Effectiveness of different spatial interpolators in estimating heavy metal contamination in shallow groundwater: a case study of arsenic contamination in Hanoi, Vietnam

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Abstract

Starting from emerging issues of arsenic contamination of groundwater, this study was conducted in Thanh Tri, a sub-urban district in southeastern side of Hanoi, in order to: (1) archive comprehensive understandings of arsenic contamination in shallow groundwater, (2) generate risk map and compare effectiveness of different spatial interpolation approaches including Kriging, IDW and Radial Basis Function of Geographic Information System (GIS) in estimating arsenic concentration.

The study found that the concentration of arsenic varied from 4.71µg/L to 394.93µg/L, with an average of 81.92µg/L, far higher than the standard of 10µg/L set by the World Health Organization. Distinct distributions of arsenic concentrations were observed for different geographical and geohydrological aspects. High arsenic concentrations were found mostly in the southwest of the study area and concentrations decreased gradually in other directions. Regarding geohydrological distribution, the upper aquifer (Holocene) yielded levels of arsenic ranging from 4.71µg/L to 316.67µg/L; while concentrations in the lower aquifer (Pleistocene) varied between 5.43µg/L and 394.93µg/L. The lowest arsenic concentration was found in the upper aquifer and the highest concentration was found in lower aquifer.

IDW gave the best prediction with an average error (MAPE) of 32.82%. An arsenic risk map was created from the IDW method. The map showed groundwater arsenic contamination and high contaminated areas in up to 99.8% of the district. The findings from this study will be valuable for households and policymakers to initiate early mitigation efforts and protect the population from chronic arsenic poisoning

Key words: Arsenic/ groundwater contamination/ GIS/ Kriging/ IDW/ Radial Basis Function

1. Introduction

Natural contamination of anoxic groundwater by arsenic has become a crucial water quality issue in many parts of the world. Recent studies report that the safe limit for arsenic in water supplies set by the World Health Organization (WHO) is 10µg/L, but 137 million people in all over the world drink water with arsenic content higher than that, meanwhile 57 million use water supplies with a level of 50µg/L or higher (Ravenscroft, 2007). The problem has been being alarmed more urgently supported by abundant evidences on human disease caused by arsenic toxicity. Chronic exposure to arsenic is a cause of reproductive, cardiovascular, respiratory, neurological, hepatic and haematological as well as diabetic effects. More dangerously, ingestion of arsenic can cause many kinds of cancer including bladder, lung and skin cancer.

Groundwater in Hanoi area was first exploited for water consumption in domestic and industry in 1909 (Nguyen et al., 2002). It has been extracted intensively to meet rapidly increasing

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water needs and recently become the main water supply at a production of 780,000 cubic meters per day (MONRE, 2009). Along with increasing water consumption, the problem of elevated arsenic concentration has been emerged and detected. The arsenic concentrations in the Hanoi area are varied from 1 to 3,050µg/L in private tubewell water samples with an average of 159µg/L (Berg et al., 2001). High arsenic concentrations denote that some million people using untreated groundwater are at risk of chronic arsenic poisoning.

Obviously, arsenic is poisonous and millions of people are suffering its effects. However, arsenic analysis is time consuming and costly, so that groundwater sources of many regions still remain to be tested. Even in the place that arsenic contamination has been studied over a long time. The results of those studies just only showed arsenic concentration in very few randomly tested points while inhabitants need exactly the information about their residential places. Hence, pinpointing maps of arsenic contamination covering over areas are necessary to be established.

2. Research Methodology

This research mainly aims at comparing different spatial interpolation methods in GIS environment for estimating arsenic contamination in residential groundwater. 72 groundwater samples were taken from private tube-wells over the whole district based on the theory of Systematic Random Sampling (1 sample in each 1km x 1km block). Generally, crystal clear water samples were collected in 500mL plastic bottles and acidified with 5mL of hydrochloric acid 2M, then they were analyzed by using Silver Diethyldithiocarbamate Method. Results from 60 samples were conducted to interpolate by Ordinary Kriging, Inverse Distance Weighting (IDW) and Completely Regularized Spline method. The remaining results from 12 samples were used for validation step. Thus, error, absolute percent error and Mean Absolute Percent Error (MAPE) were identified and MAPE was employed as the criteria for choosing the best interpolator. The best interpolator is which yielded the lowest MAPE value. Finally, results were illustrated by the arsenic risk map of the study area.

