

## EFFECTS OF AERATION ON GROUNDWATER QUALITY FOR IRRIGATION

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### Summary

*Volatility in agricultural production caused by the reliance on natural factors, and water is one of the basic, which provides greater production. Volatility in agricultural production caused by the reliance on natural factors, and water is one of the basic, which provides greater production.*

*The authors in their professional praxis have seen that the presence and absence of vadose zone in the upper part of aquifer; with inter-granular porosity type, is a prerequisite for enhanced concentrations of iron and manganese in groundwater. The natural aeration zone in vadose zone of the upper part of aquifer enables additional enrichment of groundwater with oxygen, which is spent on the account of biochemical processes in the direction of their flow. The absence of this zone in aquifer directly influences higher iron and manganese content in groundwater, often above the permissible concentration in drinking water. In order to eliminate this problem, in this paper proposal of future works were made, different of the usual procedure of hydro geological research. It will be possible to examine the effect of aeration of groundwater in the aquifer, during the preparation of wells from which to irrigate the land.*

**Key words:** *irrigation, unsaturated zone, iron, manganese, aeration, groundwater*

**JEL:** *Q10, Q25*

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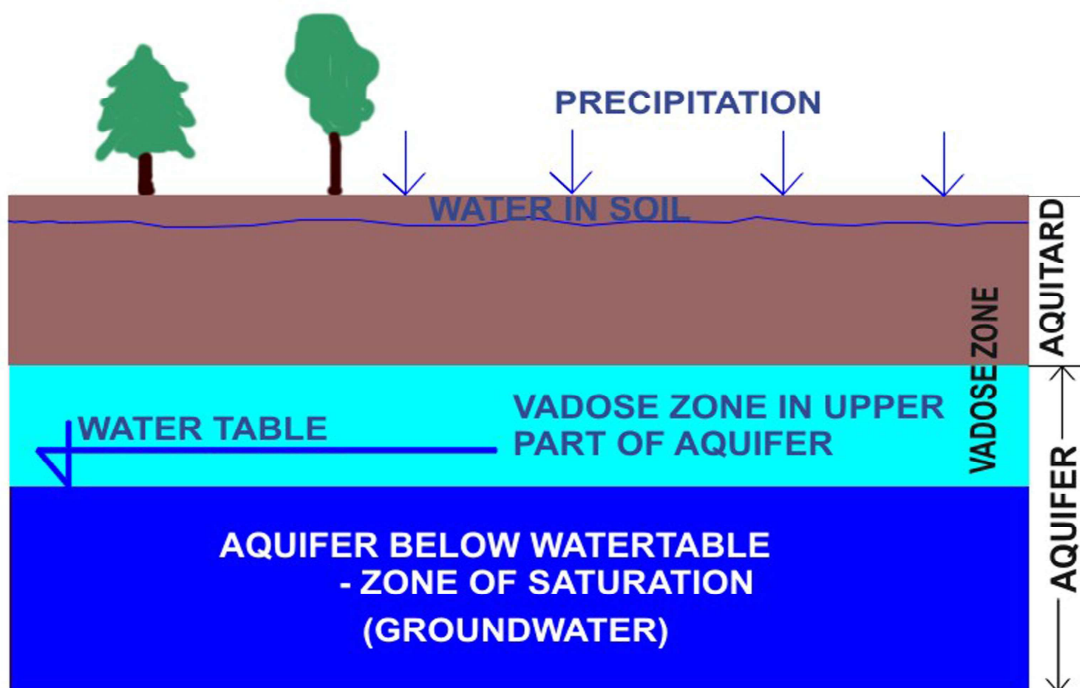
## Introduction

