Enrichment of iron in the Gannoruwa well field: Causes and pathways

K.M. PREMATILAKA.
Assistant General Manager (Groundwater),
National Water Supply and Drainage Board
Telawala Road, Rathmalana.

INTRODUCTION

The excessive concentration of iron in drinking water is one of the wide-spread hydrogeochemical problems in Sri Lanka, particularly in groundwater drawn from the bore hole wells located within the alluvial sand deposits. When iron content is high in water, the quality of drinking water is poor due to unpleasant taste, color and odor. Alluvial sandy aquifers are very useful as sources of water supply bore holes wells particularly for Rural Water Supply Schemes in Sri Lanka. About 10 % of the sources of rural water supply schemes, based on these aquifers scattered around Sri Lanka are affected by iron enrichment. Iron enrichment in groundwater is largely controlled by the natural environment and there are large numbers of drinking water wells affected by the iron enrichment, National Water Supply and Drainage Board of Sri Lanka carry out necessary treatment methods to improve water quality.

The present study has focused on causes and pathways of iron enrichment with in the
Gannoruwa well field which is situated in an unconsolidated alluvial sand deposit on the left bank floodplain of the Mahaweli river at Peradeniya (figure: 1.1). The extent of the sand deposit is about 35,000 square meters and the average elevation of the area is 470 m above mean sea level. In this well field, three productive boreholes (TW2, TW3 and TW5) have been constructed during 1989 to supply drinking water to Gohagoda area. During the initial testing stage, iron concentration of the three wells of TW 2, TW 3, and TW 5 varied from 0.01 to 0.03 mg/l. The pH of the groundwater was varied from 6.1 to 6.5.

These three boreholes have been in operation since 1994 and the total pumping capacity per day is about 2000 cubic meters per day. The usual pumping rates of TW 1, TW 2 and TW 5 are 30 m^3/h, 30 m^3/h, and 24 m^3/h respectively. The water quality monitoring has revealed that iron concentration of the bore hole wells has increased with time. After ten years, iron concentration of borehole TW 5 situated 58 m away from the river has shown a very high value, an average of 3.00 mg/l, compared with the other wells. Whereas TW 2 and TW 3 has shown iron concentrations of 0.12 and 0.15 mg/l respectively. Iron concentration of the river has also varied with time monitored during the period between 1993 and 2008. The maximum iron concentration of 0.95 mg/l has been recorded in October, 1995 and the lowest iron concentration of 0.11 mg/l in January 2001. However; iron concentration variation in the river water does not show any relationship with that of the borehole wells.

With the increasing water demand of the area, five new shallow bore holes (TW4, TW6, TW7, TW8 and TW9) were drilled in the same well field in 2000. These new wells are situated closer to the river with respect to other existing wells. The flushing yields of the new wells located closer to the river were higher (more than 2000 l/min.) compared to the other wells. The iron concentration in all new wells was above the 1 mg/l norm of Sri Lanka Standard guideline. Therefore, these wells are not in use at present. The present study reveals the causes, distribution and path ways of iron in groundwater of the Gannoruwa well field.

METHODOLOGY

In order to study the iron problem in the well field, a simultaneous pump testing program (72 hours) was launched on four shallow productive wells (TW2, TW3, TW4 and TW5) with a rate of 122 m^3/hour. Water samples were collected every three hour intervals during pumping and fourteen water samples were also collected from the Mahaweli River during the testing period. Eh, pH and temperature of the samples were measured at the site and total iron, manganese, colour, turbidity and conductivity were measured in the laboratory. The Eh and pH values were plotted on the stability-field diagram (Hem, 1959/1985) for a 10^{-6} molal solution of iron to determine the ferric (Fe^{3+}) and ferrous (Fe^{2+}) states at different time intervals.

RESULTS AND DISCUSSION

Hydrogeology and Geochemistry of the Gannoruwa Well Field

The alluvial deposit having a thickness varying from 10.30 m to 18.00 m consists of fine to gravelly sand, pebble and clayey top soil is underlain by the Precambrian metamorphic rocks. One boundary of the deposit is Mahaweli River and the sandy and gravely layers are confined to the river meander, the lower part of the alluvial deposit acting as an unconfined aquifer. Thickness of this aquifer formation varies from place to place with a maximum of 8 m. The iron Generally, average iron concentration of the wells under different pumping conditions and distance from the river shows a negative correlation based on the (Figure:2.1).

