InterCriteria Analysis of the Geographic Distribution of the ABO System Blood Groups in the Patients of the University Hospital "Saint Anna", Sofia, Bulgaria, from 2015 to 2021

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Abstract. The paper presents the results of the application of the method of InterCriteria Analysis on a dataset of the blood group of 47562 Bulgarian individuals, patients of the University Hospital "Saint Anna", Sofia, Bulgaria collected in the period from 2015 to 2021. Apart of the ABO system blood groups, the recorded data contain information about the patients' A1 and A2 subgroups and the Rh(D) antigen. In the current leg of research, in addition to the easily extracted information about the patients' year of birth and sex, here for the first time, the patients' birthplace regions are algorithmically extracted on the basis of the recorded personal identification numbers. This allows us to have a deeper and more insightful picture of the regional distribution of the frequencies of the ABO system, A1 and A2 subgroups and the Rh(D) antigen in the frames of the Bulgarian population, which is a level of detail that has not been yet reported in the existing literature and is considered an important contribution of the current research work to the state-of-the-art. The conducted InterCriteria Analysis on these data gives additional details that may help decision makers on national and regional level with respect to regional and cross-regional demand and supply of blood and blood products in Bulgaria.

Keywords: ABO system, Blood group distribution, Rh(D) antigen distribution, InterCriteria Analysis, Intuitionistic fuzzy sets.

1 Introduction

Ever since the discovery of the ABO system of blood groups and blood group antigens, their frequency in the human population has been a subject of research study. The ABO system's significance for transfusion medicine is due to the fact that transfusion of an incompatible ABO type of blood is the most common cause of death from blood transfusion, [15]. Antigens furthermore appear to play a significant role in human evolution because the frequencies of different ABO blood types exhibit significant variability among various human populations, [12, 15, 19, 20], suggesting that a particular blood type conferred a selection advantage like resistance against an infectious disease, etc. [15].

Every country needs to maintain a regular, up-to-date record with respect to the blood group distribution profile of its population. In this respect, various publicly available online sources contain rather outdated or approximate information about the blood group frequencies of Bulgarian population, in order to be considered reliable and usable. For example, in a top-ranking web source dated to 2013, [12], the data for the Bulgarian population's blood group distribution is roughly given as 44% of A, 15% of B, 32% of O and 8% of AB, and one of the most popular reference websites Wikipedia has provided in [22] as of June 2017 (without citing a particular source) the following frequencies: A Rh(+) 37.4%, A Rh(-) 6.6%, B Rh(+) 12.8%, B Rh(-) 2.2%, O Rh(+) 28.0%, O Rh(-) 5.0%, AB Rh(+) 6.8%, AB Rh(-) 1.2%, summing respectively to the percentages in [12]. Identical numbers, rounded to the nearest integer, are contained in another public database dated to 2019, [20]. A rather different picture is presented in a 2015 research [21] where the blood group distributions for the Bulgarian population are reported as 39.96% of A, 16.84% of B, 35.80% of O, and 7.60% of AB. Literature review of the blood group distributions in Bulgarian population also comprises sources from the years 1977 (Anastasov et al., [1]), 1988 (Dobreva et al, [16]), and 2012 (Popov et al., [19]), which we have discussed in comparison with our recent findings in [3, 4, 10].

These observations of available online information sources demonstrate the particular need for a detailed contemporary investigation of the problem and establishing an accurate database for Bulgaria, which motivates the present research. In addition, here a next level of detail regarding the geographic distribution of ABO blood groups on subnational / regional level is presented for the first time for the country's population.

The present paper is structured as follows: in Section 2, we give the background of our study: source of the patients' data and methods of data cleansing and retrieval. Section 3 contains the results of the study, namely the established frequencies the ABO system blood groups and subgroups, Rh(D) antigen frequencies, and respective maintained ratios, categorized by and analyzed in the light of the patients' birthplace location. The subsequent Section 4 analyzes the reported data with the apparatus of the intuitionistic fuzzy sets based method of InterCriteria Analysis. Finally, Section 5 gives conclusion and directions for future research.

2 Materials and Methods

The data collection for the present research is performed by the Centre of Transfusion Hematology in University Hospital "Saint Anna", Sofia, which is the source of the dataset of hospital patients registered in the period between January 1, 2015, and December, 31, 2021. In determining the blood group characteristics, all legal requirements related to the blood samples collection, test reagents and test erythrocytes, have been addressed, as stipulated in Ordinance No. 18 / 2004 of the Bulgarian Ministry of Health. The immune-hematological diagnostics comprises determination of the ABO blood group by the crossmatching method, determination of the A1 and A2 antigen subgroups, and determination of the Rh(D) antigen, followed by recording these data in the “Saint Anna” Hospital internal information system. The present research does not contain data of the investigated erythrocyte antigens beyond the ABO and Rhesus factor systems.

We are specifically noting the fact that, being one of the largest multispecialty hospitals in the capital city of Bulgaria, Sofia, University Hospital “Saint Anna” (locally known as ‘*The District Hospital*’) treats both city residents and patients from all regional districts of Bulgaria. This fact served as an additional motivation for our research, as it suggested the idea to extract from the patients’ data the information about their birthplace and collect as an additional parameter (column) of the dataset.

At the stage of primary data collection, we obtained the tabular data of: 6469 samples in 2015, 13716 samples in 2016, 8748 samples in 2017, 10214 samples in 2018, 10534 samples in 2019, 8769 samples in 2020, and 8968 samples in 2021.

We conducted the following procedure of cleansing the primary data, including:

1. Removal of records with incomplete or inaccurate entered personal data about the patients or data about their blood groups (e.g. recorded valued ‘A’ instead of ‘A1’ or ‘AB’, missing value of Rh(D) antigen, etc.),
2. Removal of records for patients of foreign nationality (where the personal identification number is not in the “EGN” (Unique citizenship number) format for Bulgarian nationals but in the “LNC” format for resident people of foreign nationality),
3. Removal of duplicate records with respect to the “EGN” (including numerous records of the blood samples of one and the same patient within a calendar year, as well as across the full six-year period),
4. Extraction from the “EGN” of the data about the patient’s sex, year of birth and birthplace location (region) (notably, this is the novel aspect of the present research),
5. Anonymization of the data.

As a result of the data cleansing procedure (Steps 1 – 3), the total number of 67418 records in the primary input was reduced and the dataset over which our investigation was conducted and results are reported, includes data of 47562 unique individuals. In 2019 and 2021, two similar studies, with a part of this data locked in the period 2015–2019, and 2015–2020, respectively were reported in [3] and [4]. The full results from the authors’ research of the dataset from 2015–2021 are provided in [10], as which continuation the present paper is standing.

We will comment here specifically on Step 4 of the followed procedure. Extraction from the unique citizenship number (“EGN”) of the information about the person’s sex, year of birth and place of birth (on district level, Bulgaria having 28 regional districts) is an algorithmically easy job given the public nature of the algorithm itself. For the readers’ reference and convenience, we will note that a detailed explanation for the algorithm is provided in [18], and an online tool for checking the validity of the EGNs, supported with thorough information and source code is provided on the webpage [13].

For the needs of the present research, the software needed to extract the necessary relevant information has been originally developed by the third author.

On the basis of the extraction of the data regarding patients' place of birth, we can report the following geographic profile of the patients of the "Saint Anna" Hospital in Sofia, see Figure 1.

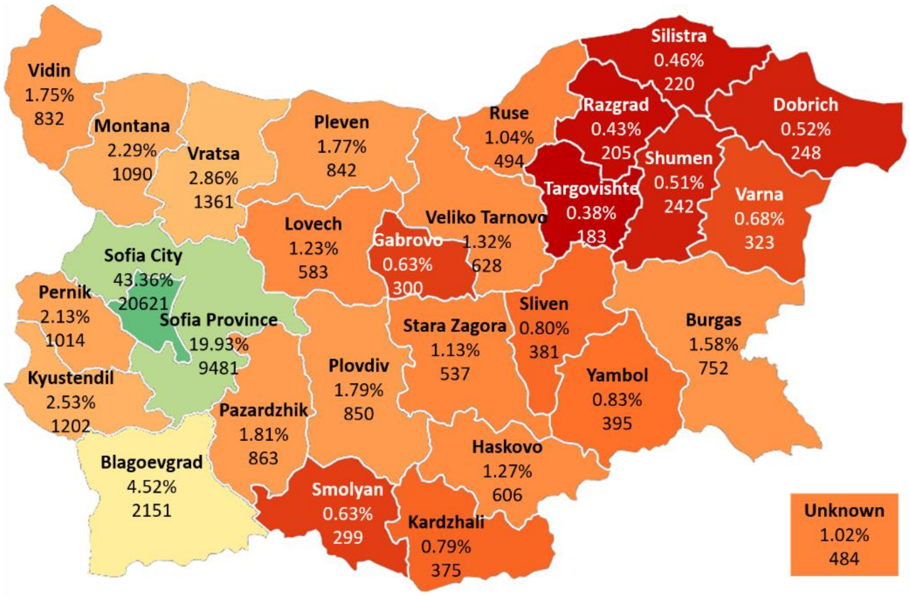

Fig. 1. Map of the distribution of "Saint Anna" Hospital patients from the period 2015–2021, covered in the study of ABO blood groups distribution

We shall immediately note that the map on Figure 1 above should be regarded with a certain level of conditionality, for several reasons that will be listed below.