Uncertainty that farmers have been following (product prices, capital and inflation rate) indicated their reservations by investing in jobs where long waits to benefit. Pros and cons of investing in irrigation systems can be found in the economic strength of the manufacturer and the state, conditions in the market of agricultural products and capital [5, 6]. Vadose zone is zone above water table, through which water is infiltrated, and in which the pores and cracks in the soil, and rocks are filled with air and partially with capillary water (Fig 1). This work processes the influence of part of the vadose zone which is situated (or is sometimes completely missing) in the aquifer with marked intergranular type of porosity, i.e. in its upper or higher part on the content of iron and manganese. Namely, in this aquifer zone, natural aeration of the groundwater is made which has a positive influence on its chemical composition. Role of vadose-zone flow process is explained by Harter T. & Hopmans J.W. 2004 [7], Hopmans J.W. and M Th. Van Genuchten, 2005 [8], Rafferty K., 2001[18] and Harter T. 2003 [9].

One major cause of manganese mobilization in aquifers is reductive decomposition and dissolution of compounds such as Mn-OOH and MnO<sub>2</sub>. In the normal pH range of groundwater (pH 5 – 8), dissolved iron is present as Fe<sup>2+</sup>. The main sources of Fe<sup>2+</sup> include [1-4,12-18]:

- the dissolution of iron (II) bearing minerals;
- the reduction of iron oxyhydroxides (Fe-OOH) present in the sediments e.g., magnetite, ilmenite, pyrite, siderite, iron (II) bearing silicates and clay minerals such as smectites,
- the oxidation of arsenopyrites.

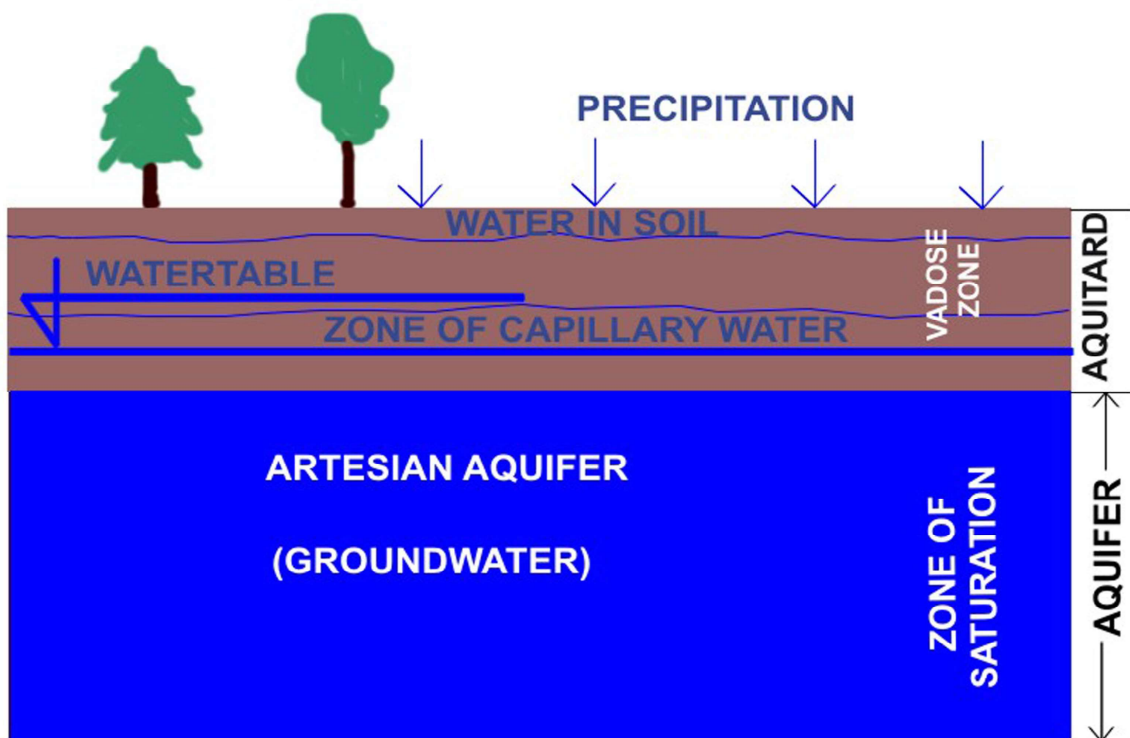
**Figure 1.** The scheme of the aquifer with present vadose zone in the aquifer itself



If the saturation zone in direct contact with aquitard in overlie of the aquifer, with marked inter-granular type of porosity, i.e. if the aquifer is sub-artesian or artesian (Figure 2), due to biochemical processes, anaerobic conditions are created which generates an increased content of iron and manganese in groundwater.