Behavior of water quality during pumping

During the pumping period, Eh values have varied from +0.260 to -0.125 V(figure:2.2) pH varied from 7.32 to 6.45 (figure:2.3). TW 2, TW 03 and river water showed positive Eh values. TW 05 showed negative Eh values during the total testing period and TW 04 initially showing positive Eh values (+0.260v) changed to negative values (-0.090v) during pumping. However, pH has not varied with pumping time. The average values of electrical conductivity of groundwater and river water were 100 µS/cm and 60 µS/cm respectively. The variation of iron in the pumping wells and river during the testing period is shown in figure (2.4). The iron concentration only in TW 4 showed a significant variation during pumping. The manganese content has varied from 0.1 to 0.8 mg/l. The water temperature (26-27 C^0) in all wells and river water did not vary with pumping time.

Hydrogeological characterization of the iron problem

The part of the well field where TW 04, TW 5, TW 8, TW 6, and TW9 are located has high concentration of total iron in the groundwater while the other part of the well field where TW 02, TW 3 and TW 7 are located, had low total iron concentrations. During the testing period, iron concentrations only in TW 4 has increased with the pumping time while Eh has decreased from positive to negative values. TW 5 showed negative Eh values and high iron concentrations (more than 3.00 mg/l) during the total test period. TW 2 and TW 03 showed low iron concentration (Fig 4.12) while Eh had positive values. The river water also showed positive values of Eh and low iron concentrations (0.28 to 0.54) mg/l. The Eh and iron showed a negative relationship during the pumping period where total iron concentration was high when Eh was low. The pH and Eh values of all sources were plotted on the Eh –pH diagrams for a 10^{-6} molal solution of iron in Figures 2.5-a, b, c, d, and e.

All water samples other than samples from TW 5, occupied the position in the boundary of Fe^{2+} and Fe $(OH)_3$ in the Eh-pH diagram, whereas TW 5 occupied the Fe^{2+} zone (Fig 2.5-e). Samples of TW 4 in the early and latter part of the test occupied the boundary of $Fe^{2+}/Fe(OH)_3$ area and Fe^{2+} zone respectively (Fig 2.5- d). Groundwater from the TW 5 and TW 4 fell in the Eh-pH diagram towards the reduced zone while river water and water from TW 2 and TW 3 fell towards the oxidized zone, closer to the Fe^{2+} and ferric hydroxide boundary. Water from the oxidizing environments generally shows higher (positive) Eh value than those from the reduced environment (Fetter, 1993). Therefore in our study area the mobility of iron was taking place in the direction from reducing area to the oxidizing area. The groundwater inflow directions to the discharging wells and iron mobility directions were generally the same. In TW 4 iron content showed positive correlation with the pumping rate based on the step test results (Figure:2.6). This was mainly due to rapid groundwater flow in to well at high pumping rates where iron does not have enough time to be converted from soluble Fe^{2+} form to insoluble Fe^{3+} form. When the flow is slow iron can transform in to insoluble Fe^{3+} from while water is still on its way to the well within the aquifer. Therefore, most of the insoluble iron precipitates is trapped in the aquifer material, which is common in sand and silt.

According to the hydrogeological environment of the Gannoruwa well field, two zones can be identified using Eh-pH conditions; reducing zone area closer to the river and oxidizing zone area away from the river.

CONCLUSIONS

The study revealed that the iron content of groundwater from bore bole wells shows high levels close to the river gradually decreasing from the river. Iron mobility takes place in the direction of the groundwater flow from river towards the wells and the concentration increase with increasing flow rate. The distribution and enrichment of the iron in the groundwater are mainly controlled by the Eh-pH conditions. There are two groundwater environments identified in the study area; reducing environment close to the river and oxidizing environment away from the river.

The source of iron is dispersed iron bearing minerals in the aquifer materials and the iron from river water. According to the findings of the study, construction of new bore holes should be done on the oxidizing zone and rate of pumping should be controlled in order to get low iron concentration in pumping wells.

Reference

1)Fetter,C.W., 1993. Contaminant Hydrogeology. Macmillan Publishing Company,U.S.A.
2)Hem, J.D and Cropper, W.H., 1959., Survey of the ferrous-ferric equilibria and redox potential. U.S. Geological Survey water Supply Paper 1459-A.