First, it is not based on all of the hospital patients but on that portion of them, who are Bulgarian nationals, and whose EGN and blood related data were completely and correctly input in the hospital information system, after removing duplication of patients with multiple entries across the years, which means it is based on the 47562 unique individuals out of the 67418 data records from the system. Moreover, the statistics above does not contain information about patients who did not have their blood checked as a part of the routine of emergency diagnostics.

Second, the map reflects the patients' birthplace, not the place of residence – and specifically for a large Sofia-based hospital it is of importance that many residents of Sofia are actually not born in the city or in the province of Sofia. So, while the map cannot directly suggest the actual transfusion capacity of the population by place of residence (which is the one that would make sense), it can be – to a certain extent – informative regarding the regional blood group profiles in the different parts of Bulgaria, regardless of the internal migration.

Our third notable consideration is that our capability of making certain conclusions on national level on the basis of the so derived data, suffers from the limitation related to the disproportionate representation of all the regions in the presented statistics. Expectedly, for various reasons (geographic, logistic, financial, etc.), the largest share of patients of “Saint Anna” are people from the city and the region of Sofia, with several neighbouring regions from Western Bulgaria being far better represented compared to regions from the Eastern Bulgaria. Patients from these regions get most of their treatment in the local town and provincial hospitals, so our data collected in “Saint Anna” hospital is evidently skewed towards the patients from the region of Sofia. We have attempted to overcome this shortcoming of comparing datasets with different scales by normalization of the data, i.e. having all of its variations falling between zero and one, or as represented here in percentages. Indisputably, local statistics derived using the same rigorous and detailed data collection, data cleansing and data extraction methodology will surely yield more representative results for those provinces than the one we have been able to present here.

3 Results: Blood Group Distributions on Regional Level

In this section, the findings from the conducted analysis of the cleansed patients’ dataset will be presented, from the most general to the most particular results. Thus, on the basis of the 47562 unique patients’ records, we have established in Table 1 the following frequencies of the ABO system blood groups per province of birthplace (see also [10]). The patients with their birthplace province, number and percentage of representativeness, are as follows (sorted by representativeness): Sofia–City – 20621 patients (43.36%), Sofia–Province – 9481 patients (19.93%), Blagoevgrad – 2151 patients (4.52%), Vratsa – 1361 patients (2.86%), Kyustendil – 1202 patients (2.53%), Montana – 1090 patients (2.29%), Pernik – 1014 patients (2.13%), Pazardzhik – 863 patients (1.81%), Plovdiv – 850 patients (1.79%), Pleven – 842 patients (1.77%), Vidin – 832 patients (1.75%), Burgas – 752 patients (1.58%), Veliko Tarnovo – 628 patients (1.32%), Haskovo – 606 patients (1.27%), Lovech – 583 patients (1.23%), Stara Zagora – 537 patients (1.13%), Ruse – 494 patients (1.04%), Yambol – 395 patients (0.83%), Sliven – 381 patients (0.80%), Kardzhali – 375 patients (0.79%), Varna – 323 patients (0.68%), Gabrovo – 300 patients (0.63%), Smolyan – 299 patients (0.63%), Dobrich (ex. Tolbuhin) – 248 patients (0.52%), Shumen – 242 patients (0.51%), Silistra – 220 patients (0.46%), Razgrad – 205 patients (0.43%), Targovishte – 183 patients (0.38%), and finally “Unknown birthplace province” – 484 patients (1.02%). Due to the high level of detail achieved with presenting the data on regional level, we will not additionally slice it here by male/female sex, although we have this information in hand.

We will note that for a better comprehension and evaluation of the data presented in Table 1, the provinces are given with the percentage of representativeness in the statistics. The rows with data for patients with unknown birthplace and the total national have been left uncoloured. The colour codes of the table cells (from blue to red) are defined as follows: provinces recording lowest frequencies of a given blood group compared to all the other provinces are in blue colour, and provinces recording the highest frequencies of a given blood group compared to all the other provinces are in red colour. For instance, the province with the highest frequency of the AB blood group is Silistra (10.00%) compared to Varna with the lowest frequency (6.19%), all this on the basis of the dataset of registered patients in Sofia's "Saint Anna" Hospital.

Table 1. Established frequencies of the ABO system blood groups (A, B, O, AB), on provincial and national level.

Province in Bulgaria (% of data) \ Blood group		A	B	O	AB
Sofia City	43.36	44.51	16.21	31.05	8.23
Sofia Province	19.93	43.85	16.66	31.48	8.01
Blagoevgrad	4.52	43.75	15.43	33.80	7.02
Vratsa	2.86	42.40	17.49	31.45	8.67
Kyustendil	2.53	44.01	16.64	31.11	8.24
Montana	2.29	43.39	17.80	30.73	8.07
Pernik	2.13	42.31	15.68	33.33	8.68
Pazardzhik	1.81	43.22	14.95	34.99	6.84
Plovdiv	1.79	41.53	17.65	34.47	6.35
Pleven	1.77	43.59	18.65	28.98	8.79
Vidin	1.75	41.11	14.78	33.17	10.94
Burgas	1.58	41.62	15.96	34.44	7.98
Veliko Tarnovo	1.32	42.83	16.40	33.12	7.64
Haskovo	1.27	41.91	14.52	36.30	7.26
Lovech	1.23	40.65	17.15	32.59	9.61
Stara Zagora	1.13	41.15	15.27	35.38	8.19
Ruse	1.04	42.51	14.57	36.64	6.28
Yambol	0.83	44.56	18.23	30.89	6.33
Sliven	0.80	41.47	18.37	32.02	8.14
Kardzhali	0.79	41.33	16.80	32.27	9.60
Varna	0.68	42.72	16.41	34.67	6.19
Gabrovo	0.63	42.00	15.33	34.67	8.00
Smolyan	0.63	38.46	16.05	36.79	8.70
Dobrich	0.52	42.74	13.31	35.89	8.06
Shumen	0.51	44.21	12.81	35.12	7.85
Silistra	0.46	48.18	13.64	26.82	11.36
Razgrad	0.43	36.10	20.49	36.10	7.32
Targovishte	0.38	48.09	14.21	30.05	7.65
-- Unknown	1.02	*40.29*	*19.83*	*30.99*	*8.88*
Bulgaria TOTAL	**100.00**	**43.85**	**16.36**	**31.87**	**8.11**

The distribution of the blood groups after determining the Rh(D) antigen is given in the following Table 2. Again, the frequencies per province will be presented disregarding the frequencies per sex, with the data about males and females given *en gross*. The colour codes for the cells in Table 2 are identical to those described for Table 1.

Table 2. Established frequencies of the ABO system blood groups with the Rh(D) antigen determined, on provincial and national level.

Province in Bulgaria (% of data) / Blood group and Rh(D)		A		B		O		AB	
		Rh(+)	Rh(-)	Rh(+)	Rh(-)	Rh(+)	Rh(-)	Rh(+)	Rh(-)
Sofia City	43.36	38.27	6.24	13.93	2.28	26.75	4.30	7.09	1.13
Sofia Province	19.93	37.91	5.94	14.52	2.14	27.02	4.46	7.08	0.93
Blagoevgrad	4.52	38.08	5.67	13.62	1.81	29.43	4.37	6.09	0.93
Vratsa	2.86	37.25	5.14	15.06	2.42	26.67	4.78	8.01	0.66
Kyustendil	2.53	37.77	6.24	14.14	2.50	27.12	3.99	7.32	0.92
Montana	2.29	37.61	5.78	15.87	1.93	27.16	3.58	6.51	1.56
Pernik	2.13	37.38	4.93	14.10	1.58	28.50	4.83	7.40	1.28
Pazardzhik	1.81	37.43	5.79	12.75	2.20	31.17	3.82	6.03	0.81
Plovdiv	1.79	35.41	6.12	15.06	2.59	30.35	4.12	5.06	1.29
Pleven	1.77	38.24	5.34	17.10	1.54	24.11	4.87	7.96	0.83
Vidin	1.75	35.58	5.53	12.62	2.16	28.37	4.81	9.01	1.92
Burgas	1.58	36.70	4.92	14.36	1.60	28.46	5.98	7.45	0.53
Veliko Tarnovo	1.32	36.94	5.89	14.33	2.07	28.66	4.46	6.37	1.27
Haskovo	1.27	36.30	5.61	13.53	0.99	31.52	4.79	6.11	1.16
Lovech	1.23	34.65	6.00	14.24	2.92	29.16	3.43	8.06	1.54
Stara Zagora	1.13	36.50	4.66	13.97	1.30	29.80	5.59	6.89	1.30
Ruse	1.04	37.25	5.26	12.15	2.43	31.58	5.06	5.87	0.40
Yambol	0.83	38.23	6.33	16.71	1.52	25.82	5.06	5.82	0.51
Sliven	0.80	35.43	6.04	16.01	2.36	28.35	3.67	7.35	0.79
Kardzhali	0.79	35.47	5.87	14.67	2.13	29.07	3.20	8.80	0.80
Varna	0.68	37.15	5.57	13.62	2.79	29.72	4.95	5.88	0.31
Gabrovo	0.63	37.67	4.33	13.67	1.67	30.33	4.33	7.33	0.67
Smolyan	0.63	32.11	6.35	12.04	4.01	31.10	5.69	6.35	2.34
Dobrich	0.52	35.48	7.26	12.90	0.40	31.85	4.03	7.66	0.40
Shumen	0.51	40.08	4.13	12.81	0.00	29.75	5.37	6.20	1.65
Silistra	0.46	42.27	5.91	10.45	3.18	22.27	4.55	10.00	1.36
Razgrad	0.43	33.17	2.93	17.07	3.41	32.68	3.41	6.83	0.49
Targovishte	0.38	40.98	7.10	11.48	2.73	26.78	3.28	4.92	2.73
-- Unknown	1.02	*32.02*	*8.26*	*17.56*	*2.27*	*24.79*	*6.20*	*7.44*	*1.45*
Bulgaria TOTAL	**100.00**	**37.70**	**5.96**	**14.19**	**2.17**	**27.45**	**4.41**	**7.04**	**1.07**

