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Determination of Groundwater Wellhead Sanitary Protection Zones: A Case Study Application on the Wellhead in Lipjan (Kosovo)

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Abstract: Groundwater is vulnerable to several kinds of pollution which are related to developments of human activities. Successful protection from pollution can be done by determination of sanitary protection zones. In Kosovo, groundwater protection from contamination which are used to supply the population with drinking water is regulated by the Administrative Instruction No.13/07. For groundwater source (extraction water wells) in the locality "Konjuh" in Lipjan which is used to supply with drinking water it is designed its protection from contamination by determining sanitary protection zones around it. With the application of different analytical methods is rebuilt (outlined) a zone of contribution of wellhead and three sanitary protection zones are defined around it: firstzone (zone of immediate protection: 10.0 m), second zone (zone of intermediate protection; 290.0 m) and Third zone (extended zone of protection until to the hydrogeological watershed: 430.0 m). The application of different analytical methods for determining the sanitary protection zones in this case study whereas there was no sufficient hydrodynamic and hydrogeological data is shown relatively successful and reliable.

Key words: Groundwater, wellhead, aquifer protection, zone of contribution, protection sanitary zones, analytic methods

INTRODUCTION

Groundwater is an important resources for supplying population with drinking water and is very useful in industry and other human activities that way is very important to preserve them. Human activities can affect groundwater quality in urban areas infrastructure, etc. Protection of groundwater is an important objective for the country.

The contamination of the groundwater resources is in general, persistent, so that, the recuperation of the water quality is a slow and difficult process (Leitao, 1997). Geological setting plays an important role, especially in time of travelling of contaminants. Hydraulic characteristics of concerned aquifer and amount of extraction water plays an important role. Protection zone around wells are generally defined as travel time zones, either to allow for the attenuation of concentrations of contaminants in the aquifer or to provide a monitoring zone. If a contamination is detected in a monitoring zone it could be dealt with it before it enters the well (Krijgsman and Lobo Ferreira, 2001).

In "Konjuh" locality, Northeast of Lipjan (Kosovo), 400 m West of main road Pristina-Ferizaj in order to supply with drinking water the settlement of Janjeva, during the years 2002-2003, geological and hydrogeological research were carried out (cartography, potentiometer, drilling, etc.) which results in finding of considerable quantities of underground waters (Pruthi, 2002, 2003).

In order to use groundwater in location of "Konjuh" three observe-pump drillings were made, the construction was mount (pipe, filter, submersible pump) and their test was made. Wells P1-P3 with depth of 35 m were aligned in a line with SW-NE extendwith a distance from 50-60 m. The optimal extraction rate of the wells during their single use, range from 12.0-37.0 L/sec while during their group testing was 5.0-24.0 L/sec which represent an important source for supplying the population with drinking water.

At the time of utilization of groundwater, water quality was at satisfactory level. But in general, groundwater, like other waters in this locality are vulnerable from different type of pollutions (contaminants) related with human activities, although to a lesser extent than surface waters. During utilization of groundwater its protection against pollution wasn't defined because in that time in Kosovo, groundwater protection was not determined by legal provisions. For this purpose, during the accomplishment of geological-hydrogeological research, no additional hydrogeological research has not been carried out in