A good understanding of this influence can help the researchers with planning the research works, the choice of well location and projecting the well for abstraction of groundwater.

**Figure 2.** The scheme of vadose zone and saturation zone in aquifer with the level of water under pressure



The authors of this paper have noticed in their professional practice on many terrains in Republic of Srpska that the presence or absence of vadose zone in aquifer (zone of natural aeration), just above the water table, influences the content of iron and manganese in aquifers with strong inter-granular porosity type. It is often the case that this water cannot be used for water supply. In aquifers with fractured porosity type, this influence is not present because of the great speed of the groundwater flow, and the short time of retaining water in underground, and little total intensity of biochemical and chemical processes in groundwater.

Many cases with higher presence of iron and manganese and groundwater along with the absence of vadose zone in the aquifer itself, which proves spatial this dependence.

### Presence and origin of iron and manganese in the groundwater

Natural conditions in our country are such that there are large areas that are saturated with water, and surface water is lacking. If irrigation systems are used properly and if we have good water quality, then we can expect higher yields, improved product quality, improved physical and chemical properties of soil, microclimate regulation of conditions in which the plant develops in surprising and application of certain agricultural practices. Otherwise, it may cause leaching of nutrients from the soil (error in determining the time of irrigation and irrigation rate), water-logging (due to water saturation, pushing the air out of the soil and leads to suppression of the root system), salinization (if the water has a high salt content) and deterioration of water-physical properties of soil (due to compaction reduces porosity).

Higher level of iron and manganese in water changes organoleptic properties because of sediment, which stands out (orange and brown color), it has an unpleasant smell and the taste of water associates with metal. Iron and manganese react with dissolved oxygen to form insoluble compounds. Therefore, they are usually not found in waters that contain high amounts of dissolved oxygen [13-15,17,18].

Interpretation of origin of these components in certain aquifer is different. The reasons are first to be searched in the existence of local pollutants in the zone of sanitary protection of water source. In certain cases the reasons are searched in mineralogical-petro graphic, i.e. lithological characteristics of terrain, because at first glance it is thought that the rocks, through which water passes are the cause of such an unpleasant the chemical content. However, the most common cases are those with higher presence of iron and manganese in groundwater, where there are no mineral deposits, rich with iron (alluvial, pliocene and pleistocene gravelly-sadly aquifers). In sand and gravel, there are different minerals in the structure of grains made from dissolution of primary rocks, their transport and sedimentation in river valley and neogene basin. From the iron minerals, in sand the following can be found: magnetite ( $\text{Fe}_3\text{O}_4$ ), siderite ( $\text{FeCO}_3$ ), hercynite ( $\text{FeAl}_2\text{O}_4$ ), jacobsite ( $\text{MnFe}_2\text{O}_4$ ), franclinite ( $\text{ZnFe}_2\text{O}_4$ ), chromite ( $\text{FeCr}_2\text{O}_4$ ), etc. Frequently minerals of manganese are galaxite ( $\text{MnAl}_2\text{O}_4$ ) and hrodochrosite ( $\text{MnCO}_3$ ).

Apart from these, the presence of the following iron-manganese minerals is also possible: axinite, pyralspite, almadine, spessartine, turmaline, etc. Excerpts of dolomite and limestone, and deposited conglomerates, gravel and sand made from transport of these parts, usually contain chemical impurities of iron and manganese.

So, iron and manganese are practically present in all geo-environments, but in groundwater of all these environments, they are not present in higher percentage.