The characterization of the subgroups of the A and AB blood groups is presented in the next Table 3.

Table 3. Established frequencies of the A and AB blood group subgroups with the Rh(D) antigen determined, on provincial and national level.

Blood subgroup and Rh(D) / Province in Bulgaria (% of data)		A1		A2		A1B		A2B	
		Rh(+)	**Rh(-)**	**Rh(+)**	**Rh(-)**	**Rh(+)**	**Rh(-)**	**Rh(+)**	**Rh(-)**
Sofia City	43.36	35.38	5.66	2.89	0.57	6.28	1.01	0.82	0.13
Sofia Province	19.93	34.62	5.38	3.29	0.56	6.19	0.89	0.89	0.04
Blagoevgrad	4.52	35.43	5.07	2.65	0.60	5.72	0.79	0.37	0.14
Vratsa	2.86	33.73	4.63	3.53	0.51	7.05	0.59	0.96	0.07
Kyustendil	2.53	35.19	5.66	2.58	0.58	6.66	0.83	0.67	0.08
Montana	2.29	33.94	5.32	3.67	0.46	5.87	1.19	0.64	0.37
Pernik	2.13	35.60	4.44	1.78	0.49	6.21	1.18	1.18	0.10
Pazardzhik	1.81	34.18	5.56	3.24	0.23	4.98	0.70	1.04	0.12
Plovdiv	1.79	31.41	5.53	4.00	0.59	4.59	1.06	0.47	0.24
Pleven	1.77	34.80	4.99	3.44	0.36	7.01	0.71	0.95	0.12
Vidin	1.75	33.29	4.81	2.28	0.72	7.57	1.80	1.44	0.12
Burgas	1.58	34.18	4.52	2.53	0.40	5.85	0.53	1.60	0.00
Veliko Tarnovo	1.32	32.96	5.89	3.98	0.00	5.57	0.96	0.80	0.32
Haskovo	1.27	33.99	5.45	2.31	0.17	5.45	1.16	0.66	0.00
Lovech	1.23	31.90	4.97	2.74	1.03	7.55	1.54	0.51	0.00
Stara Zagora	1.13	31.66	4.28	4.84	0.37	6.15	1.30	0.74	0.00
Ruse	1.04	34.62	4.45	2.63	0.81	5.67	0.40	0.20	0.00
Yambol	0.83	35.44	5.82	2.78	0.51	5.06	0.51	0.76	0.00
Sliven	0.80	32.02	5.51	3.41	0.52	6.56	0.79	0.79	0.00
Kardzhali	0.79	33.87	5.87	1.60	0.00	8.00	0.80	0.80	0.00
Varna	0.68	35.29	5.26	1.86	0.31	4.64	0.31	1.24	0.00
Gabrovo	0.63	34.33	3.67	3.33	0.67	6.33	0.67	1.00	0.00
Smolyan	0.63	29.77	4.68	2.34	1.67	6.02	2.34	0.33	0.00
Dobrich	0.52	34.27	6.85	1.21	0.40	6.45	0.40	1.21	0.00
Shumen	0.51	38.84	2.89	1.24	1.24	5.79	1.24	0.41	0.41
Silistra	0.46	39.55	5.91	2.73	0.00	9.55	1.36	0.45	0.00
Razgrad	0.43	32.20	2.93	0.98	0.00	5.37	0.49	1.46	0.00
Targovishte	0.38	35.52	5.46	5.46	1.64	4.92	2.19	0.00	0.55
-- *Unknown*	1.02	*28.72*	*7.85*	*3.31*	*0.41*	*6.20*	*1.45*	*1.24*	*0.00*
Bulgaria TOTAL	**100.00**	**34.72**	**5.41**	**2.98**	**0.55**	**6.21**	**0.97**	**0.83**	**0.10**

The frequencies of the A_1 and A_2 subgroups within blood group A in this study, as well as the frequencies of the A_1B and A_2B subgroups against blood group AB have been determined, for the patients in all provinces, as listed in Table 4. The color legend in the table is similar to the legends of Tables 1–3: the higher the value of the frequencies of the A_1 subgroup in both the A and AB groups (2nd and 4th columns), the more intensive the red shade, the lower this frequency, the bluer the shade, yet since the A_2 subgroup complements A_1, the color code of the 3rd and 5th columns, i.e., the frequencies A_2 subgroup in the A and AB groups, the logic in the colour legend is the opposite.

Table 4. Established frequencies of the A and AB blood group subgroups with the Rh(D) antigen determined, on provincial and national level.

Province in Bulgaria (% of data) \ Subgroup / Group Frequency		A1/A	A2/A	A1B/AB	A2B/AB
Sofia City	43.36	92.22	7.78	88.51	11.49
Sofia Province	19.93	91.22	8.78	88.41	11.59
Blagoevgrad	4.52	92.56	7.44	92.72	7.28
Vratsa	2.86	90.47	9.53	88.14	11.86
Kyustendil	2.53	92.82	7.18	90.91	9.09
Montana	2.29	90.49	9.51	87.50	12.50
Pernik	2.13	94.64	5.36	85.23	14.77
Pazardzhik	1.81	91.96	8.04	83.05	16.95
Plovdiv	1.79	88.95	11.05	88.89	11.11
Pleven	1.77	91.28	8.72	87.84	12.16
Vidin	1.75	92.69	7.31	85.71	14.29
Burgas	1.58	92.97	7.03	80.00	20.00
Veliko Tarnovo	1.32	90.71	9.29	85.42	14.58
Haskovo	1.27	94.09	5.91	90.91	9.09
Lovech	1.23	90.72	9.28	94.64	5.36
Stara Zagora	1.13	87.33	12.67	90.91	9.09
Ruse	1.04	91.90	8.10	96.77	3.23
Yambol	0.83	92.61	7.39	88.00	12.00
Sliven	0.80	90.51	9.49	90.32	9.68
Kardzhali	0.79	96.13	3.87	91.67	8.33
Varna	0.68	94.93	5.07	80.00	20.00
Gabrovo	0.63	90.48	9.52	87.50	12.50
Smolyan	0.63	89.57	10.43	96.15	3.85
Dobrich	0.52	96.23	3.77	85.00	15.00
Shumen	0.51	94.39	5.61	89.47	10.53
Silistra	0.46	94.34	5.66	96.00	4.00
Razgrad	0.43	97.30	2.70	80.00	20.00
Targovishte	0.38	85.23	14.77	92.86	7.14
-- Unknown	*1.02*	*90.77*	*9.23*	*86.05*	*13.95*
Bulgaria TOTAL	**100.00**	**91.91**	**8.09**	**88.52**	**11.48**

4 Results: InterCriteria Analysis

The presented findings from Section 3 are analyzed with the intuitionistic fuzzy sets based decision making approach of InterCriteria Analysis. Detailed theoretical presentation of the method is provided in a number of publications [7, 8, 9, 14, 17], and its applications to problems and datasets in the area of blood transfusion are contained in [2, 3, 5, 6].

The presented dataset contains 29 rows (28 Bulgarian provinces and 1 'Unknown', rare yet permissible by the 'EGN' algorithm) and 28 columns (standing respectively for the criteria: A, B, O, AB, A(+), A(-), B(+), B(-), O(+), O(-), AB(+), AB(-), A1, A2, A1B, A2B, A1(+), A1(-), A2(+), A2(-), A1B(+), A1B(-), A2B(+), A2B(-), A1/A, A2/A, A1B/AB, A2B/AB. After running the ICA algorithm on this dataset, the following results are obtained (Tables 5 and 6).

