Gradients of Latvian Magnetic Anomalies

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Abstract. **This article discusses one of the most important geophysical factors, which produces an impact on the demographic processes and reflects the nature of variability in the anomalous magnetic field intensity in space. The article characterises the horizontal magnetic gradients, which vary within the wide range: from 10 to 2400 nT/km. It distinguishes magnetic scale and magnetic gradient areas. The article gives an ecodemographic evaluation of the territory of Latvia by the gradience of the anomalous magnetic field.**

Keywords: **horizontal magnetic gradient, magnetic scale, magnetic gradient area, ecodemographic evaluation of territory by magnetic gradience.**

The gradient is an important parameter of anomalous magnetic field. The discussion deals with the spatial intensity variations. The thing is that the intensity of the anomalous field is not constant and varies from one location to another. Those are both abrupt reductions and increases of the intensity level, or gradual, step-by-step transition from certain values to different ones. Spatially, variations of the intensity of the anomalous magnetic field are expressed in gradients, which reflect the degree of the field variability. Depending on their values, the magnetic field is "calm" or contrasting, "rugged" or gradually changing, differentiated or uniform. Besides that, parameter reflects the character of the boundaries between anomalies, and, consequently, those between magnetic geological bodies causing such anomalies. The value of the gradient is important. Special attention is paid to the gradient maximum values, which are a proof of abrupt boundaries between geological bodies. They are of interest, since abrupt boundaries might indicate the existing tectonic faults, which separate magnetic bodies. It is known that tectonic faults could serve as a satellite of harmful deep fluids and radiation, negatively influencing the population.

The term "gradient" (from the Latin gradiens (gradientis) - marching), in physics, denotes the vector indicating the direction in which the fastest change in a certain quantity takes place, and its value changes in space from one point to another. In relation to geomagnetism, the gradient is the value of the vector, which characterises changes in the velocity of the anomalous magnetic field in a certain direction. It is known that the anomalous magnetic field at each point is characterised by intensity, which is the force with which an anomaly impacts the mass unit. The greater is the distance from the anomaly source, the lower is its intensity. The intensity diminishes from the anomaly deep source (the magnetic geological body) in the horizontal direction (towards the edges) and in the vertical direction (up – towards the Earth surface). Spatial variations of the velocity of the magnetic intensity above the Earth surface are expressed as horizontal and vertical gradients. It is possible to determine those gradients by calculations or measurements using special instruments – magnetic gradiometers. Instrumented gradient measurements are predominantly utilised in local areas during prospecting and exploration for minerals. In regional investigations, to which concrete operations associated with investigating the impact of geophysical factors on demographic processes belong, horizontal gradients are the main factor; they are determined by calculations.

CHARACTERISATION OF HORIZONTAL MAGNETIC GRADIENTS

The magnetic field is represented in the Latvian territory by a complex set of anomalies with different signs, intensity, size and morphology. The transitions from one anomaly to another are expressed through changes in the field intensity and are either gradual, occurring step-by-step, or abrupt. On magnetic maps, the boundaries between anomalies are marked as zones with more or less dense isodynamic lines, representing horizontal gradients. They show the velocity of the change of the magnetic intensity in the horizontal direction, perpendicular to the trend of the isodynamic lines. The values of the horizontal magnetic gradients are determined by calculations as the difference of the values of the field intensity in two points, divided by the distance. They are measured in nanotesla per kilometre (nT/km).

Our calculations are based on sheets of the anomalous magnetic field maps of the USSR M1: 200 000 (N. Furtsev, E. Lapina, et al, 1957-1954), and magnetic maps of different parts of Latvia, M1: 50 000 (O. Myasnikov, 1987, E. Lapina, 1967, and N. Lapin, 1967, et al) within development of the scientific research topic: "Effect of geodesic factors on demographic processes and human habitat" (RTU, 2010).

The data of the calculations show that the gradient values vary in a wide range, from 0 to 2400 nT/km. Based on the quantity, three groups of the gradients have been singled out: a) low gradients (lower than 100 nT/km); b) medium gradients (100 – 200 nT/km); c) high gradients (exceeding 200 nT/km). The horizontal gradients, which are represented by zones of large extent and small width ($l > 3d$), belong to the category of the magnetic gradient steps, while the gradients forming isometric zones or zones of small extent ($l < 3d$) belong to the category of magnetic gradient areas.

