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Original scientific paper

VULNERABILITY ASSESSMENT OF POLLUTION OF GROUNDWATER IN THE ŠTIP AQUIFER WITH APPLICATION OF GOD METHOD

Darko, Pižov, Vojo Mirčovski, Gjorgji Dimov

Institute of Geology, Faculty of Natural and Technical Sciences, , "Goce Delčev" University in Štip,
Blvd. Goce Delčev 89, 2000 Štip, Republic of North Macedonia
darkopizov@yahoo.com

A b s t r a c t: The creation of vulnerability maps for potential aquifer pollution is widely used in developed countries and is a basic tool for groundwater protection. This paper presents the assessment of the vulnerability from pollution of groundwater in the Štip aquifer, with the help of GOD method, where are used three parameters: Type of aquifer, lithology of the unsaturated zone and depth of groundwater. The data for the three parameters are obtained from the geological-hydrogeological profiles of 22 exploitation wells and exploration boreholes. Analyzing the three parameters a GOD index value was obtained in the range of < 0.4–0.5, which corresponds to the medium vulnerability class and a value > 0.5, which corresponds to the high vulnerability class.

Key words: vulnerability; GOD method; groundwater; Štip aquifer; alluvial sediments

INTRODUCTION

The Štip aquifer is presented as a boundary type of aquifer, formed in the alluvial and terrace sediments of the river of Bregalnica. It is located on the northern peripheral part of Štip and is used for water supply of the city (Figure 1). The water supply is performed from three springs: Fortuna, Arm and Lake Štip, of which about 250 l/s are exploited. The shallow groundwater level in the aquifer, urbanized environment in its immediate vicinity where there are a large number of anthropogenic industrial and communal pollutants, as well as the surrounding arable land that is intensively treated with chemicals are a potential possibility for pollution of the aquifer. The GOD method was used to determine the degree of vulnerability from groundwater pollution in the Štip aquifer and depending on the results, taking preventive measures for protection.

The concept of determining the degree of natural vulnerability of groundwater pollution was firstly introduced by the French scientist Margat (Vrba & Zaporozec, 1994). The idea was to determine the degree of vulnerability of groundwater pollution, depending on the geological, hydrological and hydrogeological characteristics of the investegated terrain. The GOD method is widely used to determine the degree of vulnerability for aquifers with intergranular porosity: (Boufekane et al., 2013; Knouz et al., 2017; Nugraha, 2020; Rukmana et al., 2020; Saheed, 2017).

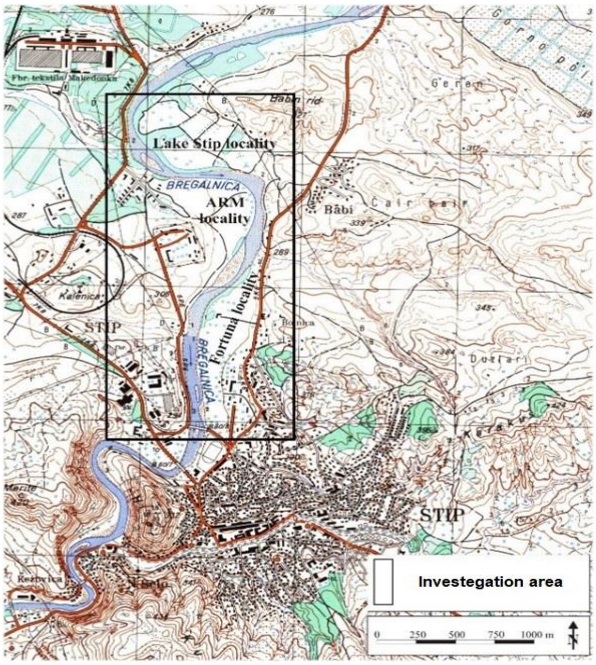

Fig. 1. Geographic position of the investigated area

For the first time in our state, the Republic of North Macedonia, this method was used to determine the degree of vulnerability of the Štip aquifer, north from the city of Štip (Mircovski et al., 2021). The degree of vulnerability of the Štip aquifer is determined based on the data obtained from 22 exploitation wells and exploration boreholes. The investegated zone covers the area of the first and part of the second protection zone established around the springs (Mircovski et al., 2009; Micevski et al., 2007).