Table 5. Results of ICA analysis on the patients' dataset showing the links between the data sorted per district: μ values

μ	Sofia - Cit	Sofia - Pro	Blagoevgr	Vratsa	Kyustendi	Montana	Pernik	Pazardzhil	Plovdiv	Pleven	Vidin	Burgas	Veliko Tar	Haskovo	Lovech	Stara Zago	Ruse	Yambol	Sliven	Kardzhali	Varna	Gabrovo	Smolyan	Dobrich	Shumen	Silistra	Razgrad	Targovisht	..Unknown
Sofia - Cit	1.00	0.99	0.99	0.98	0.99	0.99	0.98	0.97	0.97	0.99	0.99	0.96	0.98	0.97	0.96	0.96	0.95	0.95	0.97	0.95	0.94	0.96	0.93	0.92	0.95	0.94	0.91	0.93	0.97
Sofia - Pro	0.99	1.00	0.98	0.99	0.98	0.98	0.98	0.97	0.97	0.99	0.97	0.96	0.97	0.96	0.95	0.95	0.94	0.96	0.98	0.95	0.94	0.97	0.92	0.92	0.94	0.93	0.91	0.92	0.96
Blagoevgr	0.99	0.98	1.00	0.97	0.98	0.98	0.96	0.96	0.97	0.97	0.97	0.94	0.97	0.96	0.97	0.96	0.96	0.94	0.97	0.93	0.93	0.96	0.94	0.91	0.95	0.94	0.90	0.94	0.96
Vratsa	0.98	0.99	0.97	1.00	0.98	0.98	0.98	0.98	0.96	0.99	0.97	0.97	0.97	0.96	0.94	0.95	0.94	0.97	0.97	0.94	0.95	0.98	0.92	0.93	0.94	0.92	0.92	0.91	0.96
Kyustendi	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.96	0.97	0.98	0.99	0.96	0.97	0.98	0.96	0.96	0.94	0.95	0.97	0.95	0.94	0.96	0.92	0.93	0.96	0.94	0.92	0.92	0.97
Montana	0.99	0.98	0.98	0.98	0.99	1.00	0.97	0.97	0.98	0.98	0.98	0.95	0.97	0.97	0.96	0.96	0.95	0.95	0.98	0.94	0.93	0.96	0.93	0.91	0.94	0.93	0.90	0.93	0.97
Pernik	0.98	0.98	0.96	0.98	0.98	0.97	1.00	0.96	0.95	0.98	0.99	0.96	0.96	0.96	0.94	0.94	0.93	0.94	0.97	0.96	0.94	0.96	0.91	0.93	0.95	0.93	0.93	0.90	0.95
Pazardzhil	0.97	0.97	0.96	0.98	0.96	0.97	0.96	1.00	0.97	0.98	0.96	0.97	0.98	0.96	0.94	0.94	0.93	0.97	0.96	0.93	0.96	0.97	0.91	0.95	0.92	0.91	0.92	0.91	0.97
Plovdiv	0.97	0.97	0.97	0.96	0.97	0.98	0.95	0.97	1.00	0.96	0.96	0.94	0.97	0.96	0.95	0.94	0.94	0.96	0.96	0.92	0.93	0.95	0.93	0.92	0.93	0.91	0.89	0.94	0.98
Pleven	0.99	0.99	0.97	0.99	0.98	0.98	0.98	0.98	0.96	1.00	0.97	0.97	0.97	0.96	0.95	0.95	0.94	0.97	0.97	0.95	0.96	0.98	0.92	0.93	0.94	0.93	0.92	0.91	0.96
Vidin	0.99	0.97	0.97	0.97	0.99	0.98	0.99	0.96	0.96	0.97	1.00	0.96	0.97	0.97	0.95	0.95	0.94	0.94	0.96	0.95	0.94	0.95	0.92	0.93	0.96	0.94	0.92	0.91	0.96
Burgas	0.96	0.96	0.94	0.97	0.96	0.95	0.96	0.97	0.94	0.97	0.96	1.00	0.95	0.95	0.94	0.94	0.93	0.95	0.96	0.93	0.96	0.97	0.91	0.94	0.93	0.91	0.93	0.88	0.95
Veliko Tar	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.98	0.97	0.97	0.97	0.95	1.00	0.96	0.94	0.95	0.94	0.95	0.96	0.94	0.94	0.96	0.92	0.92	0.93	0.93	0.92	0.92	0.97
Haskovo	0.97	0.96	0.96	0.96	0.98	0.97	0.96	0.96	0.96	0.96	0.97	0.95	0.96	1.00	0.95	0.96	0.94	0.94	0.96	0.94	0.94	0.95	0.93	0.94	0.94	0.93	0.91	0.91	0.97
Lovech	0.96	0.95	0.97	0.94	0.96	0.96	0.94	0.94	0.95	0.95	0.95	0.94	0.94	0.95	1.00	0.95	0.98	0.93	0.96	0.94	0.92	0.94	0.96	0.90	0.92	0.96	0.89	0.92	0.95
Stara Zago	0.96	0.95	0.96	0.95	0.96	0.96	0.94	0.94	0.94	0.95	0.95	0.94	0.95	0.96	0.95	1.00	0.95	0.93	0.95	0.92	0.91	0.96	0.93	0.91	0.93	0.92	0.90	0.92	0.95
Ruse	0.95	0.94	0.96	0.94	0.94	0.95	0.93	0.93	0.94	0.94	0.94	0.93	0.94	0.94	0.98	0.95	1.00	0.92	0.94	0.92	0.91	0.94	0.97	0.89	0.92	0.95	0.88	0.91	0.94
Yambol	0.95	0.96	0.94	0.97	0.95	0.95	0.94	0.97	0.96	0.97	0.94	0.95	0.95	0.94	0.93	0.93	0.92	1.00	0.96	0.92	0.97	0.97	0.90	0.94	0.91	0.90	0.90	0.90	0.97
Sliven	0.97	0.98	0.97	0.97	0.97	0.98	0.97	0.96	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.95	0.94	0.96	1.00	0.96	0.94	0.97	0.92	0.92	0.92	0.92	0.91	0.91	0.96
Kardzhali	0.95	0.95	0.93	0.94	0.95	0.94	0.96	0.93	0.92	0.95	0.95	0.93	0.94	0.94	0.94	0.92	0.92	0.92	0.96	1.00	0.94	0.93	0.91	0.92	0.91	0.97	0.93	0.88	0.93
Varna	0.94	0.94	0.93	0.95	0.94	0.93	0.94	0.96	0.93	0.96	0.94	0.96	0.94	0.94	0.92	0.91	0.91	0.97	0.94	0.94	1.00	0.95	0.89	0.96	0.90	0.92	0.92	0.88	0.95
Gabrovo	0.96	0.97	0.96	0.98	0.96	0.96	0.96	0.97	0.95	0.98	0.95	0.97	0.96	0.95	0.94	0.96	0.94	0.97	0.97	0.93	0.95	1.00	0.92	0.94	0.93	0.91	0.92	0.90	0.96
Smolyan	0.93	0.92	0.94	0.92	0.92	0.93	0.91	0.91	0.93	0.92	0.92	0.91	0.92	0.93	0.96	0.93	0.97	0.90	0.92	0.91	0.89	0.92	1.00	0.88	0.90	0.93	0.88	0.89	0.93
Dobrich	0.92	0.92	0.91	0.93	0.93	0.91	0.93	0.95	0.92	0.93	0.93	0.94	0.92	0.94	0.90	0.91	0.89	0.94	0.92	0.92	0.96	0.94	0.88	1.00	0.91	0.90	0.92	0.87	0.93
Shumen	0.95	0.94	0.95	0.94	0.96	0.94	0.95	0.92	0.93	0.94	0.96	0.93	0.93	0.94	0.92	0.93	0.92	0.91	0.92	0.91	0.90	0.93	0.90	0.91	1.00	0.90	0.89	0.89	0.92
Silistra	0.94	0.93	0.94	0.92	0.94	0.93	0.93	0.91	0.91	0.93	0.94	0.91	0.93	0.93	0.96	0.92	0.95	0.90	0.92	0.97	0.92	0.91	0.93	0.90	0.90	1.00	0.91	0.88	0.92
Razgrad	0.91	0.91	0.90	0.92	0.92	0.90	0.93	0.92	0.89	0.92	0.92	0.93	0.92	0.91	0.89	0.90	0.88	0.90	0.91	0.93	0.92	0.92	0.88	0.92	0.89	0.91	1.00	0.84	0.90
Targovisht	0.93	0.92	0.94	0.91	0.92	0.93	0.90	0.91	0.94	0.91	0.91	0.88	0.92	0.91	0.92	0.92	0.91	0.90	0.91	0.88	0.88	0.90	0.89	0.87	0.89	0.88	0.84	1.00	0.93
..Unknown	0.97	0.96	0.96	0.96	0.97	0.97	0.95	0.97	0.98	0.96	0.96	0.95	0.97	0.97	0.95	0.95	0.94	0.97	0.96	0.93	0.95	0.96	0.93	0.93	0.92	0.92	0.90	0.93	1.00