3. Results and Discussion

3.1 Arsenic concentration

In this research, Arsenic concentrations were divided into 7 levels in which the first level is below 10µg/L, the threshold set up by the WHO as well as recent Vietnamese drinking water standard; and the second level is from 10µg/L to 50µg/L, the previous drinking water standard of Vietnam and currently used in many other countries such as India, Bangladesh and Cambodia. The highest class was set at over 300 microgram of arsenic per litter.

It was noticed that 100% of samples have detectable concentration of arsenic. In general, arsenic concentration varies from 4.71µg/L to 394.93µg/L with the average of 81.92µg/L, far higher than the standard set up at 10µg/L. There were only 13 samples, accounting for 18.06% total number of samples, containing arsenic level less than 10µg/L, meanwhile the ratio of samples below another threshold of 50µg/L is 48.62%. The number of tubewells has concentration greater than 100µg/L, 150µg/L and 200µg/L was 17, 12 and 8, respectively. More considerably, it was found that 5 investigated tubewells reached highest class at more than 300µg arsenic per litter.

3.2 Geographical distribution of arsenic

There was a distinct geographical distribution of arsenic within the district as the map presented in figure 1. The Peak values of over 300µg of arsenic per litter were found in 3 communes namely Ta Thanh Oai, Vinh Quynh, Dai Ang in southwest and the lowest values of below 10µg/L were found in Tan Trieu, Thanh Liet, Tam Hiep in the north and in Dong My, Duyen Ha, Tu Hiep in the east of the district. It was recognized that the areas with high arsenic concentration were located near the rivers, which have been being heavily contaminated by waste water and solid waste from the upstream areas in the Hanoi urban districts. These areas were also surrounded by large paddy fields. In contrast, the areas where industrial factories concentrate on such as Van Dien, Thanh Liet were affected by a lower level of arsenic with an average of below 100µg/L in fact. This finding seems to indicate that heavy pollution of surface water i.e. river water in this case has strong influences on the level of groundwater contamination.