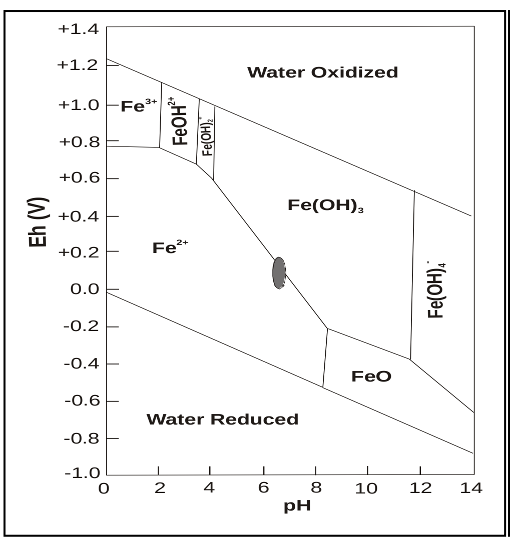


Figure (2.5-b): Stability relations for iron at 25⁰C, with 10^{-6} moles for River water

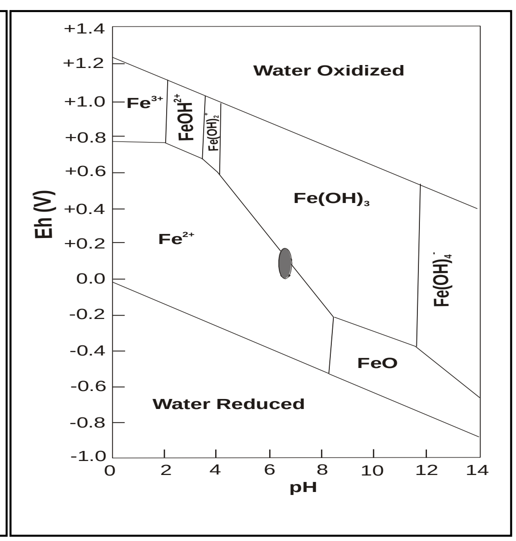
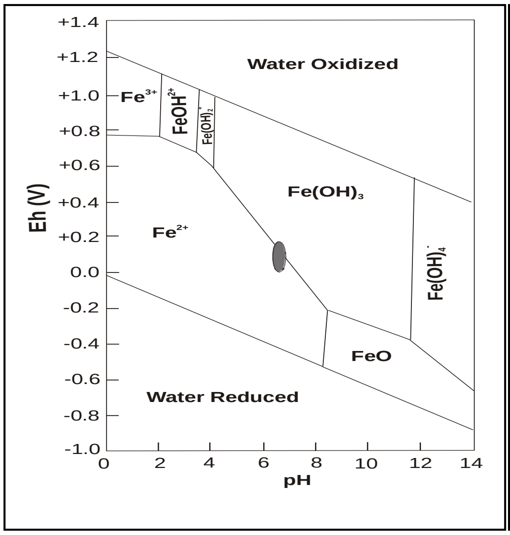


Figure (2.5-a): Stability relations for iron at 25⁰C, with 10^{-6} moles for TW 2.



Figure(2.5 d): Stability relations for iron at 25⁰C, with 10^{-6} moles for TW 4;A-early pumping(iron trapped in aquifer),B-late pumping (iron in solution).

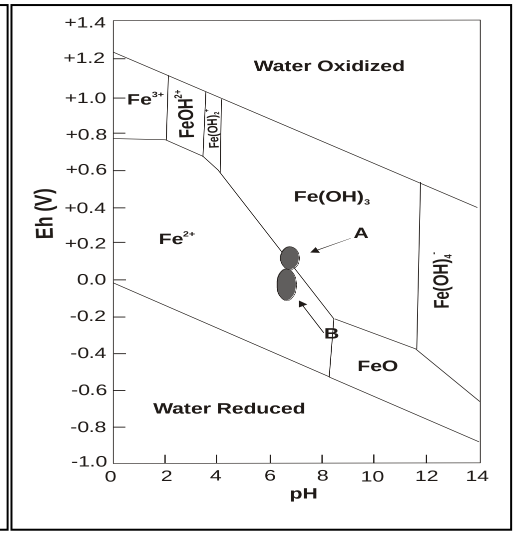
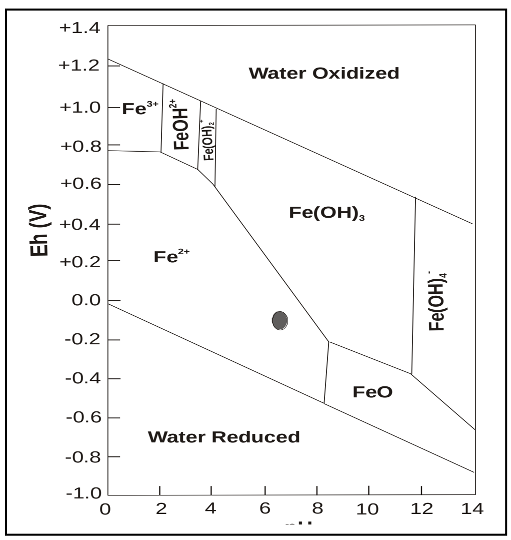