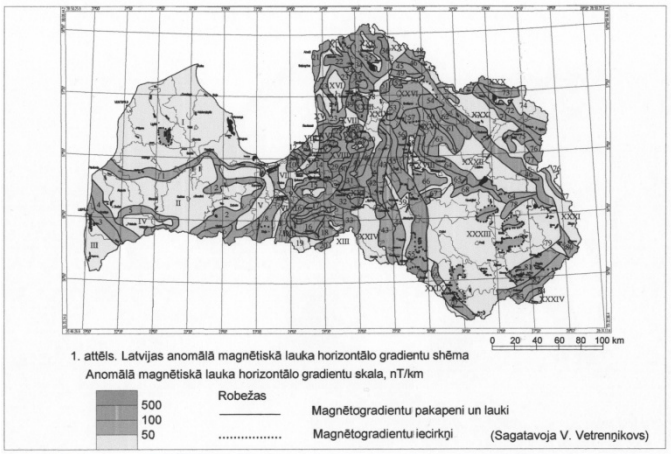
The steps are predominantly characterised by high gradient values (mostly hundreds of nT/km), while the areas – by low values (tens of nT/km). The steps are normally associated with the edges of anomalies, bounding their epicentral domes. In narrow, pectinate domes, side steps connect along the axial lines of anomalies, while in wide domes, the near-axis epicentral parts of anomalies are separated as low-gradient areas bounded by side steps.

The magnetic gradient areas are most frequently associated with large anomalous structures with a low level of the magnetic field intensity.

Within the areas and steps, the gradient values are not constant; they vary from one location to another, forming gradient zones. Those zones reflect local variations of the gradient values within the steps and areas.

SPATIAL DISTRIBUTION OF HORIZONTAL GRADIENTS

The spatial distribution of horizontal gradients in the Latvian territory and their values are shown in the scheme (Fig. 1). It can be seen from the scheme that the shown magnetic steps and areas are distributed in an irregular fashion in different parts of Latvia.



Areas of magnetic gradients

I Zieme| – Kurzemes	XVIII Allaži – Straupe
II Dienvid – Kurzemes	XIX Nurmiži
III Nīca	XX Jūdaži ez.
IV Vaiņode	XXI Jumprava
V Nākotne	XXII Sēli
VI Ozolnieki	XXIII Daile
VII Salaspils	XXIV Cēsis – Nereta
VIII Ādaži	*XXV Lode - Omuļi*
IX Vangaži st.	XXVI Smiltene
X Baldone	XXVII Jaunpiebalga
XI Vecumnieki	XXVIII Madona
XII Mūsa	XXIX Ilūkste
XIII Bārbele	XXX Ape
XIV Rozīni	*XXXI Zeltiņi – Zilupe*
XV Mustkalns	XXXII Lubāna
XVI Limbaži	XXXIII Latgale
XVII Bīriņi	XXXIV Lupangi

Steps of magnetic gradients

1. Pāvilosta – Kandava	22. Staicele – Aloja	43. Līčupe – Saukas ez.	64. Cesvaine
2. Dobele – Kalnciems	23. Lādezers – Umurga	44. Koknese – Viesīte	65. Kusa
3. Liepāja	24. Puikule	45. Daksti	66. Vestiena
4. Grobiņa	25. Liedurga – Ragana	46. Gulbene – Kārsava	67. Ļaudona
5. Priekuļi	26. Siguļda – Līgatne	47. Valka	68. Barkava
6. Auce	27. Vangaži- Inčukalns	48. Pedele	69. Līdumi
7. Augstkalne	28. Allaži – Jūdaži	49. Sēda	70. Medumi
8. Eleja	29. Ropaži	50. Oliņas	71. Kuprava
9. Olaine – Sesava	30. Ķegums	51. Valmiera	72. Alūksne – Viļaka
10. Imanta	31. Mālpils	52. Strenči	73. Pededze
11. Sarkandaugava	32. Birzgale	53. Rauna	74. Alūksne –
12. Vecāķi	33. Kurmene	54. Bilska – Mēri	Katleši
13. Carnikava	34. Matīši	55. Ērgļi – Subate	75. Balvi
14. Ulbroka - Saurieši	35. Mazsalaca – Rūjiena	56. Taurene	76. Rekava
15. Ogre	36. Naukšēni	57. Ķieģeļceplis	77. Baltinava
16. Bauska	37. Ozols – Zilais kalns	58. Ineši	78. Lūdza
17. Iecava	38. Dauguļi	59. Pļaviņas	79. Rundani
18.Skaistkalne	39. Stalbe – Lietezers	60. Ranka	80. Lauderi
19. Uzvara	40. Nītaure – Ieriķi	61. Lizums	81. Dagda
20. Jodava	41. Viršu kalns	62. Sinole	82. Krāslava
21. Ainaži	42. Annas - Taurupe	63. Druviena	83. Kalnieši
			84. Indra