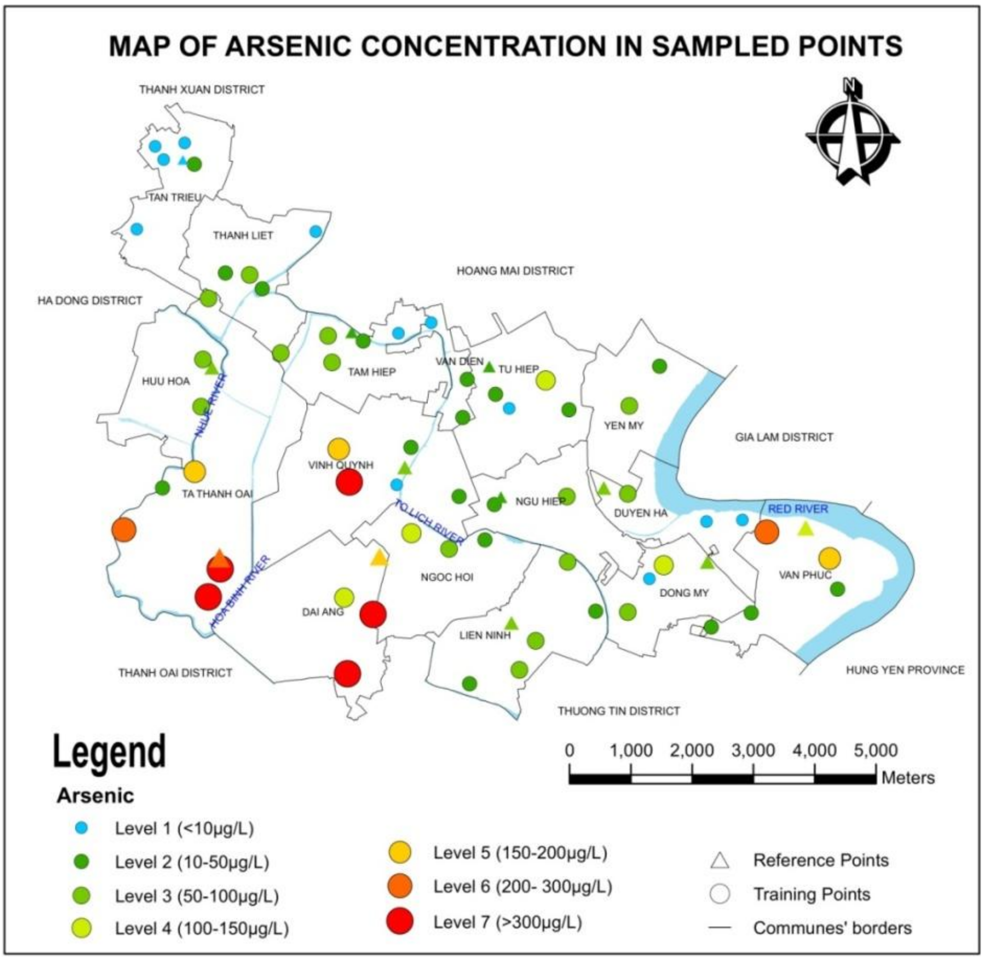

Figure 1 Arsenic concentration in sampled points

3.3 Geological distribution of arsenic

Tubewells in Thanh Tri district are usually opened to 2 shallow aquifers namely Holocene and Pleistocene. In this study, based on the map of hydro-geology and depth of wells, it was recognized that 37 out of total 72 investigated tubewells were opened to Holocene aquifers and the remaining 35 tubewells were opened to the Pleistocene one. The concentrations of arsenic in the 2 aquifers were relatively different. The Holocene aquifer yielded the level of arsenic from 4.71µg/L to 316.67µg/L with an average of 78.10µg/L, while the concentration in lower aquifer (Pleistocene) varied between 5.43µg/L and 394.93µg/L with a higher average (85.96µg/L). Notice that the lowest arsenic level was found in upper aquifer and the highest one was found in lower aquifer.

In Holocene aquifer, 32 out of 37 wells are contaminated by arsenic levels over the standard of 10µg/L and 22 wells had concentrations exceeding 50µg/L. The number of wells exceeded 100µg/L and 200µg/L were 8 and 3, respectively. Only one well was contaminated by arsenic level greater than 200µg per litter.

In Pleistocene aquifer, as noted earlier, the presence of arsenic is different from in the Holocene one. In fact, 27 out of 35 investigated wells presented arsenic level over the threshold of 10µg/L and only 15 wells, making up less than 43% total number of wells, surpassed 50µg/L. However, the number of wells exceeded 100µg/L and 200µg/L were 9 and 5, respectively, more than in Holocene aquifer. More noticeably, 4 out of 5 wells in highest level (over 300µg/L) were opened to this aquifer.

3.4 Spatial Interpolation

Interpolated surfaces produced from the three interpolators are presented in figure 2 and the calculation of affected area is given in Table 1.