In the area of fractured limestone and dolomite terrains of Herzegovina and Romanija, and the basin of the upper flow of the river Drina, Bosna and Vrbas where the groundwater flow is fast, and where the upper part of aquifer has present vadose zone, i.e. the aquifer is not artesian, ground-waters do not have a higher content of iron and manganese. However, ground-waters of the Pannonia basin rim (in the immediate catchment of the

river basin in the territory of Republic of Srpska) and some aquifers in northern part of Republic of Srpska and Brcko district have higher content of these elements in wider area, in what the authors of this work convinced through their own hydro geologic and hydro chemical research, i.e. based on the results of physical-chemical water analysis results, whose statement is given in this paper.

### **Correlation of vadose zone existence in aquifers with inter-granular porosity type and iron and manganese content in groundwater**

In the following text, the examples of presence or absence of close zone of natural aeration in vadose zone of the aquifer itself are presented, with present air above the level of groundwater, and along with that, the presence of iron and manganese in those aquifers. This type of correlation of two characteristics of aquifer can give contribution to the understanding of existence and intensity of this dependence, i.e. influence.

In the far northeast of Republic of Srpska, in peripheral part of Pannonia basin (Semberija and Posavina), with many years of research and following, we established that groundwater in pliocene gravel and sand sediments from the recharge zone (I) and closer zone (II) in mountainous part of Majevisa mountain, have good quality. But, in further zones of ground flow (IV), ground-water have increased content of iron and manganese sometime in some of boreholes in artesian aquifer near river Sava. In Fig. 3 a conceptual hydrogeological model of peripheral part of Pannonia neogene basin, which in the zone far from the recharge zone, does not have vadose zone in the aquifer itself, i.e. there is no natural aeration, so it has anaerobe conditions and by that the conditions for generating higher content of iron and manganese. Figure 3 shows simplified schematic display of the zone of higher iron content in artesian groundwater on the peripheral part of Pannonia basin in the function of nonexistence of vadose zone in aquifer itself, and on the account of consumption oxygen during transport of groundwater

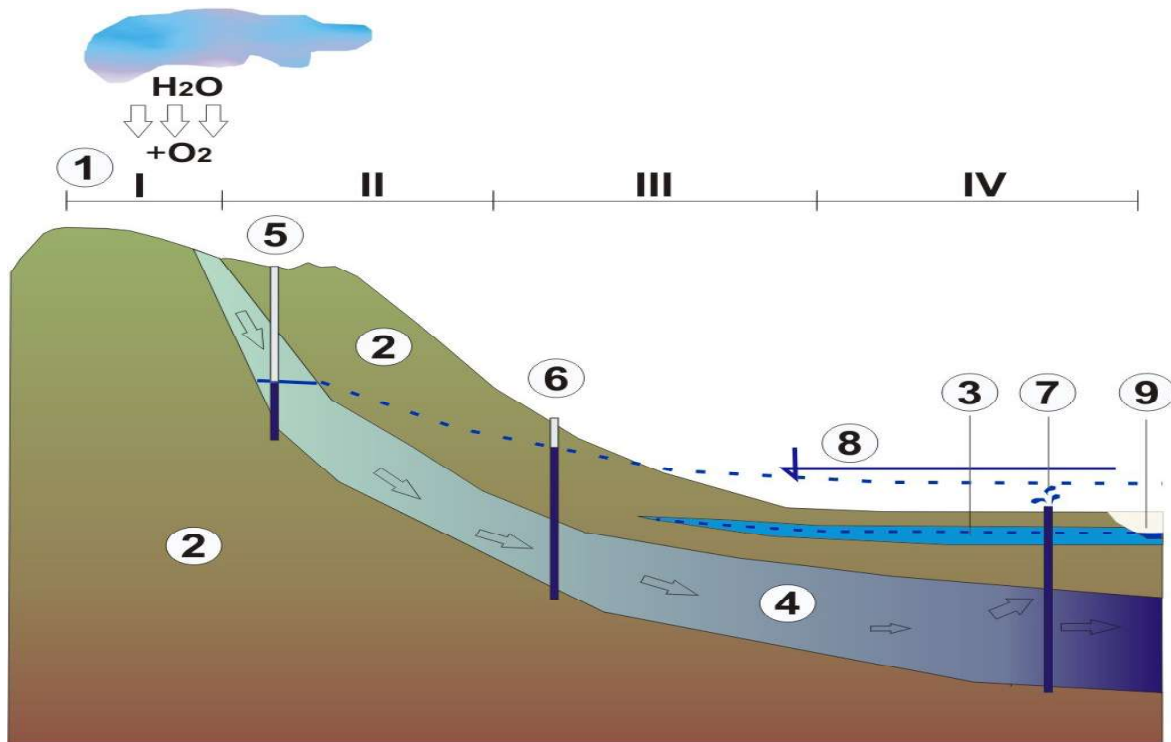
The so-called consumption oxygen in groundwater flow happens because of present microorganisms in water, on the account of biodegradation of organic matters in groundwater and geo-environment, and on the account of chemical processes of oxidation in geo-environment. A rainwater contents average 63,2% nitrogen, 35,0% oxygen and 1,8 % CO<sub>2</sub> [3,7]. That implies high content of dissolved oxygen in groundwater, because in hilly terrains, where pliocene layers have contact with surface, recharge of aquifer is done mainly from rainfall with dissolved oxygen.