GEOLOGICAL SETTING

The geological setting in the nearby area of the Štip aquifer is presented with rocks from Mesozoic, Tertiary and Quaternary age, according to Rakičević et al. (1968, 1976) (Figure 2). Mesozoic rocks are found in the southwestern part of the investigated area and are represented by biotite Jurassic granites (γ) (155±5 m.y. by Rb/Sr method, Šoptrajanova, 1967). The Tertiary is represented by a basal series formed of eocene sandstones, marl and conglomerates (${}_{1}E_{3}$), lower yellow sandstones (${}^{2}{}_{2}E_{3}$) and an upper flysch zone (${}^{4}E_{3}$), represented by sandstones, marls, limestones and clays.

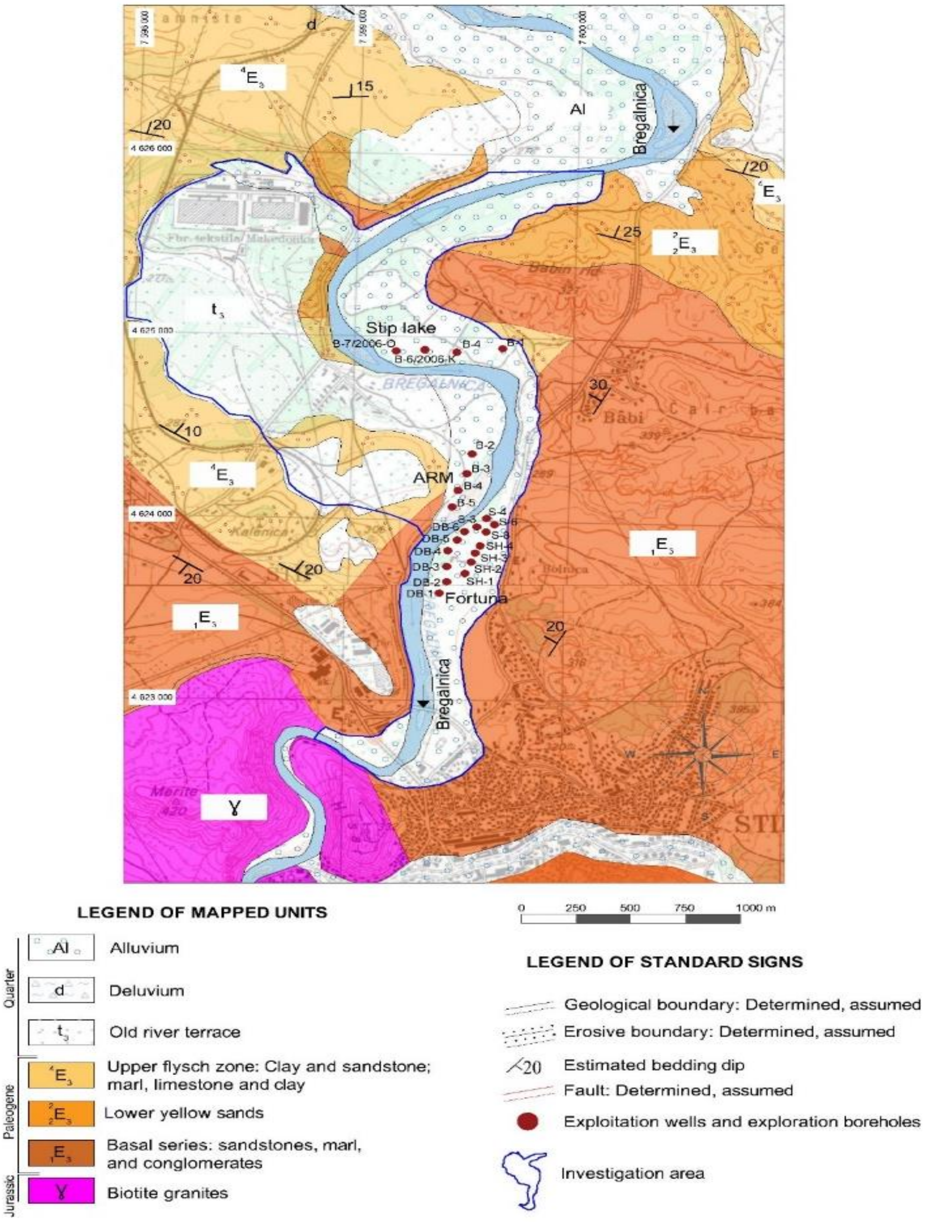

Fig. 2. Geological map of the wider area of the Štip aquifer (Rakičević et al., 1968)

The Quarter is represented by old river terraces (t_3), and alluvium (al). The old river terraces appear along the valley of the river Bregalnica and lie on the sediments from the upper flysch zone. They are composed of rounded andesite rocks, rarely of quartz and gneiss. Their thickness ranges from 10 – 15 m.