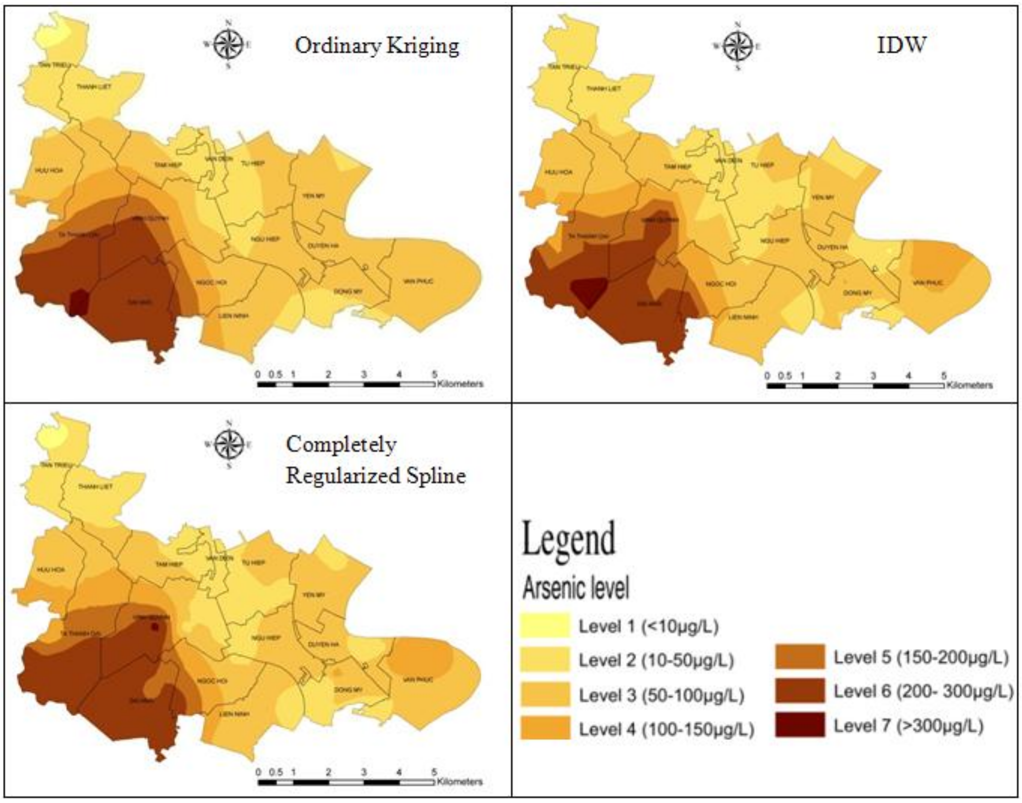

Figure 2 Surfaces of arsenic concentration produced by the three interpolators

In general, these methods seem to focus on the range from 10µg/L to 300µg/L, thus only a small area of the district (approximately 1%) was predicted to be outside this range. According to all of these interpolators, level 3 of arsenic contamination (from 50µg to 100µg per litter) dominated approximately a half district, whereas about 20% to 25% area of the district was found under threat of arsenic level 2 (from 10µg to 50µg arsenic per litter). The area affected by level 4 and level 5 of arsenic concentration were from 8% to 11% and from 5% to 7% area of the whole district respectively. More considerably, around 14% to 17% area of the district was contaminated by arsenic concentration level 6 (from 200µg to 300µg per litter).

Overall, though each interpolator has a different prediction, it can be concluded that majority of groundwater in the study area is heavily contaminated. The hotspot of arsenic occurs in Ta Thanh Oai, Vinh Quynh and Dai Ang, meanwhile the lowest level of arsenic can be found in Van Dien, Tu Hiep and Tam Hiep commune.

Table 1 Calculation of area affected by different arsenic levels

Arsenic concentration	Ordinary Kriging		IDW		Completely Regularized Spline	
	Area (ha)	% of Area	Area (ha)	% of Area	Area (ha)	% of Area
Level 1 (<10 µg/L)	58.16	0.91	1.28	0.02	45.99	0.72
Level 2 (10-50 µg/L)	1330.7	20.93	1631.0	25.65	1596.9	25.12
Level 3 (50-100 µg/L)	2962.2	46.59	2674.5	42.07	2539.7	39.95
Level 4 (100-150 µg/L)	514.33	8.09	637.86	10.03	733.3	11.53
Level 5 (150-200 µg/L)	375.81	5.91	449.53	7.07	397.51	6.25
Level 6 (200-300 µg/L)	1078.7	16.97	898.8	14.14	1040.2	16.36
Level 7 (>300 µg/L)	38.02	0.6	65.02	1.02	4.35	0.07
Total	**6358.0**	**100**	**6358.0**	**100%**	**6358.0**	**100**

3.5 Verification of interpolation

All predictions of 3 interpolators were validated by using 12 reference points which were determined randomly all over the whole district and named R_i (i=1, 2,...,12). Validation process evaluated each method by comparing predicted value and measured value of every reference point. Thus, error, absolute percent error and Mean Absolute Percent Error (MAPE) were identified and MAPE was employed as the criteria for choosing the best interpolator. The best interpolator is which yielded the lowest MAPE.

Results of verification showed that, Ordinary Kriging, IDW and Completely Regularized Spline had very accurate predictions for several points i.e. R_2, R_3 with Absolute percent errors below 5%. In general, most of Absolute percent errors were smaller than 30% except errors of prediction of point R_{11} was greater than 230%.

To sum up, all of the three employed interpolators were relatively accurate with average errors (MAPEs) of less than 40%. Among these, IDW was the best interpolator with an average error (MAPE) of 32.82%, followed by Completely Regularized Spline and Ordinary Kriging with MAPE values of 35.75% and 37.14% respectively

3.6 Arsenic risk map of the study area

Based on prediction of IDW, the best interpolator in this case study, an arsenic risk map of Thanh Tri district was established as presented in figure 3. The map shows highest arsenic concentration over 300µg/L in southwest and the concentration decreases gradually towards north, northeast and east portion of the district, except an occurrence of high concentration in Van Phuc commune in southeast. It is necessary to consider that the hot posts of arsenic are in Vinh Quynh, Dai Ang and Ta Thanh Oai communes where 2 seriously polluted rivers namely Nhue and Hoa Binh flow through. The communes at lowest risk are Tan Trieu and Thanh Liet in the north and Van Dien, Tu Hiep in middle of the district.