In transitional zone (III), i.e. in the first part of groundwater flow, although there is no present vadose zone of natural aeration in the aquifer itself, oxygen dissolved in water is “wasted”, so water in that part of aquifer in its physical-chemical characteristics corresponds drinking water.

Spatial distribution of water with different quality is interesting in the same aquifer, from the aspect of drinking water norms.

In the zone closer to the recharge zone of this part of ground water flow, water in its physical-chemical structure, often matches the norms of drinking water, but is microbiologically faulty. In transitional zone it is both physically-chemically and bacteriologically valid. However, om the zone further from the recharge zone, i.e. in the zone where the whole aquifer is in saturation zone, where vadose zone in aquifer is completely missing, water becomes faulty to drink due to higher content of iron, and sometimes manganese, although it is still bacteriologically correct (example of Posavina). Higher content of iron in aquifers is contributed by little speed of underground flow, present marly sediments and peat, as well as low pH [13-15].

**Figure 3.** Simplified schematic display of the zone of higher iron content in artesian groundwater on the peripheral part of Pannonia basin

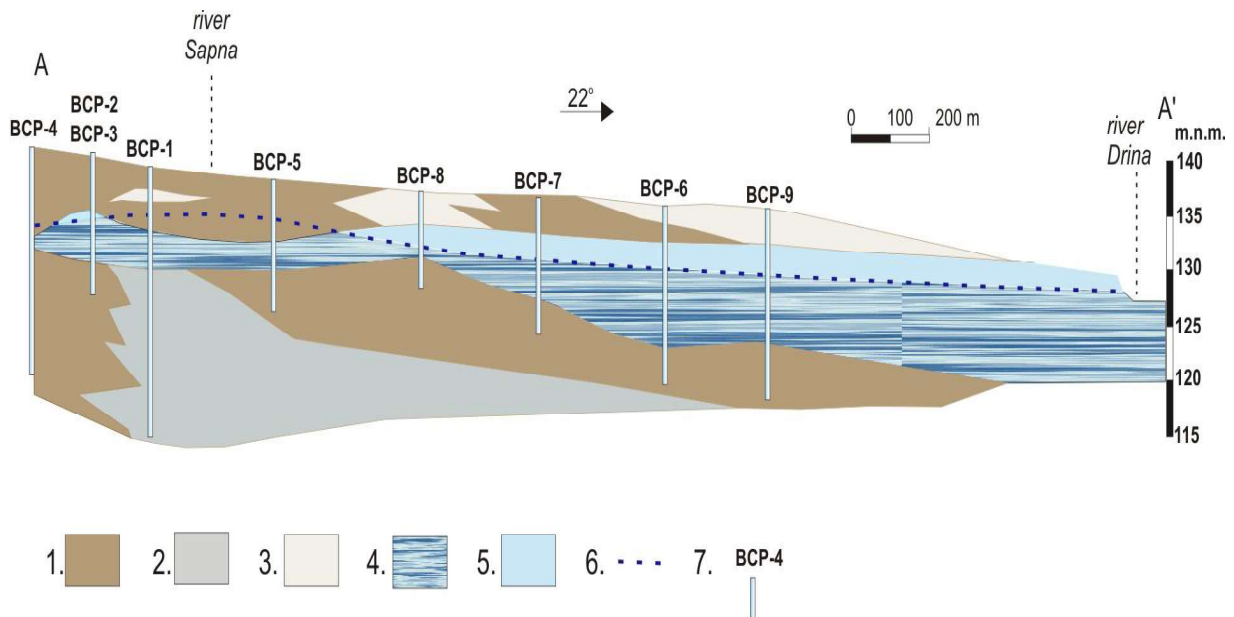


Legend: I Recharge zone, II Zone of good quality of groundwater, III Transitional zone, IV Zone of groundwater with higher content of iron and sometimes manganese, 1 - Infiltration area, 2 - aquitard, 3 - Unconfined aquifer, 4 Confined aquifer, 5 Water well, 6 Nonflowing artesian well, 7 Flowing artesian well, 8 Water table, 9 River.

Higher content of iron near the City of Zvornik (Fig. 4) is recorded in water from piezometer BCP-4 [3,8], concentration 9,8 mg/l and manganese 4,0 mg/l, and in piezometers BCP-7, 6 and 9 in the limits of drinking water [13-15].

This can be explained by presence, i.e. absence of vadose zone and bigger speed of underground flow in the parts of alluvium which is closer to the river Drina.

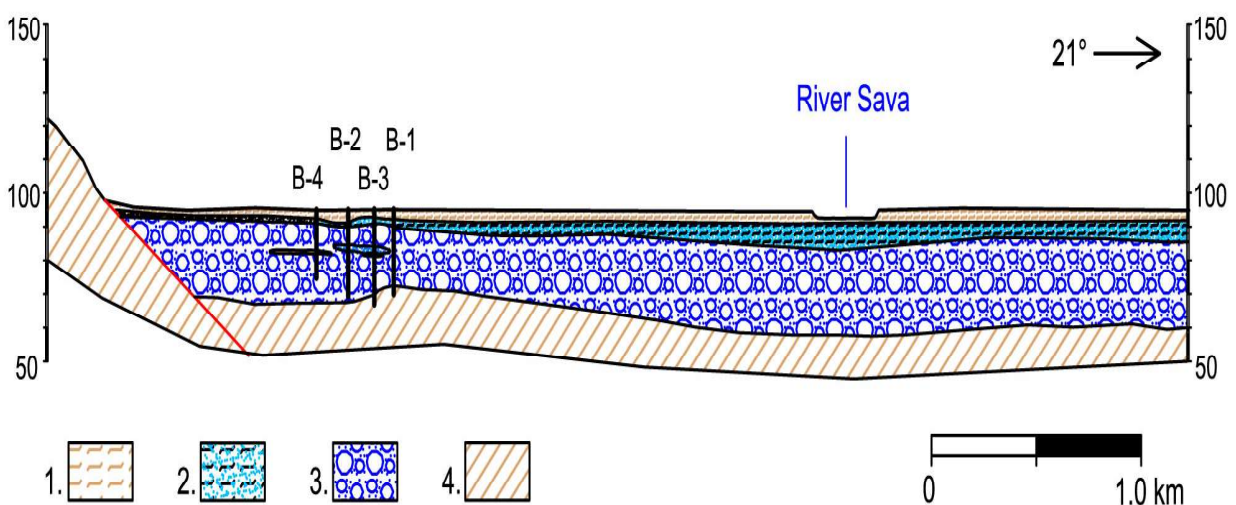
**Figure 4.** Hydro geological cross section of area near Zvornik with higher content of iron in water in one part of cross hole (borehole BCP-1 where the level of the groundwater is in the zone of clay over layer i.e. there is no vadose zone in aquifer)