Fig.1. Scheme of horizontal gradients of the Latvian anomalous magnetic field Scale of horizontal gradients of the anomalous magnetic field, nT/km (Prepared by V. Vetreņņikovs).

In Western Latvia, the magnetic horizontal gradients in its northern part, which is called Northern Kurzeme, differ from the gradients in its southern part (the Southern Kurzeme anomalous area).

In the Northern Kurzeme anomalous area, the horizontal gradients pertain to the low gradient category (lower than 100 nT/km). Magnetic steps are absent there. Gradients with varying directions form a single magnetic gradient area with the gradient level from 10 to 60 nT/km.

In the Southern Kurzeme anomalous area, the horizontal gradients form steps and areas having different directions, with the areas predominant. The gradient levels within the steps vary from 60 to 100 nT/km, reaching 200 nT/km (in the south-eastern part of the anomalous area). The gradient levels within the areas comprise 15 – 25 nT/km. The Pāvilosta – Kandava regional magnetic step, stretching in the horizontal direction, separates the Southern Kurzeme and the Northern Kurzeme anomalous areas (Fig. 1). The length of the step is 150 km, the gradient level - 50 – 100 nT/km.

Central Latvia is characterised by gradients, which predominantly form steps with subordinate values of magnetic gradient areas. As regards their morphology, the steps differ in the western part of Central Latvia (the Riga anomalous area) and its eastern part (the Gārsene – Cēsis anomalous area).

In the Riga anomalous area, the magnetic steps have mostly circular and arched configuration, stretching for tens of kilometres, bounding central magnetic gradient areas. The gradients, forming the steps, belong to the group with the medium and high gradients (hundreds of nT/km), reaching 1050 nT/km. Within the areas, the gradients vary from 25 to 100 nT/km.

In the Gārsene – Cēsis anomalous area, magnetic steps with the linear configuration are predominant. They form a meridional gradient system, in which steps with different gradients mutually alternate. The longest steps (l > 50 km) belong to the category of regional ones (Ērgļi, Koknese – Viesīte, Cēsis – Nereta). The gradient levels within the steps vary from tens to thousands of nT/km (in the Subate area – 1050, Gārsene – 1400, Zaube – 2400 nT/km).

Eastern Latvia is characterised by heterogeneous distribution of horizontal gradients. They differ in the northern (the Ape – Valmiera anomalous area), central (the Alūksne – Madona anomalous area), southern (the Rēzekne – Daugavpils anomalous area) and south-eastern (the Krāslava anomalous area) parts.

The Ape – Valmiera anomalous area incorporates horizontal steps and isometric gradient areas. The gradient levels within the areas do not exceed 100 nT/km, those within the steps are mostly below 200 nT/km, increasing to 1000 nT/km in intensive anomalies (Strenči).

In the Alūksne – Madona anomalous area, the horizontal gradients are represented by alternating linear, predominantly regional steps of the north-western direction and by magnetic gradient areas of the same direction. The horizontal gradient levels vary from 45 - 70 nT/km (in the areas) to 95 - 200 nT/km (in the steps).