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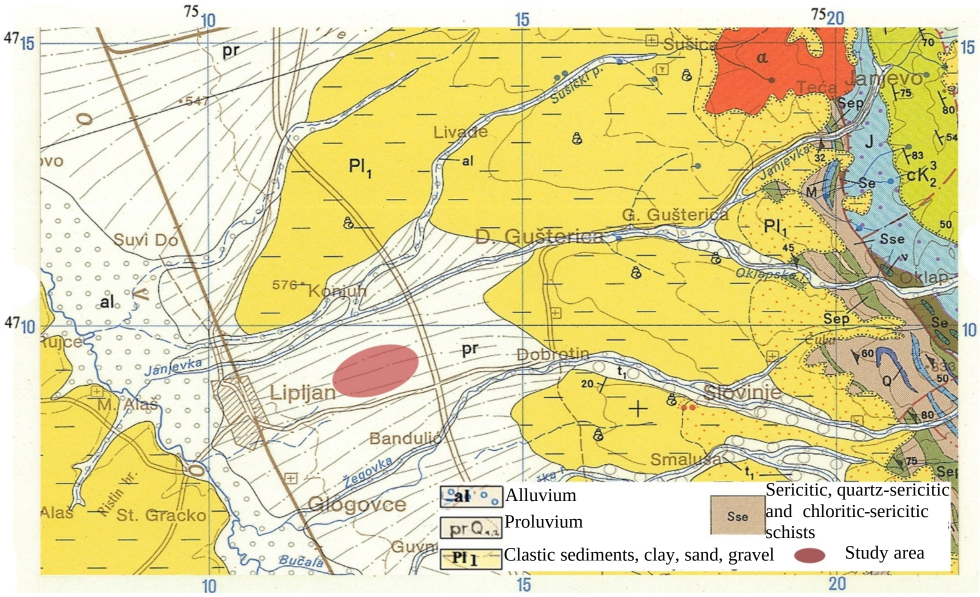

Fig. 1: Geologic map of Lipjan area

which based on the resulting research should be conceived the protection of underground water resources.

However, in this case it has been proven that a preliminary protection from the contamination of this groundwater well has been conceived on the basis of hydrogeological and hydrodynamic data available by defining the dimension of respective protection zone.

Basic geological and hydrogeological characteristics of locality: In geological settings, locality of "Konjuh" (Lipjan, Kosovo) is composed from Pliocene and Quaternary sediments. Pliocene sediments are represented by gravel, sand and sandy clay while quaternary sediments are represented by river terrace rocks (sand, gravel) and Pleistocene prolluvuim (gravel and heterogenic sand) and also Holocene alluvium deposition, represented by mud, sand and gravel (Anonymous, 2007). Figure 1 quaternary deposited aquifers appears in characteristic shape of isometric lenses, placed over Pliocene clay. They are represented by gravel and heterogenic sand, poorly sorted and rounded (quartzite sand, diabase, limestone, serpentines, etc.) interrupted by thin layers (intercalations) of gravelly-sand with clay and clays. They cover is made of clay with humus with different thickness.

In the locality of "Konjuh" in quaternary deposits, an intergranular aquifer of phreatic-sub artesian type is formed with relatively large dimensions with underground water table in depth of 2.0-4.0 m. Total thickness of aquifer interrupted by poor water layer in its explored part, ranges from 18.0-24.0 m and filtration coefficients of 4.5-20.86 m/day. Water flow direction in its explored part is approximately from Northeast to Southwest. Eastern boarder of the aquifer is about 150 m away from main road Pristina-Ferizaj while Western boarder isn't well research and define but can be predicted that the aquifer will go further Southwest.

Protection of groundwater wells from pollution: Drinking water for the supply of the population should not pose a risk to public health, therefore, groundwater wellhead should be protected from any kind of pollution. Today, the protection of groundwater has become a national priority and is focused more on preventing their pollution and less in the rehabilitation process. The protection is done by defining (outlining) the protective areas around groundwater wellhead and by limiting the developments of human activities within it.

When defining the protection areas, different aspects have to be taken into account. These are economic aspect and characteristics of aquifer system, vulnerability to pollution, extrusion rate of water, time of travel, hydrodynamic parameters, etc.

Economic aspects are very important because protection sanitary zones can impose restrictions on land use and therefore, land compensation payments makes the supply with drinking water extremely expensive. A compromise between groundwater protection and follow activities in the process are indispensable. The protection of a wide area causes the increase of price for water supply, if for this purpose, an effective area in not set.