Legend: 1. Clay, 2. Marl, 3. Sand and sand with clay, 4. Aquifer below the water table, 5. Vadose zone of aquifer, 6. The water table, 7. Borehole

Higher content of iron from 0,72 – 1,7 mg/l and manganese from 0,20 to 1,55 mg/l (Table 1), and occasionally ammoniac in groundwater near Kozarska Dubica (Figure5) is the result of anaerobic conditions in the zones where vadose zone in the aquifer itself is missing (this is determined by boreholes in areas Djolovi and Medjedja).

**Figure 5.** Cross section of spring Medjedja for water supply of Dubica – the whole aquifer in saturation zone i.e. below the water table



Legend: 1. Clay, 2. Clay and sand with clay below the water table (zone of saturation), 3. Sandy gravel, 4. Underlie aquifer

Table 1 shows the values of iron and manganese content in groundwater at the fourteen different locations in river basin of rivers Drina, Bosna, Ukrina, Vrbas, Sana and direct basin of Sava. The authors of this work have established the same dependence.

**Table 1.** Display of results of analyses of content of Fe, Mn in quaternary age aquifers in the neogene basins of Republic of Srpska

Location	Name of water well/borehole	Age of aquifer: 1. Quaternary (alluvial or terrace sediments) 2. Pliocene or pleistocene(pl)	River basin	Fe (mg/l)	Mn (mg/l)	Presence of vadose zone in aquifer itself +/-
PS Mejdan at City of Zvornik	B-1	al	Drina	max 0,1	max 0,01	+
Čelopek near City of Zvornik	BČP-1	al	Drina	9,80	4,00	-
Čelopek near City of Zvornik	BČP-6	al	Drina	0,08	0,00	+
Kozluk near City of Zvornik	VEB-1	al	Drina	max 2,80	max 0,10	-
Brodac near City of Bijeljina	B-1	pl	Sava	0,57	0,00	-
PS Grmić near City of Bijeljina	*	al	Drina	max 0,1	max 0,01	+
PS Plazulje near City of Brčko	*	al	Sava	max 2,00	max 0,35	-
EFT Stanari near City of Doboj	BS-12	pl	Ukrina	max 3,27	max 0,30	-
PS Rudanka near City of Doboj	*	al	Bosna	max 0,2	max 0,01	-
PS in City of Brod	*	al	Ukrina	max 4,00	max 0,07	-
PS Rafinerija Modriča	*	al	Bosna	max 0,2	max 0,01	+
“Stirokard” City of Srbac	BS-2	al	Vrbas	1,70	0,05	-
PS Međeđa City of Koz. Dubica	*	al	Sava	max 1,70	max 1,55	-
Mira in City of Prijedor	BM-2	pl	Sana	max 1,74	max 1,75	-

\* - group of wells

The results of correlation with presence, i.e. absence of vadose zone in the aquifer itself shows the clear connection between the lack of vadose zone and higher content of ions in water. This influence is present in such degree that water cannot be used for water supply without previous treatment.



In alluvium of bigger rivers such as the river Sava, the river bed is carved in clay and alluvial gravel and sand which often have no direct connection with significant aquifer in depth of several tens of meters because of clay aquitard layers between them. Recharge of deeper aquifer happens, most frequently upstream, and it is far tens of kilometers from exploitation well. Great lengths of the underground flow from the zone of recharge as well as in regimes of artesian aquifer of peripheral parts of big neogene basins, slow water replacement, biochemical processes and aquifers, and the lack of vadose zone in the aquifer itself are a precondition for higher content of iron and manganese.

The consumption of oxygen in a slow groundwater flow because of biochemical processes happens as well in this type of aquifer, by the bio-degradation processes of organic matters, presence microorganisms in groundwater, and by chemical processes of oxidation in aquifer.