In the Krāslava anomalous area, the horizontal gradients are represented by magnetic steps, with the linear configuration similar to the Alūksne – Madona anomalous areas, but with a different trend of the steps, which stretch in the north-eastern direction, perpendicular to the trend of the steps of the Alūksne – Madona anomalous area. Bands of the steps mostly continue outside Latvia, in the territory of Belarus. The horizontal gradient levels within the steps are 70 - 210 nT/km.

The Rēzekne - Daugavpils anomalous area is characterised by predominantly low gradients, which form a unified large isometric magnetic gradient field (XXXIII Latgale – see Fig. 1). There are practically no magnetic steps inside it. The predominant horizontal gradients in the area are 20 – 30 nT/km, increasing in the Malta – Viļāni – Atašiene anomalous area to 130 – 140 nT/km.

Thus, the above presented review of the horizontal magnetic gradients in different parts of Latvia has demonstrated the existence of certain regularities in the spatial distribution of that parameter of the anomalous magnetic field. That is: the highest gradient values (exceeding 200 nT/km) are associated with Central Latvia (between the 240 and 260 meridians), the medium ones (100 – 200 nT/km – predominantly with Central and North-Eastern Latvia, and the low ones (less than 100 nT/km) – predominantly with Western and South-Eastern Latvia. A similar regularity is evident in the distribution of the magnetic steps and areas. The steps mostly concentrate in Central Latvia, as well as in North-Eastern Latvia, while the areas – in Western and Eastern Latvia.

AVERAGE GRADIENT LEVELS OF THE ANOMALOUS MAGNETIC FIELD

The levels of the field gradients are calculated for a particular area, including anomalous areas and administrative territorial units. They are determined with the purpose of easier utilisation of gradients for the comparison of various territories and determination of their impact on the demographic indices.

CALCULATIONS OF THE AVERAGE GRADIENT LEVELS OF THE ANOMALOUS MAGNETIC FIELD

The levels of the field gradients are determined using the weighted mean method based on the following formula:

$$Gav = \frac{S1 \cdot G1 + S2 \cdot G2 + Sn \cdot Gn}{S1 + S2 + ...Sn} \quad (1)$$

where

Gav. – the weighted mean horizontal gradient of the territory;

S1 + S2 + ... Sn – areas of zones with the identical value of the horizontal gradient;

G1 + G2 + ...Gn – particular gradient values in those zones;

n – the number of zones and particular gradient values.

The calculations have demonstrated that the average levels of the horizontal gradients of the anomalous areas and the Latvian administrative districts have the following values (see Table 1).

TABLE 1

AVERAGE GRADIENT LEVELS OF MAGNETIC FIELDS IN THE ANOMALOUS TERRITORIES AND LATVIAN ADMINISTRATIVE DISTRICTS

Anomalous area	Average horizontal gradients, nT/km	Map No.	Administrative district	Average horizontal gradients, nTl/km	Map No.	Administrative district	Average horizontal gradients, nTl/km
Western Latvia:	34	1	Aizkraukle	95	14	Limbaži	232
Northern Kurzeme area	25	2	Alūksne	72	15	Ludza	53
Southern Kurzeme area	43	3	Balvi	83	16	Madona	72
		4	Bauska	168	17	Ogre	669
Central Latvia:	259	5	Cēsis	207	18	Preiļi	27
Riga area	263	6	Daugavpils	78	19	Rēzekne	53
Gārsene - Cēsis area	254	7	Dobele	85	20	Riga	224
		8	Gulbene	91	21	Saldus	36
Eastern Latvia:	79	9	Jēkabpils	96	22	Talsi	19
Ape - Valmiera area	210	10	Jelgava	70	23	Tukums	31
Alūksne – Madona area	90	11	Krāslava	73	24	Valka	127
Krāslava area	100	12	Kuldīga	29	25	Valmiera	84
Rēzekne – Daugavpils area	32	13	Liepāja	36	26	Ventspils	20
Latvia, total	131						

ECOLOGICAL – DEMOGRAPHIC EVALUATION OF THE LATVIAN TERRITORY BASED ON GRADIENTS OF ANOMALOUS MAGNETIC FIELD

Based on the biogeophysicists' opinion, taking into account the impact of geophysical fields, where the gradient is one of the parameters, "during the establishment of settlements allows to ensure the comfort of the human habitation, i.e. the psychic and physical health of people both regionally and in local areas, influencing the density of population and its reproduction, solving demographic problems" [2].