Table 6. Results of ICA analysis on the patients' dataset showing the links between the data sorted per district: ν values

ν	Sofia - Cit	Sofia - Pro	Blagoevgr	Vratsa	Kyustendi	Montana	Pernik	Pazardzhil	Plovdiv	Pleven	Vidin	Burgas	Veliko Tar	Haskovo	Lovech	Stara Zago	Ruse	Yambol	Sliven	Kardzhali	Varna	Gabrovo	Smolyan	Dobrich	Shumen	Silistra	Razgrad	Targovisht	..Unknown
Sofia - Cit	0.00	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.02	0.01	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.03	0.01	0.03	0.04	0.02	0.06	0.05	0.04	0.05	0.07	0.05	0.02
Sofia - Pro	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.04	0.03	0.04	0.02	0.00	0.03	0.04	0.01	0.06	0.04	0.04	0.05	0.06	0.05	0.02
Blagoevgr	0.01	0.01	0.00	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.02	0.04	0.03	0.03	0.02	0.03	0.03	0.04	0.01	0.04	0.06	0.03	0.04	0.07	0.04	0.05	0.08	0.04	0.03
Vratsa	0.02	0.01	0.03	0.00	0.02	0.02	0.02	0.02	0.04	0.01	0.03	0.02	0.03	0.03	0.05	0.04	0.05	0.02	0.01	0.03	0.04	0.01	0.06	0.04	0.05	0.07	0.06	0.07	0.03
Kyustendi	0.01	0.01	0.02	0.02	0.00	0.01	0.01	0.04	0.03	0.02	0.01	0.03	0.02	0.01	0.04	0.03	0.05	0.03	0.01	0.02	0.04	0.03	0.06	0.05	0.03	0.04	0.07	0.06	0.03
Montana	0.01	0.01	0.02	0.02	0.01	0.00	0.02	0.03	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.03	0.05	0.03	0.00	0.03	0.05	0.03	0.06	0.06	0.04	0.06	0.08	0.04	0.02
Pernik	0.02	0.02	0.03	0.02	0.01	0.02	0.00	0.03	0.04	0.02	0.00	0.02	0.02	0.02	0.05	0.04	0.06	0.03	0.02	0.02	0.04	0.02	0.07	0.03	0.03	0.05	0.05	0.07	0.04
Pazardzhil	0.03	0.02	0.04	0.02	0.04	0.03	0.03	0.00	0.03	0.02	0.04	0.02	0.02	0.03	0.06	0.05	0.07	0.01	0.02	0.04	0.02	0.02	0.07	0.03	0.07	0.08	0.07	0.07	0.03
Plovdiv	0.02	0.02	0.03	0.04	0.03	0.02	0.04	0.03	0.00	0.04	0.03	0.05	0.02	0.03	0.04	0.04	0.05	0.02	0.02	0.05	0.05	0.04	0.06	0.06	0.06	0.07	0.09	0.03	0.01
Pleven	0.01	0.01	0.03	0.01	0.02	0.02	0.02	0.02	0.04	0.00	0.02	0.02	0.03	0.03	0.04	0.04	0.06	0.02	0.01	0.03	0.03	0.01	0.07	0.04	0.05	0.06	0.06	0.07	0.03
Vidin	0.01	0.02	0.02	0.03	0.01	0.02	0.00	0.04	0.03	0.02	0.00	0.03	0.02	0.02	0.04	0.04	0.05	0.04	0.02	0.02	0.04	0.03	0.06	0.04	0.03	0.04	0.06	0.06	0.03
Burgas	0.03	0.02	0.04	0.02	0.03	0.04	0.02	0.02	0.05	0.02	0.03	0.00	0.03	0.04	0.06	0.04	0.07	0.03	0.02	0.04	0.03	0.02	0.08	0.03	0.05	0.07	0.05	0.08	0.04
Veliko Tar	0.02	0.01	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.00	0.02	0.04	0.04	0.05	0.03	0.01	0.04	0.04	0.03	0.06	0.04	0.06	0.06	0.07	0.06	0.02
Haskovo	0.02	0.02	0.03	0.03	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.04	0.02	0.00	0.04	0.03	0.06	0.04	0.02	0.03	0.05	0.03	0.06	0.04	0.03	0.05	0.07	0.06	0.02
Lovech	0.03	0.04	0.02	0.05	0.04	0.03	0.05	0.06	0.04	0.04	0.04	0.06	0.04	0.04	0.00	0.04	0.02	0.06	0.03	0.04	0.07	0.05	0.03	0.08	0.06	0.04	0.09	0.05	0.05
Stara Zago	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.00	0.05	0.05	0.03	0.06	0.07	0.03	0.06	0.08	0.05	0.07	0.08	0.05	0.04
Ruse	0.04	0.04	0.03	0.05	0.05	0.05	0.06	0.07	0.05	0.06	0.05	0.07	0.05	0.06	0.02	0.05	0.00	0.06	0.04	0.06	0.08	0.05	0.02	0.09	0.06	0.04	0.11	0.07	0.06
Yambol	0.03	0.02	0.04	0.02	0.03	0.03	0.03	0.01	0.02	0.02	0.04	0.03	0.03	0.04	0.06	0.05	0.06	0.00	0.02	0.04	0.02	0.02	0.07	0.04	0.07	0.08	0.07	0.06	0.02
Sliven	0.01	0.00	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.03	0.03	0.04	0.02	0.00	0.03	0.04	0.01	0.05	0.04	0.04	0.05	0.06	0.05	0.02
Kardzhali	0.03	0.03	0.04	0.03	0.02	0.03	0.02	0.04	0.05	0.03	0.02	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.03	0.00	0.03	0.04	0.06	0.04	0.05	0.02	0.05	0.07	0.05
Varna	0.04	0.04	0.06	0.04	0.04	0.05	0.04	0.02	0.05	0.03	0.04	0.03	0.04	0.05	0.07	0.07	0.08	0.02	0.04	0.03	0.00	0.04	0.09	0.03	0.08	0.07	0.06	0.08	0.04
Gabrovo	0.02	0.01	0.03	0.01	0.03	0.03	0.02	0.02	0.04	0.01	0.03	0.02	0.03	0.03	0.05	0.03	0.05	0.02	0.01	0.04	0.04	0.00	0.06	0.04	0.05	0.07	0.06	0.07	0.03
Smolyan	0.06	0.06	0.04	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.08	0.06	0.06	0.03	0.06	0.02	0.07	0.05	0.06	0.09	0.06	0.00	0.09	0.07	0.05	0.09	0.07	0.06
Dobrich	0.05	0.04	0.07	0.04	0.05	0.06	0.03	0.03	0.06	0.04	0.04	0.03	0.04	0.04	0.08	0.08	0.09	0.04	0.04	0.04	0.03	0.04	0.09	0.00	0.06	0.07	0.04	0.09	0.05
Shumen	0.04	0.04	0.04	0.05	0.03	0.04	0.03	0.07	0.06	0.05	0.03	0.05	0.06	0.03	0.06	0.05	0.06	0.07	0.04	0.05	0.08	0.05	0.07	0.06	0.00	0.07	0.08	0.07	0.06
Silistra	0.05	0.05	0.05	0.07	0.04	0.06	0.05	0.08	0.07	0.06	0.04	0.07	0.06	0.05	0.04	0.07	0.04	0.08	0.05	0.02	0.07	0.07	0.05	0.07	0.07	0.00	0.08	0.08	0.07
Razgrad	0.07	0.06	0.08	0.06	0.07	0.08	0.05	0.07	0.09	0.06	0.06	0.05	0.07	0.07	0.09	0.08	0.11	0.07	0.06	0.05	0.06	0.06	0.09	0.04	0.08	0.08	0.00	0.12	0.09
Targovisht	0.05	0.05	0.04	0.07	0.06	0.04	0.07	0.07	0.03	0.07	0.06	0.08	0.06	0.06	0.05	0.05	0.07	0.06	0.05	0.07	0.08	0.07	0.07	0.09	0.07	0.08	0.12	0.00	0.04
..Unknown	0.02	0.02	0.03	0.03	0.03	0.02	0.04	0.03	0.01	0.03	0.03	0.04	0.02	0.02	0.05	0.04	0.06	0.02	0.02	0.05	0.04	0.03	0.06	0.05	0.06	0.07	0.09	0.04	0.00

Notably, the closer relation of part of the districts and their better representation in the dataset results in the strong positive consonances detected (green), but also suggests that more precise conclusions will be possible in a dataset where all districts are more or less equally represented.

The same dataset has been transposed, thus allowing another insight on the data and determining the ICA relationships between the blood groups across the provinces (Tables 7 and 8).