The protection sanitary zone of wellhead (water wells) of groundwater serve as "Passive protection" against pollution. Defining and creating of protection sanitary zones around groundwater wellhead represents the highest level of protection and it is the best way of guaranteeing the production of drinking water from underground aquifers.

Protection of underground waters from pollution and the defining of protection sanitary zones around wellheads in different countries is made in different ways.

In USA, protection from pollution of ground water wellhead is based on protection concepts of "Wellhead Protection Area"-WHPA which represent part of aquifer in which underground water flows into well direction. WHPA is known as "Zone of contribution" or as "Capture zone". Determination of wellhead protection zones is based not only in aquifer characteristics (type of aquifer, type of groundwater flow, etc.) but also on wellhead construction and operation mode. Within the "Wellhead Protection Area" in the USA in addition to fixed area up to 30 m, usually are determined two or three protection zone based on "Time of Travel" of pollutants (TOT) for example for a "Time of travel" of 1, 3 and 5 years. This definition of protection sanitary zone is made with different methods such as: Calculated Fixed Radius (CFR), analytical method, numerical models, etc. (Anonymous, 1987).

In European countries, usually, protection of groundwater from pollution is made by determination of sanitary protection zones around wellhead or well construction. There are three protection zones (in some cases subzones): first protection zone area around construction work (water well) which protects, it from direct penetration of any harmful pollutants second protection zone an isolated area to protect the wellhead from any pathogenic microbes which could be located in third zone and third protection zone which provides groundwater protection from chemical and radioactive pollutants and other harmful impacts. Dimensions of protection sanitary zones vary in different countries in Europe. The boarder of first protection zone usually is defined in a distance from 10-50 m from wellhead of groundwater; The boarder of second protection zone is based on 50-180 day time period of bacteria to travel in water to the construction well or minimum distance of 50-150 m and third protection zone is defined with time interval of at least 200 days up to 10-15 years or at a distance at least 200 m up to 2.0 km (Strobl and Robillard, 2005).

In Kosovo, groundwater protection from contaminants is regulated by the Administrative Instruction "Criteria's for defining the water protection zones and their protection measures for water resources that are used for drinking water" (Anonymous, 2007). According to the instruction, the protection depends on the type of groundwater aquifer (intergranular, karst-fissured and mineral water-termomineral) it is determined by defining the protective zone and setting up the necessary protective measures. In water resources protection area (wells, other construction site for extraction of water), three protection areas have been identified which can be freely defined as:

First zone protection zone of severely regime it is determined for directly severely protection around the wellhead and construction facilities for water supply and also to protect the sources from pollution discharges that could have direct impact in the water from human activities. The boarder of first zone represents the line which should be recessed at least 10 m (50 m for mineral water sources) from the object of water supply.

Second zone protection zone of limited regime which insure protection from movements of microbiological, chemical and other pollutants towards wells. The second protection zone (zone 2), represents external boarder of protection zone 1 until the line (limit) in which underground water needs at least 50 days (for karstic and fissured aquifers at least 4 days or more than 1,000 m) to enter in well (water construction object).

Third zone protection zone of slightly regime. The area of this zone represents the preventive protection of contribution area of wellhead and increases the efficiency of protection from chemical and radioactive pollution. The area of third protection zone includes the area until external boarder of second zone until hydrogeological divide (watershed), determined by condition of well use.

For all three protection zones in administrative Instruction are determined the restriction for human and other economic activities.

Determination of protection sanitary zone in wellhead "Konjuh" (Lipjan): From hydrogeological-geological research and the testing (observing) of pumping wells (P1-P3) (Pruthi, 2003) are gained hydrogeological and hydrodynamic parameters, from which even not a necessary number of well are determined wellhead protection sanitary zones (Table 1).

Wellhead protection sanitary zones of water sources "Konjuh" (Lipjan) are determined with analytical method of Calculated Fixed Radius (CFR (Anonymous, 1987; Wyssling, 1979; Krijgsman and Lobo Ferreira, 2001).