Considering affected area, according to the map, almost all area of the district (99.8%) is effected by an arsenic concentration over the WHO's standard of 10µg/L, while the area threatened by arsenic level over another threshold of 50µg/L is approximately 58% area of the district. This finding warns that most shallow groundwater in the study area is unsafe for residential use, especially for drinking purpose.

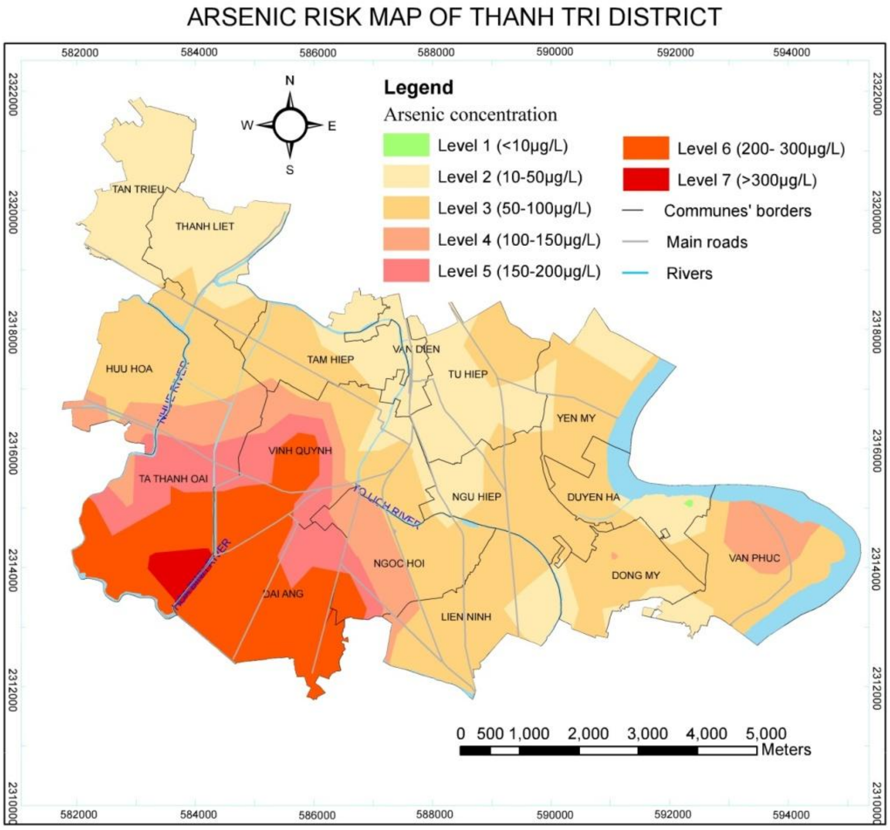

Figure 3 Arsenic risk map of Thanh Tri district

4. Conclusion and recommendation

As the results showing above, majority of investigated tube wells in the study area are affected by an arsenic level exceeding the standard. This problem has been being alarmed since the last 10 years and this study once again affirms that more than 80% of households are probably using unsafe water.

In this study, though three employed interpolators had different performances and yielded different predictions, these methods were relatively accurate, especially IDW. This finding is somewhat similar to other studies which also found that geostatistical approach is acceptably suitable for estimating concentration of heavy metal in soil and groundwater. Therefore, the result of interpolation indicating most of area of the district is under threat of high arsenic level is believable.

The finding of this study has pointed out the areas at risk of arsenic contamination. It will be valuable for households as well as researchers and policy-makers, to initiate early mitigation extents and protect the populations from chronic arsenic poisoning. There should be more studies in this area regarding high arsenic contamination issue, especially on the effects of arsenic exposure on human health. On the other hand, government should firstly prevent and mitigate the effects of arsenic by providing clean water for local people. Furthermore, raising residents' awareness about the arsenic contamination problem in their groundwater through public educational programs and schools is also necessary.

On the other hand, although spatial interpolation technique has been applied and assessed to a case study in Vietnam, the specific approach formulated herein is general and is expected to have applications in other countries where arsenic contamination of groundwater is widespread. These countries could conveniently assess the utility of a simple interpolation approach such as IDW in a fashion similar to what was reported in this study for deriving preliminary yet cost-effective management strategies of their groundwater resources until a long-term complete solution is implemented.

5. References

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