Table 7. Results of ICA analysis on the transposed patients' dataset showing the links between the data sorted per blood indicator: μ values

μ	0 (-)	0 (+)	A1 (-)	A1 (+)	A2 (-)	A2 (+)	B (-)	B (+)	A1B (-)	A1B(+)	A2B (-)	A2B (+)
0 (-)	1.00	0.46	0.41	0.52	0.52	0.45	0.39	0.46	0.51	0.46	0.29	0.53
0 (+)	0.46	1.00	0.36	0.39	0.50	0.35	0.47	0.35	0.42	0.35	0.30	0.48
A1 (-)	0.41	0.36	1.00	0.50	0.37	0.55	0.52	0.53	0.51	0.52	0.38	0.49
A1 (+)	0.52	0.39	0.50	1.00	0.52	0.42	0.41	0.36	0.43	0.47	0.46	0.45
A2 (-)	0.52	0.50	0.37	0.52	1.00	0.51	0.57	0.37	0.60	0.50	0.46	0.32
A2 (+)	0.45	0.35	0.55	0.42	0.51	1.00	0.52	0.58	0.58	0.47	0.48	0.42
B (-)	0.39	0.47	0.52	0.41	0.57	0.52	1.00	0.47	0.55	0.51	0.33	0.44
B (+)	0.46	0.35	0.53	0.36	0.37	0.58	0.47	1.00	0.40	0.53	0.34	0.61
A1B (-)	0.51	0.42	0.51	0.43	0.60	0.58	0.55	0.40	1.00	0.56	0.48	0.33
A1B(+)	0.46	0.35	0.52	0.47	0.50	0.47	0.51	0.53	0.56	1.00	0.30	0.55
A2B (-)	0.29	0.30	0.38	0.46	0.46	0.48	0.33	0.34	0.48	0.30	1.00	0.28
A2B (+)	0.53	0.48	0.49	0.45	0.32	0.42	0.44	0.61	0.33	0.55	0.28	1.00
0	0.57	0.89	0.34	0.39	0.51	0.34	0.45	0.34	0.42	0.39	0.27	0.52
A	0.47	0.34	0.61	0.83	0.51	0.55	0.44	0.41	0.47	0.47	0.53	0.38
A1	0.49	0.39	0.63	0.87	0.48	0.42	0.39	0.37	0.45	0.50	0.47	0.45
A2	0.47	0.41	0.48	0.38	0.62	0.90	0.55	0.53	0.62	0.46	0.47	0.37
B	0.45	0.36	0.54	0.34	0.41	0.59	0.59	0.88	0.43	0.52	0.33	0.59
AB	0.50	0.34	0.54	0.43	0.49	0.49	0.54	0.53	0.69	0.86	0.33	0.53
A1B	0.49	0.33	0.53	0.45	0.53	0.51	0.56	0.49	0.72	0.84	0.34	0.46
A2B	0.52	0.47	0.49	0.47	0.33	0.44	0.41	0.61	0.37	0.50	0.38	0.90
A(-)	0.40	0.38	0.84	0.46	0.53	0.58	0.62	0.50	0.59	0.51	0.37	0.40
A(+)	0.50	0.32	0.50	0.85	0.54	0.57	0.41	0.40	0.50	0.49	0.53	0.40
AB(-)	0.52	0.43	0.50	0.45	0.62	0.59	0.53	0.40	0.95	0.52	0.53	0.32
AB(+)	0.48	0.37	0.52	0.43	0.41	0.43	0.49	0.57	0.54	0.89	0.28	0.66
A1/A	0.51	0.57	0.53	0.64	0.34	0.13	0.42	0.48	0.37	0.53	0.29	0.63
A2/A	0.49	0.43	0.46	0.35	0.64	0.87	0.58	0.52	0.63	0.47	0.45	0.36
A1B/AB	0.46	0.48	0.50	0.52	0.66	0.54	0.59	0.37	0.66	0.56	0.37	0.14
A2B/AB	0.52	0.51	0.48	0.46	0.30	0.44	0.39	0.61	0.32	0.42	0.38	0.84

μ	0	A	A1	A2	B	AB	A1B	A2B	A(-)	A(+)	AB(-)	AB(+)	A1/A	A2/A	A1B/AB	A2B/AB
0 (-)	0.57	0.47	0.49	0.47	0.45	0.50	0.49	0.52	0.40	0.50	0.52	0.48	0.51	0.49	0.46	0.52
0 (+)	0.89	0.34	0.39	0.41	0.36	0.34	0.33	0.47	0.38	0.32	0.43	0.37	0.57	0.43	0.48	0.51
A1 (-)	0.34	0.61	0.63	0.48	0.54	0.54	0.53	0.49	0.84	0.50	0.50	0.52	0.53	0.46	0.50	0.48
A1 (+)	0.39	0.83	0.87	0.38	0.34	0.43	0.45	0.47	0.46	0.85	0.45	0.43	0.64	0.35	0.52	0.46
A2 (-)	0.51	0.51	0.48	0.62	0.41	0.49	0.53	0.33	0.53	0.54	0.62	0.41	0.34	0.64	0.66	0.30
A2 (+)	0.34	0.55	0.42	0.90	0.59	0.49	0.51	0.44	0.58	0.57	0.59	0.43	0.13	0.87	0.54	0.44
B (-)	0.45	0.44	0.39	0.55	0.59	0.54	0.56	0.41	0.62	0.41	0.53	0.49	0.42	0.58	0.59	0.39
B (+)	0.34	0.41	0.37	0.53	0.88	0.53	0.49	0.61	0.50	0.40	0.40	0.57	0.48	0.52	0.37	0.61
A1B (-)	0.42	0.47	0.45	0.62	0.43	0.69	0.72	0.37	0.59	0.50	0.95	0.54	0.37	0.63	0.66	0.32
A1B(+)	0.39	0.47	0.50	0.46	0.52	0.86	0.84	0.50	0.51	0.49	0.52	0.89	0.53	0.47	0.56	0.42
A2B (-)	0.27	0.53	0.47	0.47	0.33	0.33	0.34	0.38	0.37	0.53	0.53	0.28	0.29	0.45	0.37	0.38
A2B (+)	0.52	0.38	0.45	0.37	0.59	0.53	0.46	0.90	0.40	0.40	0.32	0.66	0.63	0.36	0.14	0.84
0	1.00	0.33	0.37	0.41	0.34	0.36	0.36	0.50	0.34	0.33	0.42	0.40	0.56	0.44	0.46	0.52
A	0.33	1.00	0.87	0.49	0.40	0.42	0.45	0.41	0.58	0.88	0.48	0.42	0.54	0.46	0.54	0.44
A1	0.37	0.87	1.00	0.36	0.35	0.44	0.45	0.48	0.57	0.81	0.46	0.46	0.68	0.32	0.50	0.48
A2	0.41	0.49	0.36	1.00	0.57	0.49	0.53	0.39	0.58	0.52	0.63	0.41	0.04	0.96	0.59	0.39
B	0.34	0.40	0.35	0.57	1.00	0.54	0.50	0.57	0.55	0.40	0.42	0.54	0.44	0.56	0.41	0.58
AB	0.36	0.42	0.44	0.49	0.54	1.00	0.92	0.52	0.56	0.45	0.66	0.84	0.49	0.51	0.57	0.42
A1B	0.36	0.45	0.45	0.53	0.50	0.92	1.00	0.44	0.55	0.48	0.68	0.80	0.45	0.55	0.64	0.34
A2B	0.50	0.41	0.48	0.39	0.57	0.52	0.44	1.00	0.39	0.43	0.39	0.61	0.62	0.38	0.08	0.89
A(-)	0.34	0.58	0.57	0.58	0.55	0.56	0.55	0.39	1.00	0.46	0.57	0.48	0.42	0.58	0.58	0.40
A(+)	0.33	0.88	0.81	0.52	0.40	0.45	0.48	0.43	0.46	1.00	0.52	0.43	0.50	0.49	0.55	0.43
AB(-)	0.42	0.48	0.46	0.63	0.42	0.66	0.68	0.39	0.57	0.52	1.00	0.50	0.36	0.64	0.64	0.34
AB(+)	0.40	0.42	0.46	0.41	0.54	0.84	0.80	0.61	0.48	0.43	0.50	1.00	0.58	0.42	0.46	0.52
A1/A	0.56	0.54	0.68	0.04	0.44	0.49	0.45	0.62	0.42	0.50	0.36	0.58	1.00	0.00	0.37	0.61
A2/A	0.44	0.46	0.32	0.96	0.56	0.51	0.55	0.38	0.58	0.49	0.64	0.42	0.00	1.00	0.61	0.37
A1B/AB	0.46	0.54	0.50	0.59	0.41	0.57	0.64	0.08	0.58	0.55	0.64	0.46	0.37	0.61	1.00	0.02
A2B/AB	0.52	0.44	0.48	0.39	0.58	0.42	0.34	0.89	0.40	0.43	0.34	0.52	0.61	0.37	0.02	1.00

Table 8. Results of ICA analysis on the transposed patients' dataset showing the links between the data sorted per blood indicator: ν values

