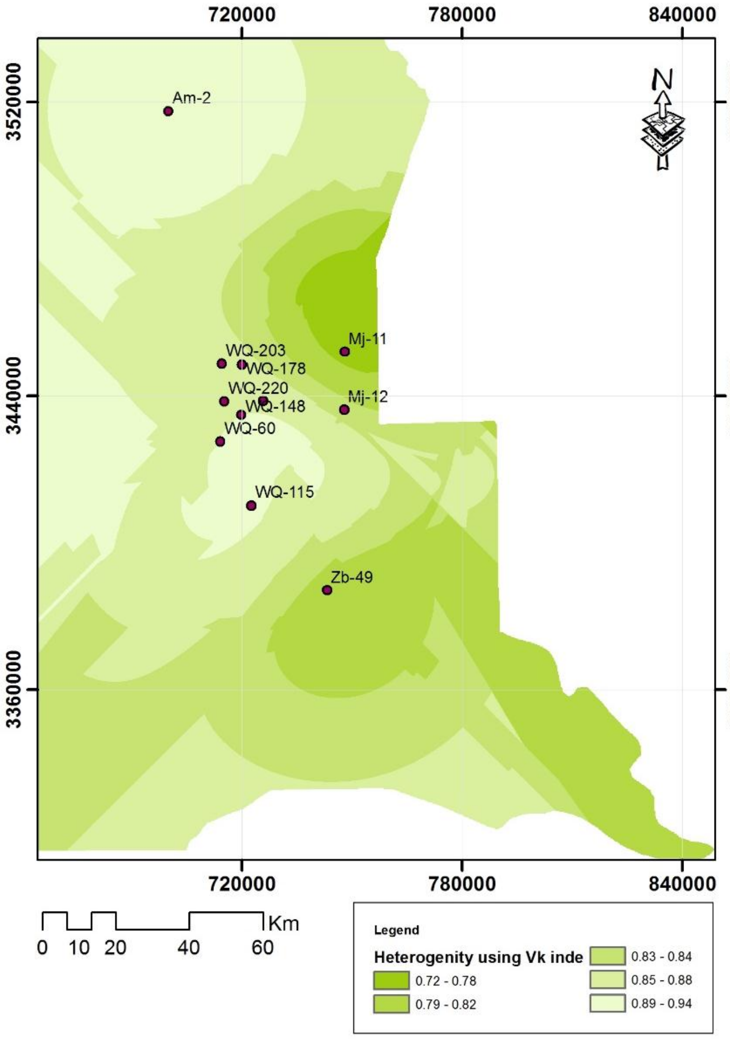

Figure 5- Spatial distribution of V_k heterogeneity index over the study area

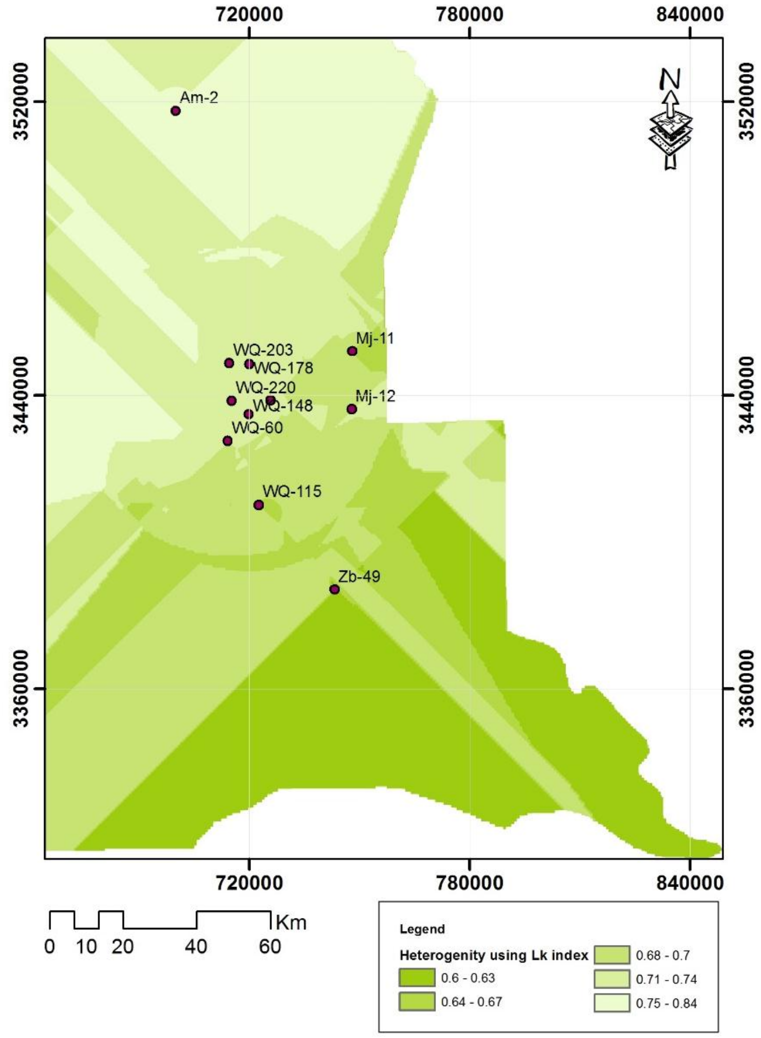

Figure 6- Spatial distribution of L_k heterogeneity index over the study area

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