The problem of the ecological – demographic evaluation of the Latvian territory based on gradients of the anomalous magnetic field practically has not been investigated as of this moment. An attempt has been made in this article to start solving this problem in a very general manner, utilising the data for a better studied parameter, i.e. the intensity of the magnetic field.

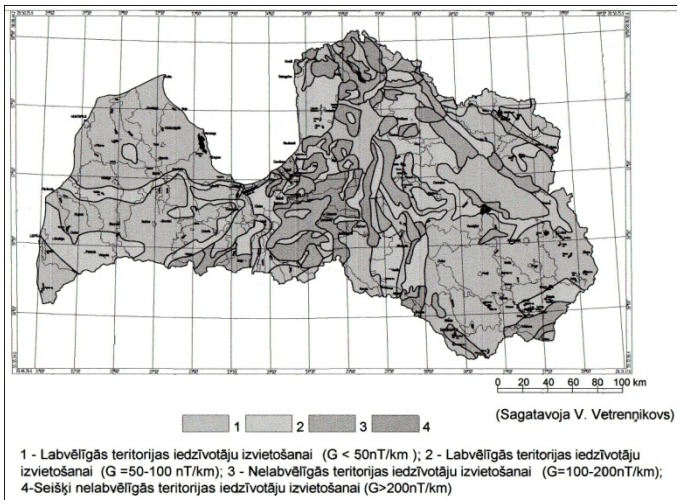
Actually, the gradient parameter is closely associated spatially with the parameter of the anomaly intensity. It is confirmed by the analysis of the structure of the anomalous magnetic field, which has demonstrated that the vast majority of high horizontal gradients (G>200 nT/km) and intensive anomalies ($\Delta Ta > \pm 500nT$) are associated with the same anomalous province (Central Latvia), while the majority of low gradients (G<50nT/km) and low intensity anomalies ($\Delta T = 0 \mid \pm 500nT$) – with Western and Eastern Latvia.

Thus the evaluation of the impact of the horizontal magnetic gradient on the population is closely connected with the intensity of the anomalies.

It is known that high values of the intensity and the field gradients have predominantly negative impact on the population, while low values produce predominantly positive impact. For example, it was discovered in the neighbouring Lithuania that the heightened intensity and anomalous gradients of the magnetic field lead to a heightened risk of contracting cancer, cardiovascular diseases and schizophrenia [1].

It was shown empirically that the intensity of magnetic anomalies in Latvia exceeding ± 500 nT negatively impacts the population, whereas the weak magnetic field with the intensity from 0 to +500 nT and from 0 to -500 nT demonstrates a positive impact. The above-mentioned fact of spatial association of the high gradient zones with the zones of the intensive field and the low gradient zones with the zones of weak field makes it possible to speak about the correlation of the degree of favourability of territories based on those parameters. In other words, the territories, which are favourable based on the field intensity, are also favourable based on the gradient, and, respectively, the territories, which are unfavourable based on the field intensity, are also unfavourable based on the gradient parameter.

Figure 2 shows an ecological – demographic scheme based on the evaluation of gradients of the anomalous magnetic field in the Latvian territory. Four anomalous areas have been singled out based on the following criteria: a) most favourable for human habitation (G < 50 nT/km); b) favourable for human habitation (G = 50 - 100 nT/km); c) unfavourable for human habitation (G = 100 - 200 nT/km); d) particularly unfavourable for human habitation (G > 200 nT/km).



1 - Areas, which are the most favourable for human habitation (G < 50 nT/km).
2 - Areas, which are favourable for human habitation (G = 50 – 100 nT/km).
3 - Areas, which are unfavourable for human habitation (G = 100 - 200 nT/km).
4 - Areas, which are the most unfavourable for human habitation (G > 200 nT/km).

Fig.2. Ecological – demographic evaluation of the Latvian territory based on gradients of the anomalous magnetic field (Prepared by V. Vetreņņikovs).