ν	0 (-)	0 (+)	A1 (-)	A1 (+)	A2 (-)	A2 (+)	B (-)	B (+)	A1B (-)	A1B(+)	A2B (-)	A2B (+)
0 (-)	0.00	0.53	0.58	0.47	0.46	0.54	0.60	0.53	0.48	0.53	0.44	0.46
0 (+)	0.53	0.00	0.64	0.60	0.48	0.65	0.53	0.64	0.58	0.65	0.43	0.52
A1 (-)	0.58	0.64	0.00	0.49	0.61	0.45	0.48	0.46	0.48	0.47	0.35	0.50
A1 (+)	0.47	0.60	0.49	0.00	0.46	0.57	0.58	0.63	0.56	0.52	0.27	0.54
A2 (-)	0.46	0.48	0.61	0.46	0.00	0.47	0.41	0.61	0.37	0.48	0.27	0.66
A2 (+)	0.54	0.65	0.45	0.57	0.47	0.00	0.48	0.42	0.42	0.53	0.25	0.57
B (-)	0.60	0.53	0.48	0.58	0.41	0.48	0.00	0.52	0.44	0.49	0.40	0.55
B (+)	0.53	0.64	0.46	0.63	0.61	0.42	0.52	0.00	0.59	0.47	0.39	0.38
A1B (-)	0.48	0.58	0.48	0.56	0.37	0.42	0.44	0.59	0.00	0.43	0.25	0.66
A1B(+)	0.53	0.65	0.47	0.52	0.48	0.53	0.49	0.47	0.43	0.00	0.43	0.45
A2B (-)	0.44	0.43	0.35	0.27	0.27	0.25	0.40	0.39	0.25	0.43	0.00	0.45
A2B (+)	0.46	0.52	0.50	0.54	0.66	0.57	0.55	0.38	0.66	0.45	0.45	0.00
0	0.42	0.11	0.66	0.60	0.46	0.66	0.55	0.66	0.57	0.61	0.47	0.48
A	0.53	0.66	0.38	0.17	0.47	0.45	0.56	0.58	0.53	0.53	0.20	0.62
A1	0.50	0.61	0.36	0.13	0.50	0.58	0.61	0.62	0.55	0.50	0.27	0.54
A2	0.52	0.58	0.51	0.61	0.36	0.10	0.44	0.46	0.37	0.54	0.26	0.63
B	0.54	0.64	0.45	0.66	0.57	0.41	0.41	0.11	0.57	0.48	0.40	0.41
AB	0.50	0.66	0.46	0.57	0.50	0.51	0.46	0.46	0.30	0.14	0.40	0.46
A1B	0.50	0.67	0.47	0.54	0.45	0.49	0.44	0.50	0.27	0.16	0.39	0.53
A2B	0.47	0.53	0.50	0.52	0.64	0.55	0.59	0.38	0.62	0.49	0.35	0.10
A(-)	0.59	0.62	0.16	0.54	0.45	0.42	0.38	0.49	0.40	0.49	0.36	0.60
A(+)	0.49	0.67	0.49	0.14	0.44	0.43	0.58	0.59	0.50	0.51	0.20	0.59
AB(-)	0.47	0.57	0.49	0.54	0.35	0.40	0.47	0.59	0.05	0.47	0.20	0.67
AB(+)	0.51	0.63	0.47	0.56	0.57	0.57	0.51	0.42	0.46	0.11	0.46	0.34
A1/A	0.49	0.43	0.46	0.35	0.64	0.87	0.58	0.52	0.63	0.47	0.45	0.36
A2/A	0.51	0.57	0.53	0.64	0.34	0.13	0.42	0.48	0.37	0.53	0.29	0.63
A1B/AB	0.52	0.51	0.48	0.46	0.30	0.44	0.39	0.61	0.32	0.42	0.37	0.84
A2B/AB	0.46	0.48	0.50	0.52	0.66	0.54	0.59	0.37	0.66	0.56	0.36	0.14

ν	0.00	A	A1	A2	B	AB	A1B	A2B	A(-)	A(+)	AB(-)	AB(+)	A1/A	A2/A	A1B/AB	A2B/AB
0 (-)	0.42	0.53	0.50	0.52	0.54	0.50	0.50	0.47	0.59	0.49	0.47	0.51	0.49	0.51	0.52	0.46
0 (+)	0.11	0.66	0.61	0.58	0.64	0.66	0.67	0.53	0.62	0.67	0.57	0.63	0.43	0.57	0.51	0.48
A1 (-)	0.66	0.38	0.36	0.51	0.45	0.46	0.47	0.50	0.16	0.49	0.49	0.47	0.46	0.53	0.48	0.50
A1 (+)	0.60	0.17	0.13	0.61	0.66	0.57	0.54	0.52	0.54	0.14	0.54	0.56	0.35	0.64	0.46	0.52
A2 (-)	0.46	0.47	0.50	0.36	0.57	0.50	0.45	0.64	0.45	0.44	0.35	0.57	0.64	0.34	0.30	0.66
A2 (+)	0.66	0.45	0.58	0.10	0.41	0.51	0.49	0.55	0.42	0.43	0.40	0.57	0.87	0.13	0.44	0.54
B (-)	0.55	0.56	0.61	0.44	0.41	0.46	0.44	0.59	0.38	0.58	0.47	0.51	0.58	0.42	0.39	0.59
B (+)	0.66	0.58	0.62	0.46	0.11	0.46	0.50	0.38	0.49	0.59	0.59	0.42	0.52	0.48	0.61	0.37
A1B (-)	0.57	0.53	0.55	0.37	0.57	0.30	0.27	0.62	0.40	0.50	0.05	0.46	0.63	0.37	0.32	0.66
A1B(+)	0.61	0.53	0.50	0.54	0.48	0.14	0.16	0.49	0.49	0.51	0.47	0.11	0.47	0.53	0.42	0.56
A2B (-)	0.47	0.20	0.27	0.26	0.40	0.40	0.39	0.35	0.36	0.20	0.20	0.46	0.45	0.29	0.37	0.36
A2B (+)	0.48	0.62	0.54	0.63	0.41	0.46	0.53	0.10	0.60	0.59	0.67	0.34	0.36	0.63	0.84	0.14
0	0.00	0.67	0.63	0.58	0.65	0.64	0.64	0.50	0.65	0.67	0.57	0.60	0.44	0.56	0.52	0.46
A	0.67	0.00	0.13	0.50	0.60	0.58	0.55	0.59	0.41	0.12	0.51	0.58	0.46	0.54	0.44	0.54
A1	0.63	0.13	0.00	0.64	0.65	0.56	0.54	0.52	0.42	0.18	0.53	0.54	0.32	0.68	0.48	0.50
A2	0.58	0.50	0.64	0.00	0.43	0.50	0.46	0.60	0.42	0.47	0.36	0.59	0.96	0.04	0.39	0.59
B	0.65	0.60	0.65	0.43	0.00	0.46	0.50	0.42	0.45	0.60	0.57	0.46	0.56	0.44	0.58	0.41
AB	0.64	0.58	0.56	0.50	0.46	0.00	0.07	0.48	0.44	0.55	0.34	0.16	0.51	0.49	0.42	0.57
A1B	0.64	0.55	0.54	0.46	0.50	0.07	0.00	0.55	0.44	0.51	0.32	0.20	0.55	0.45	0.34	0.64
A2B	0.50	0.59	0.52	0.60	0.42	0.48	0.55	0.00	0.60	0.57	0.60	0.39	0.38	0.62	0.89	0.08
A(-)	0.65	0.41	0.42	0.42	0.45	0.44	0.44	0.60	0.00	0.53	0.42	0.52	0.58	0.42	0.40	0.58
A(+)	0.67	0.12	0.18	0.47	0.60	0.55	0.51	0.57	0.53	0.00	0.47	0.56	0.49	0.50	0.43	0.55
AB(-)	0.57	0.51	0.53	0.36	0.57	0.34	0.32	0.60	0.42	0.47	0.00	0.50	0.64	0.36	0.34	0.64
AB(+)	0.60	0.58	0.54	0.59	0.46	0.16	0.20	0.39	0.52	0.56	0.50	0.00	0.42	0.58	0.52	0.46
A1/A	0.44	0.46	0.32	0.96	0.56	0.51	0.55	0.38	0.58	0.49	0.64	0.42	0.00	1.00	0.61	0.37
A2/A	0.56	0.54	0.68	0.04	0.44	0.49	0.45	0.62	0.42	0.50	0.36	0.58	1.00	0.00	0.37	0.61
A1B/AB	0.52	0.44	0.48	0.39	0.58	0.42	0.34	0.89	0.40	0.43	0.34	0.52	0.61	0.37	0.00	0.98
A2B/AB	0.46	0.54	0.50	0.59	0.41	0.57	0.64	0.08	0.58	0.55	0.64	0.46	0.37	0.61	0.98	0.00

Notably, yet not unexpected, here is the presence of higher positive consonance values in cells parallel to the main diagonal like the pairs between O and O(+), A1B(+) and AB and AB(+). Again, a more detailed a meaningful analysis would be possible when ICA is performed on a dataset where all the districts are more equally represented, thus producing reliable links between the pairs of blood indicators. We can though visualize the results on the IFS interpretation triangle, and Tables 5 and 6 will be collectively exhibited on Fig. 2, and Tables 7 and 8–on Fig. 3.