Table 1: Hydrogeological-hydrodynamic parameters of wells

Available data for wells	P-1	P-2	P-3
Extraction rate (Q) (m^3/day)	2073.000	1036.800	1468.800
Hydraulic conductivity (K) (m/day)	20.860	4.500	10.640
Saturated aquifer thickness (b) (m)	24.000	21.000	18.000
Effective porosity (n) (%)	0.100	0.100	0.100
Hydraulic gradient (i)	0.022	0.022	0.022
Time for pollutants to (t) travel into well (day)	50.000	50.000	50.000

MATERIALS AND METHODS

Calculated Fixed Radius method CFR: Calculated Fixed Radius (CFR) method is used in case of lacking on geological-hydrogeological and other hydrodynamic parameters and when the type of aquifer isn't well know, then it is as alternative way to define well protection zones (Fig. 2):

$$Q.t = n.\pi.H.r^2 \Leftrightarrow = \sqrt{\frac{Q.t}{n.H.\pi}}$$

Where:

r = Protection zone radius (m)
Q = Extraction rate (m^3/day)
t = Time of travel (day)
n = Effective porosity (%)
H = Saturated thickness (m)

The limitation of this method is that its calculations does not take into account the regional water flow, caused by the hydraulic gradient. This method can be used in cases where the groundwater table is almost horizontal before pumping for example in cases of weak hydraulic gradient or lack of water. The cone of depression created by pumping of well will be a circle around the well whose radius can be calculated using the formula above.

Wyssling method: Wyssling method is an easy method that can be applied in homogenous porous aquifers. The method consists on the existence of a pumping well and the existence of the slope of the hydraulic gradient resulting in an asymmetric cone of depression. The method also enables direct calculation of transit time (flow time) of groundwater from a desire point on the flow axis to a pumping well (Fig. 3). Calculations of different parameters are made using the following Eq. 2:

$$S_0 = \frac{+1+\sqrt{1(1+8X_0)}}{2},\ S_u = \frac{-1+\sqrt{1(1+8X_0)}}{2}$$

$$X_0 = \frac{Q}{2.\pi.K.b.i},\ v_e = \frac{K.i}{n}, 1 = v_e.t$$

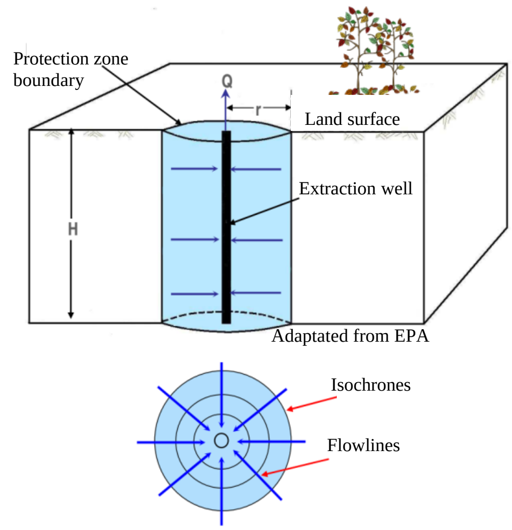

Fig. 2: Calculated fixed radius method (EPA., 1987)

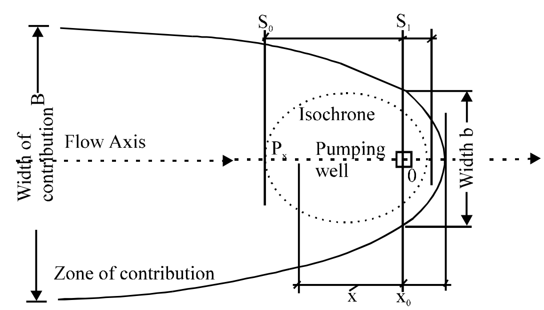

Fig. 3: Graphic representation of a flow system at a pumping well (Wyssling, 1979)

Where:

S_o = Upgradient protection distance the upper zone 2 boundaries (m)
S_u = Downgradient protection distance lower zone 2 boundaries (m)
X_o = The distance from the pumping well to the downgradient boundary of the zone of contribution (m)
v_e = Effective speed (m/day)
Q = Extraction rate (m^3/day)
K = Filtration coefficient (m/day)
t = Pollutants travel time to pumping well (day)
n = Effective porosity (%)
b = Thickness of saturated zone (m)
I = Hydraulic gradient

Incase of high water flow (v_e) it can be that the values of S_u is greater than the value of X_o, meaning something is wrong, therefore, in those cases the values of S_u and S_o should be controlled and corrected.

Krijgsman and Lobo-Ferreira (KLF) method: This method is developed to calculated the intermediate protection zone (t = 50 days) and is an alternative to hydrogeological studies in case there are insufficient information of hydrodynamic parameters which are necessary to determine wellhead protection zone. Methodology is suitable for unconfined aquifers that are directly at risk to be polluted.

According to Krijgsman and Lobo Ferreira (2001), a 50 days protection zone is ellipse shaped and more like a circle if hydraulic gradient is smaller. Researchers suggest to determine dimensions of three protection zones of intermediate protection zone (zone 2): r_{max}, r_{min}dher$_p$ (Fig. 4a):

$$r_{max} = \frac{0.00002.x^5 - 0.00009.x^4 + 0.015.x^3 + 0.37 + x}{F}$$

$$r_{min} = \frac{0.042x^3 - 0.37x^2 + 1.04x}{F}$$

$$x = 2.K.I.\sqrt{\frac{\pi.b.t}{Q.n}}$$

$$F = \frac{2.\pi.K.b.I}{Q}$$

$$r_p = 4\sqrt{\frac{Q}{nb}}$$

Where:

r_{max} = Upgradient protection distance (m)
r_{min} = Downgradient protection distance (m)
r_p = Protection distance perpendicular to flow direction (m)
Q = Extraction rate (m^3/day)
t = Pollutants travel time to pumping well (day)
n = Effective porosity (%)
b = Thickness of saturated zone (m)
i = Hydraulic gradient

Limitation on use of these equation:

- r_{max}: do not use combination of parameters resulting in a value of x>18
- r_{min}: if x<-3.5 apply a minimum protection distance of 25 m
- Do not apply equation with values of effective porosity <0.1 (10%)

In fact, the 50 days protection zone never becomes a perfect ellipse, especially, in cases of high hydraulic gradient. Krijgsman and Lobo Ferreira (2001), suggest the modification of ellipse by drawing of a circle with equivalent radius with protection distance perpendicular to flow direction in the edge of upgradient (Fig. 4b).

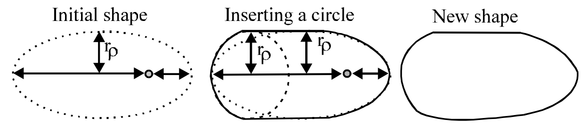

Fig. 4: Intermediate protection zone: a) and modification of upgradientlimit of the ellipse: b) (Krijgsman and Lobo Ferreira, 2001)

Table 2: Distance of second protection zone (zone II)

Methods	CFR	Wyssling		KLF		
Parameters of zone boundaries/wells	r (m)	S_u (m)	S_o (m)	r_{min} (m)	r_{max} (m)	r_p (m)
P-1	117.27	49.33	278.79	27.87	312.72	48.98
P-2	88.66	67.30	116.80	60.71	127.73	88.87
P-3	36.00	69.57	186.50	52.00	207.61	114.26

Protection zones Based on hydrogeological and hydrodynamic parameters (Table 1) with applications of three above mentioned methods, the determination of intermediate protection zone of P1-P3 wells was made (Table 2).

With the 50 days protection zone or intermediate protection zone means the contaminants infiltrated in underground water flow shall reach underground water at least for 50 days from the infiltration moment until it reaches pumping well.