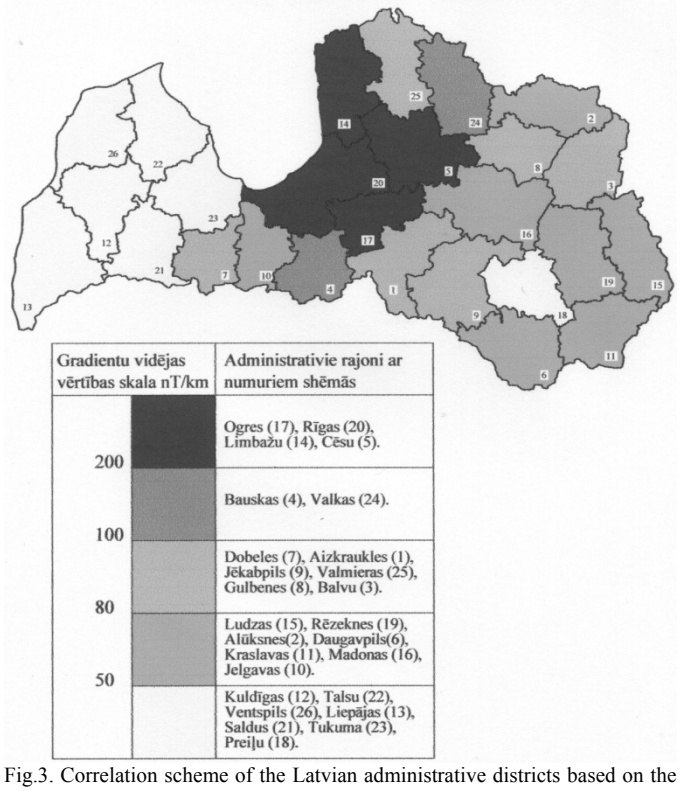


Fig.3. Correlation scheme of the Latvian administrative districts based on the gradients of the anomalous magnetic field (Prepared by V. Vetreņņikovs).

Those areas predominantly coincide with the steps and areas of the magnetic gradient (see Fig. 1) and are subdivided in accordance with the above-mentioned regularities regarding the distribution of the horizontal gradient of the anomalous magnetic field, namely: most of the unfavourable areas are associated with Central Latvia, while the favourable ones are associated with Western and Eastern Latvia.

Based on those criteria, an ecological-demographic evaluation could be made utilising the gradients of the magnetic anomalies in the anomalous areas and the Latvian administrative districts characterised by average values of that parameter (see Table 1 and Fig. 3).

Thus, based on the average level of the field gradient for groups of territories, the anomalous areas, which are the most favourable for human habitation (Gav. < 50 nT/km), are as follows: Northern Kurzeme, Southern Kurzeme, Rēzekne – Daugavpils, as well as the districts: Kuldīga, Talsi, Ventspils, Liepāja, Saldus, Tukums, Preiļi; the anomalous areas that are favourable for human habitation (Gav. 50 – 100 nT/km) are: the Alūksne - Madona and Krāslava anomalous areas, as well as the districts: Ludza, Rēzekne, Kuldīga, Daugavpils, Krāslava, Madona, Jelgava, Dobele, Valmiera, Aizkraukle, Gulbene, Jēkabpils, Balvi; the following districts are unfavourable for residence (Gav. 100 – 200 nT/km): Valka, Bauska; particularly unfavourable (Gav. > 200 nT/km) are the following anomalous areas: Riga, Gārsene – Cēsis, Ape – Valmiera and the districts: Ogre, Riga, Cēsis, Limbaži.