Alluvial sediments occur along the valley of the Bregalnica river and are represented by sand and gravel. The origin is from the surrounding rocks that formed the investigated terrain. In terms of tectonics, the wider environment of the investegated area belongs to the Vardar zone (Arsovski, 1997).

HYDROGEOLOGICAL SETTING

According to the structural type of porosity of the rocks that form the wider area around the Štip aquifer, we distinguished the following: boundary type of aquifers, fractured type of aquifers, and conditionally waterless terrains (Figure 3).

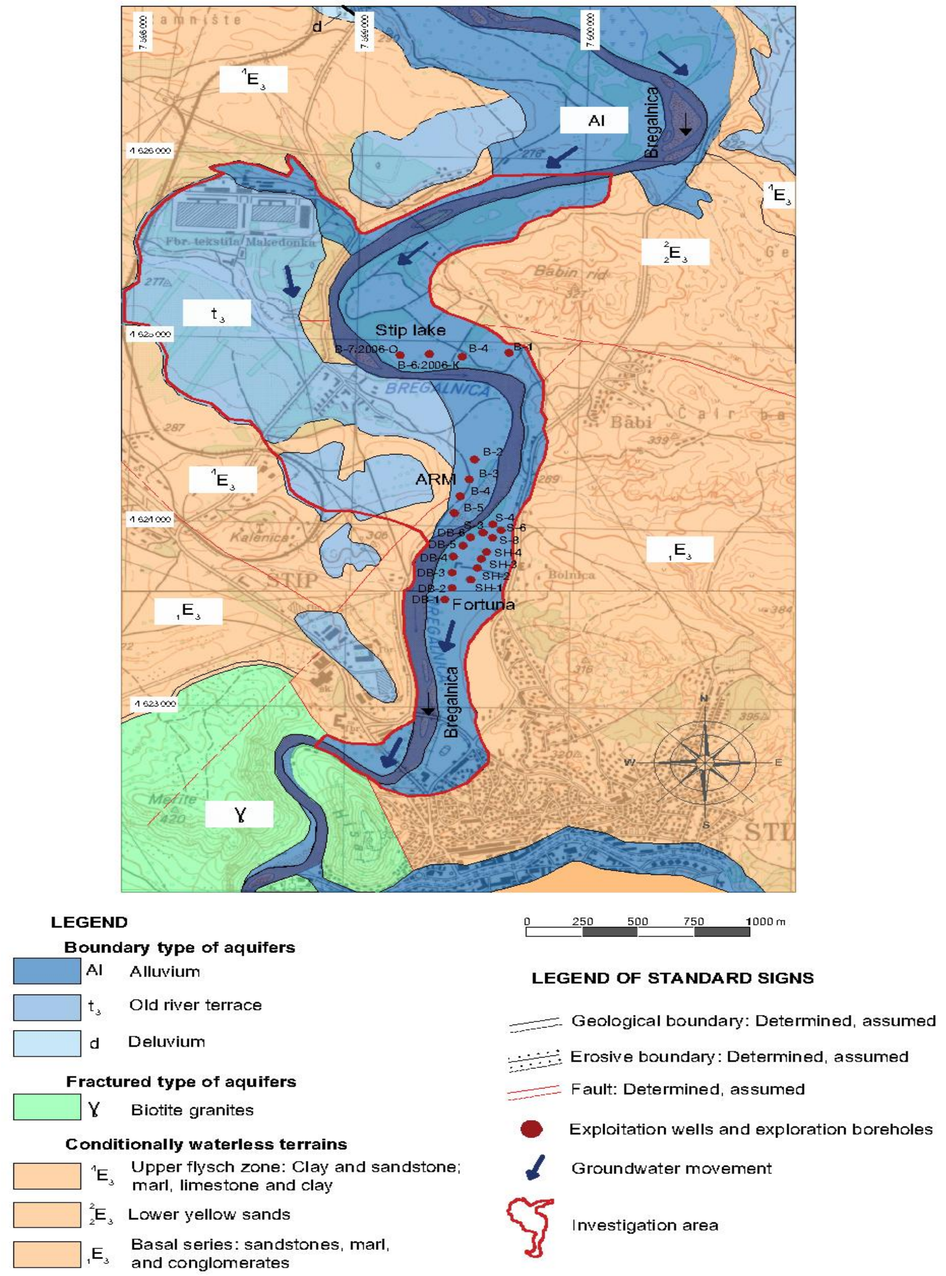

Fig. 3. Hydrogeological map of the wider area of the Štip aquifer

The boundary type of aquifer is unconfined and formed in the Quaternary alluvial and river terrace sediments developed along the valley of the river Bregalnica. They are made of various granular sands and gravels that are characterized by intergranular porosity. The thickness of these sediments according to the data from the investigation works ranges from 10 to 12 m (Terziovski, 1990, 1992).

According to data from Mircovski et al. (2009, 2002) the alluvial and river terrace sediments in which the Štip aquifer is formed, are a two-layer porous environment composed of two layers, with different granulometric and filtration characteristics. The lower aquifer lies on impermeable marls and is represented by sand and gravel with a filtration coefficient that ranges within

$$K_f = 47.6 – 281.3 \text{ m / day}.$$

The aquifer unsaturated zone is represented of dusty sand and clayey dusty sands, which have weaker filtration characteristics, compared to permeable sands and gravels. They are characterized by fine-grained porosity and the filtration coefficient in this zone is within

$$K_f = 2.173 \times 100 – 5.74 \times 10^{-2} \text{ m/day},$$

and

$$K_{mid}. = 9.57 \times 10^{-3} – 1.49 \times 10^{-3} \text{ m/day}.$$