If we compare the calculated distances with analytical applicable methods for downgradient and upgradient of intermediate protection zone (50 days zone) can be concluded: radius value r, calculated with CFR method is greater than the values of S_u and r_{min} (Downgradient) and smaller that values of S_o and r_{max} (upgradient), calculated by Wyssling and KLF method. Values of S_o and S_{max} (upgradient) and values of S_u and S_{min} (downgradient), calculated with Wyssling method and KLF method are very similar.

Based on hydrodynamic parameters for pumping and observation well P-1 are determined the parameters for protection area zone of contribution: maximal width B, width in well location b, stagnation point-x_o and some main points (x, y) of neutral line (Fig. 3) with equation: (Todd, 1980):

$$B = Q/(K\,b\,i);\ b = Q/(2\,K\,b\,i);\ x_0 = -Q/(2\pi Kbi);$$
$$x = -y/\tan(2\pi Kbiy/Q),\ \tan(y) \text{ in radians}$$

The values of calculated parameters are: B:B = 188.0 m., (B/2 = 94.0 in both side of x axis); b = 94.0 m, (b/2 = 47.0 m. in both side of x axis) and x_o = -30.0 m. In zone of contribution of wellhead "Konjuh" (Lipjan) are determined these protection zones (Fig. 5):

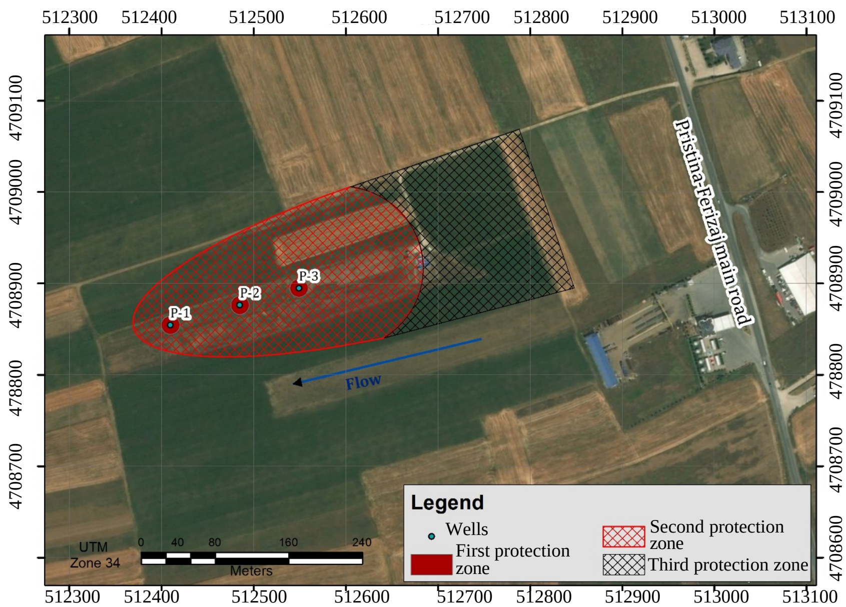

Fig. 5: Protection sanitary zones of wellheads in "Konjuh" Lipjan

First protection zone: First protection zone boarder is calculated with average radius r = 15.0 m, around pumping well P-1 whereas the distance for all wells is appropriated in value of r = 10.0 m, always based on administrative Instruction for protection zones.

Second protection zone: The calculated upgradient for second protection zone is 290.0 m from pumping well P-1 in the opposite direction of water flow, respectively in Northeast direction and the downgradiend boarder in a distance of 30.0 m from pumping well in direction of water flow, respectively in Southwest. Second protection zone of well P-2 and P-3 is inside of upgradient area of second protection zone of well P-1.