Figure (2.5-c): Stability relations for iron at 25⁰C, with 10^{-6} moles for TW 3.



Figure(2.5-e): Stability relations for iron at 25⁰C ,with 10^{-6} moles for TW 5.

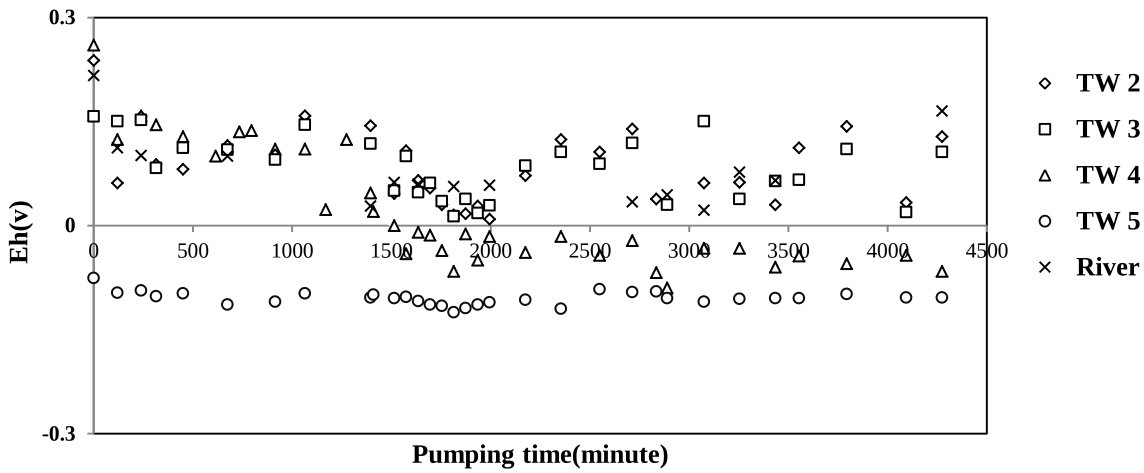


Figure (2.2)-Eh variation during the testing.

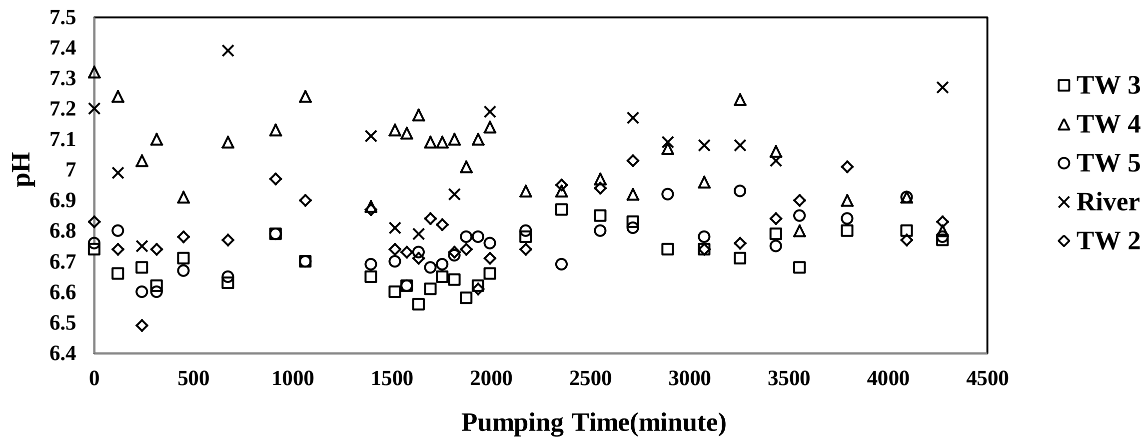


Figure (2.3)-pH variation during the testing.