The groundwater level in the wells and boreholes ranges from 1.3 to 7.0 m and it is directly dependent from the hydrological conditions with the water level in the river of Bregalnica, because the aquifer and the exploitation wells are in direct hydraulic connection with the river. The water supply of the aquifer is mostly done with the water from the river of Bregalnica, with which it is in direct hydraulic connection, secondly from the aquifers that are on a higher hypsometric level along the river of Bregalnica and with a smaller part of the seasonlly rains.

VULNERABILITY ASSESSMENT OF THE ŠTIP AQUIFER

The GOD-method was used to determine the degree of vulnerability from the groundwater pollution in the Štip aquifer.

The investegated area covers part of the alluvial terrace sediments of the river of Bregalnica around the springs: Štip Lake, Arm and Fortuna, which exploit the groundwater from the Štip aquifer (Figures 2 and 3) and covers part of the first and second protection zone around the springs. The data used for determining the degree of vulnerability of the Štip aquifer are obtained from the geological-hydrogeological profiles of 22 exploitation wells and exploratory boreholes from the springs: Štip lake: B-1, B-4, B-6/2006/K and B-7/2006-O, ARM: B-2, B-3, B-4 and B-5 Fortuna: DB-1, DB-2, DB-3, DB-4, DB-5, DB-6, S-3, S-4, S-6, S-8, SH-1, SH-2, SH-3, SH-4 Terziovski (1990, 1992), (Figures 2,3 & 4).

GOD METHOD

The GOD method (Groundwater occurence – Overall lithology – Depth to groundwater) is used for rapid assessment of the natural vulnerability of aquifers with intergranular porosity, in cases when there is a small amount of data available. It was developed by Foster (1987) to assess the vulnerability of aquifers to pollution, by leaking the pollutant from the unsaturated to the saturated zone of the aquifer (Figure 4).