From Fig. 2, we specifically notice that all the ICA results plotted as IF points are condensed in a rather small zone, locked between the set's *Interior* $\langle \mu_{\min}, \nu_{\max} \rangle = \langle 0.84, 0.12 \rangle$ and the set's *Closure* $\langle \mu_{\max}, \nu_{\min} \rangle = \langle 1, 0 \rangle$. Depending on the user selected strategy for traversing the set [11] and on the user selected scale for estimation of the degrees of consonance or dissonance between criteria [7], the results can be interpreted not on the [0,1]-scale but scaled down to the interval defined by the *Interior* and the *Closure* operators, ranked and traversed in a set of alternative procedures, detailed in [11].

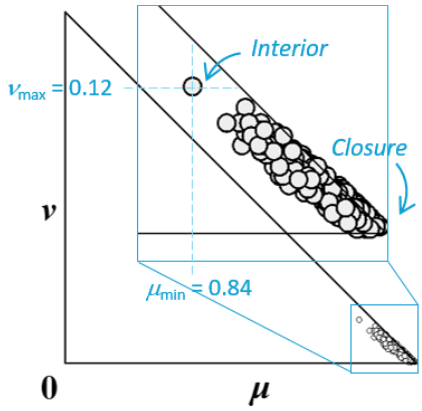

Fig. 2. The ICA results from Tables 5 and 6 visualized on the IF interpretation triangle

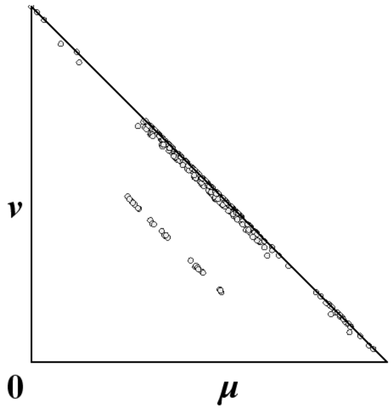

Fig. 3. The ICA results from Tables 7 and 8 visualized on the IF interpretation triangle

5 Discussions and conclusions

While the results of the ICA analysis reported in Section 4, were not fully conclusive, they are promising on a conceptual level and the method will prove fully applicable on a larger dataset featuring better representability of patients. The crucial element of the herewith presented research is the adoption as early as the research's design phase of that atomic approach to data, which has allowed then the detailed breakdown of data simultaneously in blood group / subgroup, rhesus factor, sex, year of birth and (for the first time) region of birth. The presented data collection and data extraction methodology however can be adopted in the hospital units in other regions in the country in order to assemble a wider, more representative picture of the problem considered. Notwithstanding, this atomic approach to data has allowed us for the first time, in contrast to the available literature, to group and slice the data about the blood profile of Bulgarian population, and formulate in the next sections results and conclusions regarding the geographic distribution of the different ABO blood groups, A1 and A2 subgroups and the Rh(D) antigen in the frames on national and regional level.

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References

1. Anastasov, A., Doychinova, N., Iliev, D., Kurteva, B., Nedyalkova, M., Prodanov, P., Shinkov, D. (1977). Immunohematology, Sofia, p. 55 (in Bulgarian).

2. Andreev, N., Atanassov, K., Bureva, V. (2019-2020). InterCriteria Analysis on data for blood collection. Annual of the Informatics Section, Union of Scientists in Bulgaria, 10, pp. 30-53. (in Bulgarian).
3. Andreev, N., & Atanassova, V. (2021). InterCriteria Analysis of the blood group distribution of patients of Saint Anna Hospital in 2015–2019. In: Atanassov K.T. et al. (eds) Advances and New Developments in Fuzzy Logic and Technology. Proceedings of IWIFSGN'2019. Advances in Intelligent Systems and Computing, Vol. 1308, pp. 158-165. Springer, Cham.
4. Andreev, N., & Atanassova, V. (2021). Distribution of the ABO System Blood Groups in the Patients of the University Hospital "Saint Anna", Sofia, Bulgaria in the Period 2015-2020. 1st Scientific Conference on Transfusion Hematology, Varna, Bulgaria, 24–26 September 2021 (in Bulgarian).
5. Andreev, N., Sotirova, E., Ribagin, S. (2018) Intercriteria analysis of data from the centers for transfusion haematology in Bulgaria, Comptes Rendus de l'Academie Bulgare des Science, Vol. 72, No 7, pp. 982-990.
6. Andreev, N., Vassilev, P., Ribagin, S., & Sotirov, S. (2019). InterCriteria Analysis of data for blood collection in the Transfusion Hematology Department, University Hospital "St. Anna", Sofia. Notes on Intuitionistic Fuzzy Sets. 25(2), pp. 88-95.
7. Atanassov, K., Atanassova, V., & Gluhchev, G. (2015). InterCriteria Analysis: Ideas and problems. *Notes on Intuitionistic Fuzzy Sets*, 21(1), 81–88.
8. Atanassov, K., Mavrov, D., Atanassova, V. Intercriteria Decision Making: A New Approach for Multicriteria Decision Making, Based on Index Matrices and Intuitionistic Fuzzy Sets. Issues in Intuitionistic Fuzzy Sets and Generalized Nets, Vol. 11, 2014, 1–8.
9. Atanassova, V. (2015). Interpretation in the intuitionistic fuzzy triangle of the results, obtained by the InterCriteria analysis. In: Proceedings of 16th World Congress of IFSA, 9th Conference of EUSFLAT, June 2015, Gijon, Spain, pp. 1369–1374.
10. Atanassova, V., Andreev, N., Dimitriev, A. ABO System Blood Groups Distribution in Bulgaria, Based on a Dataset of the Patients of the University Hospital "Saint Anna", Sofia, Bulgaria, from 2015 to 2021. In: Sotirov, S., T. Pencheva, J. Kacprzyk, K. Atanassov, E. Sotirova, S. Ribagin (Eds.) Recent Contributions to Bioinformatics and Biomedical Sciences and Engineering, Springer, Cham (in press).
11. Atanassova, V., Vardeva, I., Sotirova, E., & Doukovska, L. (2016). Traversing and Ranking of Elements of an Intuitionistic Fuzzy Set in the Intuitionistic Fuzzy Interpretation Triangle. In: *Novel Developments in Uncertainty Representation and Processing*, Advances in Intelligent Systems and Computing 401, 161–174.
12. BloodBook.com (2013, March 18). Racial & Ethnic Distribution of ABO Blood Types. Retrieved on October 14, 2022, from http://www.bloodbook.com/world-abo.html.
13. Chorbadzhiyski, G. (2006). Information, Check and Generator of Unique Citizen Numbers (EGN). Source code, version 1.50 (30-Sep-2006). https://georgi.unixsol.org/programs/egn.php/view/
14. Chorukova, E., Marinov, P., and Umlenski, I. (2021). Survey on Theory and Applications of InterCriteria Analysis Approach. In: Atanassov K.T. (eds) Research in Computer Science in the Bulgarian Academy of Sciences. Studies in Computational Intelligence, vol 934, pp. 453-469. Springer, Cham.
15. Dean, L. (2005). Blood Groups and Red Cell Antigens. National Center for Biotechnology Information (US), Bethesda (MD), pp. 31-33. Retrieved on October 14, 2022, from https://www.ncbi.nlm.nih.gov/books/n/rbcantigen/pdf/.
16. Dobreva, A., Doychinova, N., Vasilev, N., eds. (1988). Transfusion Hematology, pp. 68, 114-115. State Publishing House "Medicina I Fizkultura", Sofia (in Bulgarian).

17. Doukovska, L., Atanassova, V., Sotirova, E., Vardeva, I., Radeva, I.: Defining consonance thresholds in InterCriteria analysis: an overview. In: Hadjiski, M., Atanassov, K.T. (eds.) In-tuitionistic Fuzziness and Other Intelligent Theories and Their Applications. SCI, vol. 757, pp. 161–179. Springer, Cham (2019).
18. Kohler, I., Kaltchev, J., & Dimova, M. (2002). Integrated Information System for Demographic Statistics 'ESGRAON-TDS' in Bulgaria. *Demographic Research*, 6, 325–354.
19. Popov, R., Petrov, N., & Vaseva, V. (2012). Distribution of blood groups of the ABO system in the Military Medical Academy immunohematological diagnostics. Bulgarian Medical Journal, VI(2), pp. 45-48 (in Bulgarian).
20. RhesusNegative.net (2019). Blood Type Frequencies by Country including the Rh Factor. Retrieved on October 14, 2022, from http://www.rhesusnegative.net/themission/bloodtype-frequencies/.
21. Salduz, Z., Cetin, G., Karatoprak, C., Ozder, A. Bilginc, M., Gültepe, I. & Gul, O. (2015). ABO and Rh Blood Group Distribution in Istanbul Province (Turkey). Istanbul Medical Journal. 16, pp. 98-100.
22. Wikipedia contributors. (2017, June 21). Blood type distribution by country. In Wikipedia, The Free Encyclopedia. Retrieved from https://en.wikipedia.org/w/index.php?title=Blood_type_distribution_by_country&oldid=786847072.