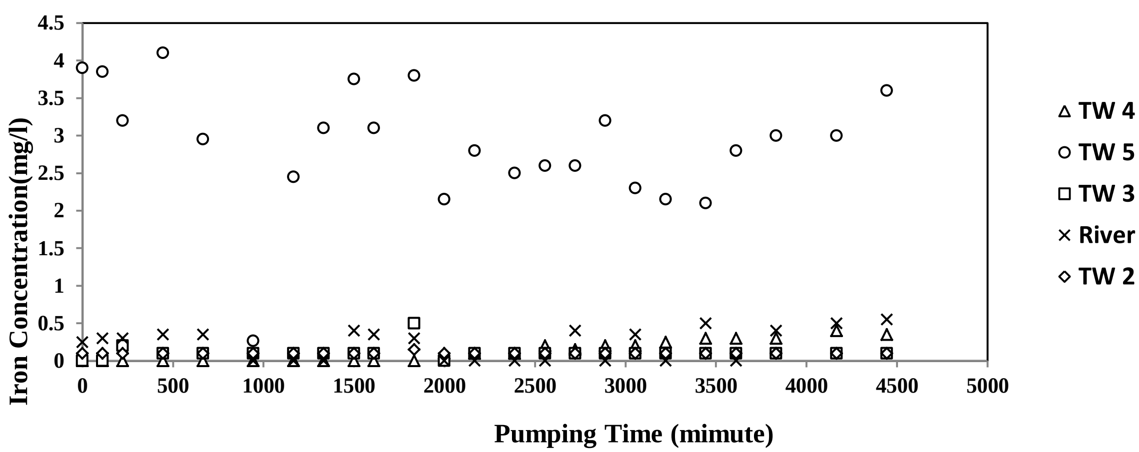


Figure (2.4): Iron variation during the testing.

Figure(1.1):Location map of Gannoruwa well field at Peradeniya.

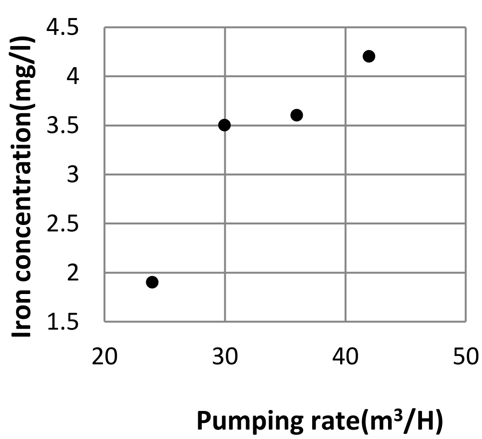


Figure (2.6): iron variation of TW 4 during step test.

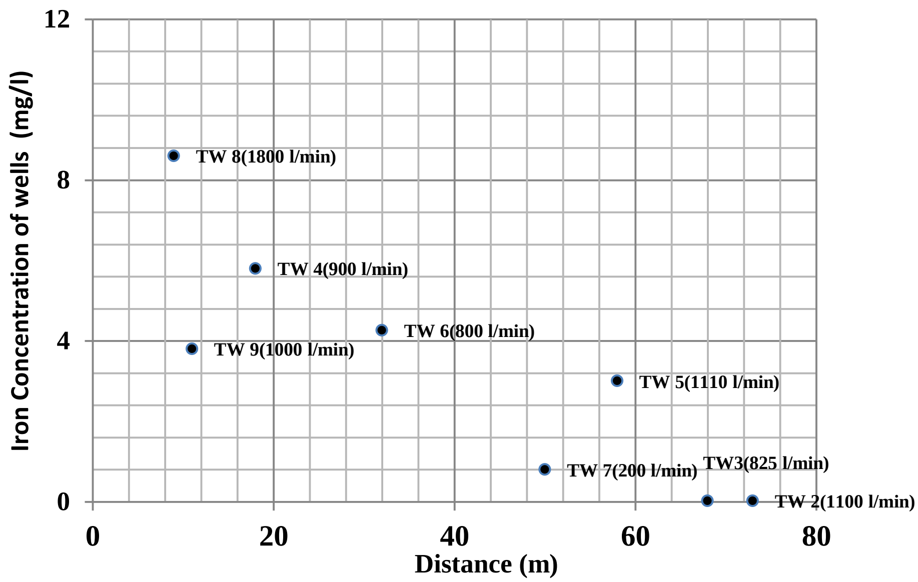


Figure (2.1): iron concentration of the wells under different pumping conditions and distance from the river.