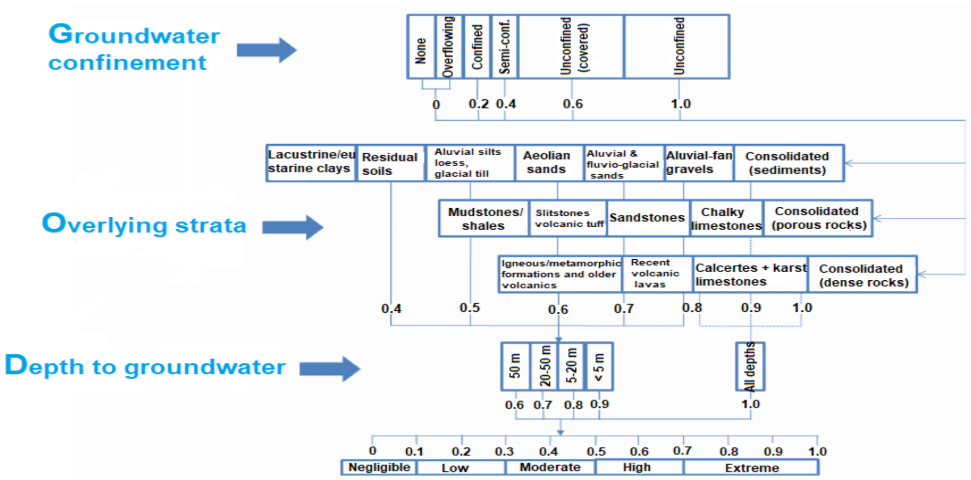

Fig. 4. GOD method for assessment of groundwater vulnerability (Forster, 1987)

This method uses three parameters with empirical approach for determine the vulnerability of the aquifer:

Ca = type of aquifer,

Cl = lithology of the unsaturated (vadose) zone,

Cd = depth of groundwater.,

GOD index is defined with multiplication of the obtained data from the three parametars:

$$\text{GOD index} = Ca \times Cl \times Cd$$

GOD index is devided into five clasess in interval from 0 to 1 (Table 1).

T a b l e 1

Index and clasess of vulnerability of the aquifer using GOD method

Index values	Level of vulnerability
0.0 – 0.1	Very low
0.1 – 0.3	Low
0.3 – 0.5	Moderate
0.5 – 0.7	High
0.7 – 1.00	Very high

Once the GOD value is obtained from the wells and exploration boreholes, it is interpolated using the IDW (inverse distance weighting) method, with the Arcgis 10.3 software. The value of each GOD parameter for the degree of vulnerability of groundwater, varies depending on the three parameters.

Type of aquifer

One of the three parameters for determining the aquifer vulnerability from contamination with GOD method is the type of aquifer. Based on the geological-hydrogeological data obtained from the boreholes and wells, the Štip aquifer belongs to the group of unconfined aquifers with free level. In addition to being a unconfined aquifer, it is also characterized by a relatively small thickness of the unsaturated zone, which ranges within 2 – 6 m (Table 2).

According to the GOD method, depending on the type of aquifer a classification of the aquifer is made and each class is scored in interval from 0 to 1. According to this classification, the Štip aquifer is set with a value of 1, which corresponds to the group of unconfined aquifers (Table 3).

T a b l e 2

Thickness of the unsaturated zone

No.	Wells & boreholes	Thickness of the unsaturated zone (m)
1	B-1	6
2	B-4	5
3	B-6	5
4	B-7	2,5
5	B-2	2
6	B-3	2
7	B-4	2
8	B-5	2
9	DB-1	2
10	DB-2	2
11	DB-3	2
12	DB-4	2
13	DB-5	2
14	DB-6	2
15	S-3	2
16	S-4	2
17	S-6	3.6
18	S-8	3.5
19	SH-3	3.9
20	SH-4	3.45
21	SH-6	3.9
22	SH-8	3.9

T a b l e 3

Value of aquifer type parametars

Type of aquifer	Value
Unconfined aquifer	1

Lithology of the unsaturated zone

The lithology of the unsaturated is another important parameter for the analysis of groundwater vulnerability. The unsaturated zone of the Štip aquifer is represented of dusty sands and clayey dusty sands. According to the GOD classification, the lithology of the unsaturated zone is scored in range of 0 to 1. This classification covers a small number of petrographic types of unconsolidated sedimentary rocks (Figure 4), and therefore when scoring the class that is the closest to the specific situation on the investigated terrain should be selected. According to this classification, the Štip aquifer is set with a value of 0.6, which according to this classification corresponds to the group of aeolian sands, which we consider to be the closest that corresponds to the lithology of the Štip aquifer (Table 4).

T a b l e 4

Value of aquifer lithology parameters

Lithology of the unsaturated zone	Value
Dusty sands and clayey dusty sands (Aeolian sands)	0,6

Depth of groundwater

Groundwater depth is the third parameter for determining the degree of groundwater vulnerability according to the GOD method. According to this method, the shallower the groundwater, the greater the vulnerability of the aquifer to pollution.