Such is the case in most part of Cities of Brcko, Samac, Brod and Gradiska.

This work also shows aquifers from alluvial and terrace's gravel and sand in which vadose zone is present in upper part of aquifer, so the content of iron and manganese in groundwater is in limits of drinking water (PS Mejdan, Čelopek - Zvornik, Grmić at Bijeljina, Refinery Modriča, PS Rudanka near City of Doboj).

Depending on the manufacturer's production orientation, economic and technical opportunities, climate and soil should endeavor to supply technology and favorable water-air regime, contribute the maximum use of cultural practices, efficient use of water and reduce operating and maintenance costs of the system. Probably, the most difficult task for manufacturers is to provide financial resources because it is an investment that has a long implementation period and a long payback period. The length of the implementation period in addition to natural factors affect the possibility of providing funds and equipment, its cost, and the state of the market for agricultural products. Application of mathematical and statistical methods can reach optimal program of agricultural production in the conditions with and without the use of irrigation and realization of given constraints and achieve optimization criteria. This also determines the justification of investments as follows the effects arising from changes in income and expenses [5, 6].

### **Conclusion**

Higher volume of agricultural production, in terms of higher degree of utilization of other factors, can be achieved by irrigation. Because of the large investment necessary to shorten the period of the investment, bearing in mind the fact that the proposed solution should preserve or disturb as little as possible of the existing properties of the soil, contribute to efficient use of water and the efficient application of other agricultural practices. By correlation of iron and manganese content in aquifers of kvartarna age and subartesian and artesian aquifers in negenskim basins of Republic of Srpska and Brcko district with the existence of vadose zone in the aquifer itself, the authors of this work have made a conclusion that nonexistence

of vadozna zone in the upper part of the aquifer itself, with the condition of sufficient length of podzemni tok in such conditions, creates a crucial prerequisite of higher iron content, and occasionally manganese in groundwater.

According to this criterion, the authors of this work stress the following:

- The zone of aquifer with present vadose zone in the aquifer itself (content of iron and manganese in the limits of drinking water),
- Transitional zone, and
- Zone of aquifer without present vadozna zone in the aquifer itself (the content of iron and manganese is higher in relation to the drinking water norms).

Contribution to the knowledge of the influence of vadozna zone in the aquifer itself to chemical content of water can help researchers with planning, research, predicting, the choice of location and projecting wells for underground water abstraction and planning treatment plants and total investments.

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## EFEKTI AERACIJE NA KVALITET PODZEMNIH VODA ZA NAVODNJAVANJE

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### Rezime

*Nestabilnost poljoprivredne proizvodnje uslovljena je oslanjanjem na prirodne faktore, a voda je jedan od osnovnih koji obezbeđuje veću proizvodnju. Ulaganja u sisteme za navodnjavanje su neophodna, ali uz konstantna tehnološka poboljšanja i ekonomsku ocenu investicije. U praksi je dokazano da je prisustvo i odsustvu vadosa zona u gornjem delu izdani, sa intergranularim tipom poroznosti, preduslov za pojavu povećane koncentracije jona gvožđa i mangana u podzemnim vodama. Prirodna aeracija oblasti u vadosa zoni u gornjem delu izdani omogućava dodatno obogaćivanje podzemnih voda sa kiseonikom, koje se izvodi na račun biohemijskih procesa u njima. Odsustvo ove zone u akviferu direktno utiče na veći sadržaj gvožđa i mangana u podzemnim vodama, često iznad dozvoljene koncentracije u vodi za piće što će imati negativno dejstvo prilikom navodnjavanja površina. Kako bi se u budućnosti eliminisao ovaj problem u radu su date preporuke, promene uobičajene procedure hidrogeoloških istraživanja, da se sagleda efekat aeracije vode u akviferu, tokom pripreme bunara iz kojih će se navodnjavati zemljište.*

**Ključne reči:** navodnavanje, nezasićena zona, gvožđe, mangan, aeracija, podzemne vode

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