Third protection zone: The boarder of third protection zone of pumping well P-1 (also for other wells P-2 and P-3), according to administrative instruction is hydrogeological watershed (determined by drilling) which is 430 m away from the wellhead in Northeast direction. According to some instruction from other countries, this boarder is determined by contaminant time of travel not <200 days or more than 500 m and in some countries the time of travel note less 2 years or 2.0 km in distance.

CONCLUSION

Groundwater is the main sources of water for supplying of population with drinking water, therefore, wellhead and groundwater should be protected from different contaminants (pollution) by defining the protection sanitary areas of contribution zone. In locality of "Konjuh" (Lipjan-Kosovo) with drilling was found an aquifer of water which is used now for supplying the population with drinking water. Therefore, it was a need of time to determine the protection zones from contaminants. The protection zones of wellhead were determined according Administrative Instruction No. 13/07 of Kosovo and also by geological-hydrogeological research in the field.

Based on hydrodynamic parameters of wellswith analytical method (Calculated Fixed Radius, Wyssling, Krijgsman Lobo Ferreira) are determined three sanitary protection zones. First protection zone (severely regime), a circle with radius of 10.0 m. which encloses the pumping well and other wellhead construction. Second protection zone (limited regime)with its external boundary of 290 m, from pumping well and third protection zone (slightly regime) whose external boundary is conditioned by the existence of hydrogeological watershed (boundary), defined at a distance of near 430 m from pumping well.

Most of the methods used in determination of protection zones ares more adaptable to determine the intermediate zone (50 days zone). It can be concluded that in cases of determination of sanitary protection zone of wellhead in rural areas or in cases where there are insufficient hydrodynamic and hydrogeological data, application of different analytical methods can be done very successful me high credibility.

Results indicate that the risk of well contamination from an interstate highway and gas station with old steel underground storage tanks were comparatively high. Medium risks included a thorough are and highway while low risks were assigned to machine shops, a body shop, septic systems and a gas station with new underground storage tanks and secondary containment (Harman *et al.*, 2001). In the case in wellhead area, there is an industrial facility in Southwest of wellhead which was built after well construction is very near and can risk groundwater with contaminant.

REFERENCES

Anonymous, 1987. Guidelines for delineation of wellhead protection areas, office of groundwater protection. United States Environmental Protection Agency, Washington, D.C., USA. https://nepis.epa.gov/ Exe/ZyNET.exe/ 00001OZC.txt?ZyActionD=ZyDocument&Client=EPA&Index=1991%20Thru%201994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=

Anonymous, 2007. Criteria's for defining the water protection zones and their protection measures for water resources that are used for drinking water. Administrative Instruction no. 13/07, MESP Inc., Agoura Hills, California.

Harman, W.A., C.J. Allan and R.D. Forsythe, 2001. Assessment of potential groundwater contamination sources in a wellhead protection area. J. Environ. Manage., 62: 271-282.

Krijgsmann, B. and J.P.C. Lobo Ferreira, 2001. A methodology for delineating wellhead protection areas. Laboratorio Nacional de Engenharia Civil, Lisboa, Portugal.

Leitao, T.E., 1997. [Methodologies for the rehabilitation of polluted aquifers]. Ph.D Thesis, Faculty of Sciences, The University of Lisbon, Lisbon, Portugal. (In Portuguese)

Pruthi, V., 2002. Report on drilling results of potentiometer Pz-1 in Lipjan locality. Community Development Initiative (CDI), Pristine.

Pruthi, V., 2003. Report on results from drilling of pumping and observing well in Lipjan locality. Community Development Initiative (CDI), Prishtine.

Strobl, R.O. and P.D. Robillard, 2005. Review of US EPA-recommended and German wellhead protection area delineation methods. J. Environ. Hydrol., 13: 1-19.

Todd, D.N., 1980. Ground Water Hydrology. John Wiley and Sons, New Delhi, India, Pages: 123.

Wyssling, L., 1979. [A new formula for calculating the inflow time (running time) of groundwater to a groundwater pumping station (In German)]. Eclogae. Helv., 72: 401-406.