The depth of the groundwater in the aquifer, according to the data from the exploitation wells and exploration boreholes, ranges between 1.3 and 7.0 m. In the springs of Fortuna it is from 2.7 to 7.0 m, in Štip Lake 2.8 – 4.6 m, and in ARM from 1.3 to 2.7 m.

Since only in two wells the groundwater level is less than 2 m, the depth of groundwater in the Štip aquifer according to GOD classification is placed in the class of 2 – 5 m, which corresponds to a value of 0.9 and in the class of 5 – 10 m, which corresponds to a value of 0.8 (Tables 5 and 6).

Aquifer vulnerability analysis

Groundwater vulnerability of pollution is higher in unconfined aquifers rather than in confined ones. The Štip aquifer according to its hydrogeological characteristics belongs to the group of unconfined aquifers. In order to preserve the quality of the groundwater from this aquifer and to prevent unexpected pollution, the degree of natural vulnerability of the aquifer is determined depending on its hydrogeological characteristics.

The values obtained by multiplying the three analyzed parameters fall in the range of < 0.,4 – 0.5, which according to the GOD index corresponds to the degree of medium vulnerability, in the range of > 0.5 it corresponds to the degree of high vulnerability (Table 7).

The vulnerability map created according to GOD method for the Štip aquifer is shown on Figure 5. From the map it can be seen that most of the investigated area belongs to the hydrogeological environment with high vulnerability, and only a small part of the area, south of the Fortuna springs, belongs to medium vulnerability. Based on the data from the map, we can generally conclude that the Štip aquifer is highly vulnerable to pollution.

T a b l e 5

Depth of groundwater

No.	Wells & boreholes	Depth of groundwater (m)
1	B-1	4,6
2	B-4	2,8
3	B-6	3,5
4	B-7	3,8
5	B-2	1,3
6	B-3	1,65
7	B-4	2,3
8	B-5	2,7
9	DB-1	4,8
10	DB-2	7,0
11	DB-3	5,4
12	DB-4	4,53
13	DB-5	5,0
14	DB-6	5,0
15	S-3	3,1
16	S-4	3,15
17	S-6	3,1
18	S-8	3,55
19	SH-1	5,2
20	SH-2	3,45
21	SH-3	3,55
22	SH-4	2,7