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Vladimirs Vetrennikovs. Latvijas magnētisko anomāliju gradienti
Gradienti ir nozīmīgi anomālā magnētiskā lauka ekoloģiski – ģeofizikāli parametri, kas atspoguļo magnētiskā sprieguma izmaiņas izplatījumā. Īpašu uzmanību pelna lineārie horizontālie gradienti (kāples), jo tie visbiežāk norāda uz tektonisko lūzumu esamību, kuri iespējams kalpo par pavadoņiem kaitīgajiem dziļumā esošajiem fluīdiem un patogēnām vielām, kas negatīvi ietekmē iedzīvotājus un demogrāfiskos rādītājus. Zinātniski pētnieciskā tēma „Ģeofizikālo faktoru ietekme uz demogrāfiskajiem procesiem un cilvēku dzīves vidi" izstrādes ietvaros sagatavoti materiāli, ko var izmantot teritorijas plānošanas procesā. Ņemot tos vērā, ir iespējams noteikt magnētisko zonu gradientu iedarbību uz cilvēkiem, kā arī to ietekmi uz demogrāfiskajiem rādītājiem.
Rakstā sniegts horizontālo magnētisko gradientu raksturojums, kuru lielumi mainās plašā diapazonā no 10 līdz 2400 nT/km. Izdalītas magnētiskās kāples un magnētisko gradientu laukumi. Pievienota to izplatības izvietojuma shēma. Noteiktas gradientu izvietojuma likumsakarības dažādās Latvijas daļās: Rietumu, Centrālajā, Austrumu. Aprēķināti lauka gradientātes vidējie līmeņi, kas ņemti par pamatu šā parametra izstrādātajām administratīvo rajonu korelācijas shēmām.
Noslēguma sadaļā ir sniegts ekoloģiski – demogrāfiskais Latvijas teritorijas vērtējums pēc anomālā magnētiskā lauka gradientātes, kas arī attēlota shēmā. Anomālā teritorijā izdalītas četras ekoloģiski – demogrāfiskas grupas: a) ļoti labvēlīgas iedzīvotāju dzīvošanai (Gm<50 nT/km; b) labvēlīgas (Gm=50–100 nT/km); c) nelabvēlīgas (Gm=100-100 nT/km; c) īpaši nelabvēlīgākas (Gm>200 nT/km. Pēc gradientu vidējiem lielumiem lielākā daļa Latvijas administratīvo rajonu attiecas uz teritorijas pirmo un otro grupu (ļoti labvēlīgas un labvēlīgas). Vairums rajonu pieder pie pirmās grupas. Trešā un ceturtā grupā (nelabvēlīgas un īpaši nelabvēlīgas) ietver šādus rajonus – Ogres, Rīgas, Cēsu, Limbažu, Valkas, Bauskas.

Владимир Ветренников. Градиенты магнитных аномалий Латвии
Градиенты являются важным эколого- геофизическим параметром аномального магнитного поля, отражающим характер изменчивости магнитной напряженности в пространстве. Особого внимания заслуживают линейные горизонтальные градиенты (ступени), ибо они указывают чаще всего на наличие тектонических разломов, которые могут служить проводниками вредных глубинных флюидов и патогенных веществ, негативно влияющих на население и демографические показатели. В рамках разработки научно- исследовательской темы «Влияние геофизических факторов на демографические процессы и среду обитания человека» были подготовлены материалы и карты, которые могут быть использованы в процессе территориального планирования. Они позволят учитывать воздействие на демографические показатели.
В статье дается характеристика горизонтальных магнитных градиентов величины, которых изменяются в широком диапазоне: от 10 до 2400 нТ/км. Выделяются магнитные ступени и магнитоградиентные площади. Приводится схема их пространственного распределения. Выявляются закономерности размещения градиентов в разных частях Латвии: Западной, Центральной и Восточной. Расчитываются средние уровни градиентности поля, на основе которых разрабатывается схема корреляции административных районов по данному параметру.
В заключительном разделе дается эколого- демографическая оценка территории Латвии по градиентности аномального магнитного поля, которая изображается также на схеме. Выделяются четыре эколого- демографические группы аномальных территорий: а) наиболее благоприятные для проживания населения (Gм<50нТ/км); б) благоприятные (Gм=5 -100нТ/км); в) неблагоприятные (Gм=100 -200нТ/км); г) особо неблагоприятные (Gм>200нТ/км). По величине средних значений градиентов, большинство административных районов Латвии относятся к первой и второй группы (наиболее благоприятной и благоприятной). В третью и четвертую группу (неблагоприятную и особо неблагоприятную) попадают районы: Огрский, рижский, Цесисский, Лимбажский, Валкский, Бауский.