T a b l e 6

Value of groundwater depth parameteres

Depth of groundwater (m)	Value
2 – 5	0.9
5 – 10	0.8

T a b l e 7

Aquifer vulnerability level

Vulnerability level	Value
Moderate	< 0.4 – 0.5
High	> 0.5

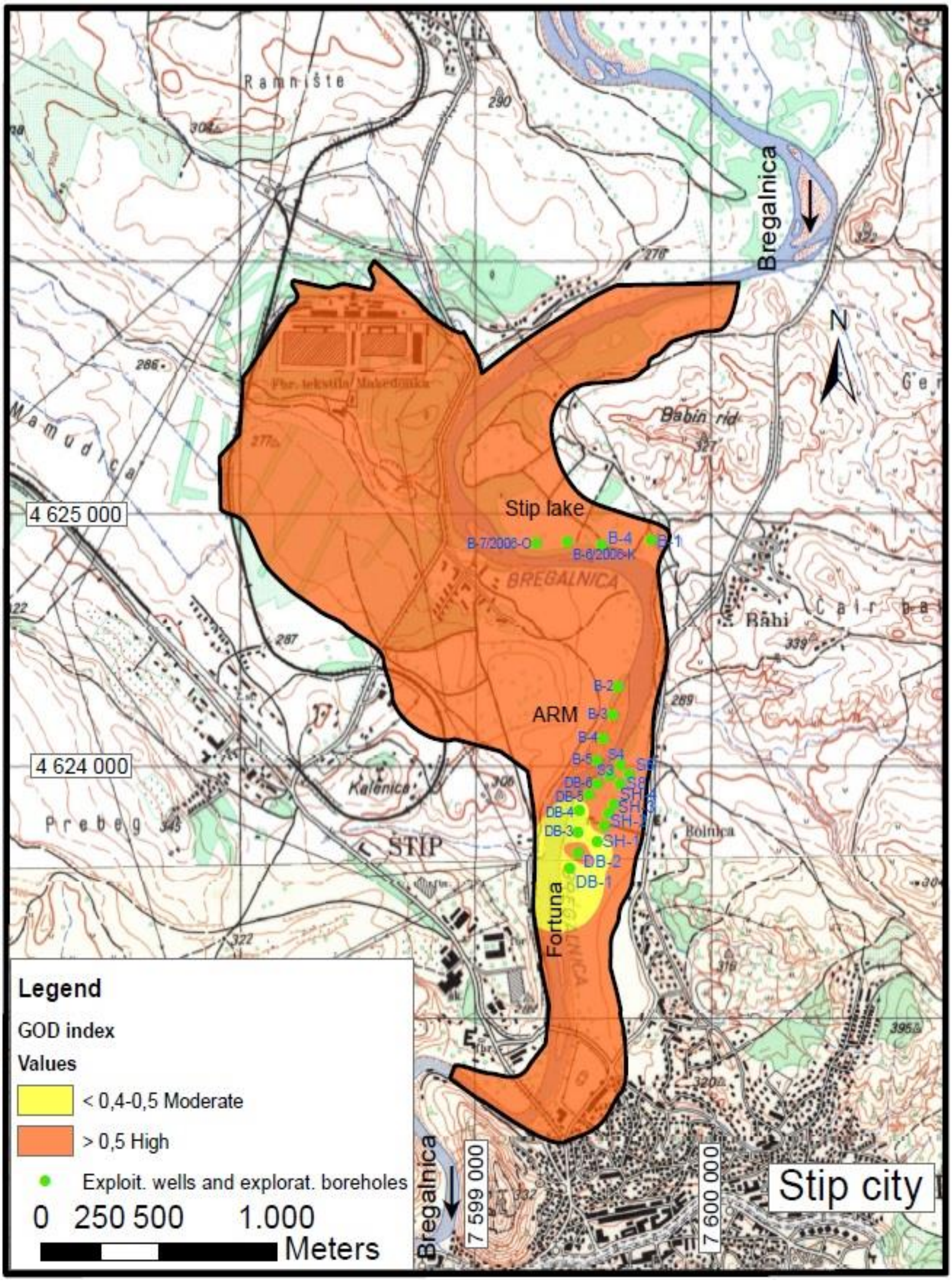

Fig. 5. Vulnerability map

CONCLUSION

The vulnerability map for the Štip aquifer created according to the GOD method shows the natural characteristics of the geological environment from the aspect of possible pollution of the groundwater accumulated in it. The map was created by analysis of three hydrogeological perimeters: type of aquifer, lithology of the aquifer unsaturated zone and depth of groundwater.

Most of the investigated area belongs to the hydrogeological environment with high vulnerability, and only a small part of the area south of the Fortuna springs belongs to the medium vulnerability, based on which we can generally conclude that the Štip aquifer belongs to the class of highly vulnerable aquifers.

The created map for vulnerability of the Štip aquifer from pollution can be used for management of the water resources from this aquifer in the development of the ecological policies of the municipality of Štip, for proper use of the space in the spirit of sustainable development and protection of the groundwaters from pollution.

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Р е з и м е

ОЦЕНА НА РАНЛИВОСТА НА ПОДЗЕМНИТЕ ВОДИ ОД ЗАГАДУВАЊЕ ВО ШТИПСКИОТ ВОДОНОСНИК СО ПРИМЕНА НА GOD-МЕТОДОТ

Дарко Пижов, Војо Мирчовски, Ѓорѓи Димов

Факултет за природни и технички науки, Институт за геологија, Универзитет „Гоце Делчев“, Бул. „Гоце Делчев“86, 2000 Штип, Република Северна Македонија
darkopizov@yahoo.com

Клучни зборови: ранливост; GOD-метод; подземни води; штипски водоносник; алувијални седименти

Изработката на картите за ранливост на водоносниците од загадување е во широка употреба во развиените земји и претставува основно средство за заштита на подземните води. Овој труд ја прикажува оцената на ранливоста на подземните води во штипскиот водоносник од загадување со помош на GOD-методот, при што се користени три параметри: тип на водоносникот, литологија на надводоносната зона и длабочина на подземнаta вода. Податоците за трите параметри се добиени од геолошко-хидрогеолошките профили од 22 експлоатациони бунари и истражни дупчетини. Со трите анализирани параметри е добиена вредност на GOD-индекс во интервал од < 0,4 до 0,5, што одговара на класата на средна ранливост, додека вредноста > 0,5 одговара на класата на висока ранливост.