CHAPTER 6

INTERPRETATION AND CONCLUSIONS

Vulnerability assessment mapping in Chiang Mai basin was completed using seven hydrogeological parameters with the DRASTIC method which was selected as most appropriate for constructing the aforementioned map. The parameters used in calculation are summarized as follows:

Depth to groundwater table; used drilled depth less than 100 meters.

Net recharge; used wet period of rainfall as net recharge.

Aquifers types; used re-grouped aquifers.

Soil types; used soil modification of soil classification.

Topography; used derived slope (in percent) from contour lines and spot height elevation.

Impact of vadose zone determined from drilled logs.

Hydraulic conductivity values obtained from pumping test method.

All parameters were compiled in the ArcView® program as a grid file and were ranged and rated according to DRASTIC ranges and rated tables. The vulnerability index value was determined using the equation below (Aller and others, 1987).

V = (Depth100rate*5) + (Rainrate*4) + (Aquirate*3) + (Soilrate*2) +
(Toporate) + (Imvadosrate*5) + (Condrate_kj*3) **(6-1)**

Where:

Depth100rate	= Depth to groundwater at drilled depth less than 100 m.
Rainrate	= Net recharge of the wet period rainfall.
Aquirate	= Aquifer media.
Soilrate	= Soil media.
Toporate	= Topography.
Imvadosrate	= Impact of vadose zone.
Condrate_kj	= Hydraulic conductivity determined by THEIS method.
Number	= Weight of vulnerability index

V = Vulnerability index value.

The 0Map Calculator in the ArcView® program automatically calculated the vulnerability index grid map of 100*100 meters cell size and assigned each value to 9 equal classes (Figures 6.1 and 6.2), ranging from 68 to 194, and re-classified them into 5 equal classes corresponding to DRASTIC classifications, very low, low, medium, high, and extremely high vulnerability. (Figures 6.3 and 6.4). The assigned colors for the vulnerability index map were identical to those described in standard vulnerability mapping (Jaroslav and Alexander, 1994).

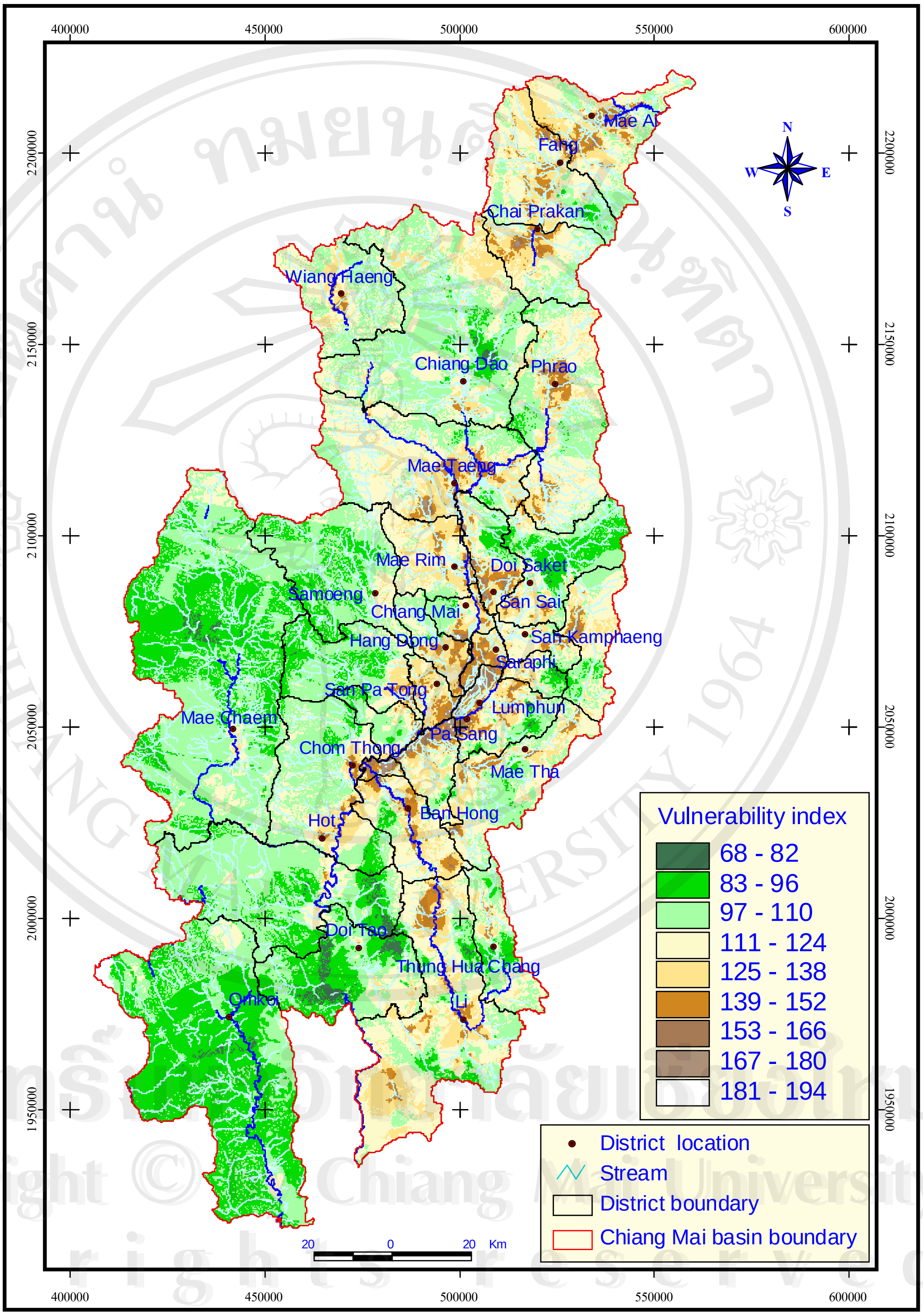

Figure 6.1 Vulnerability index map of Chiang Mai basin.

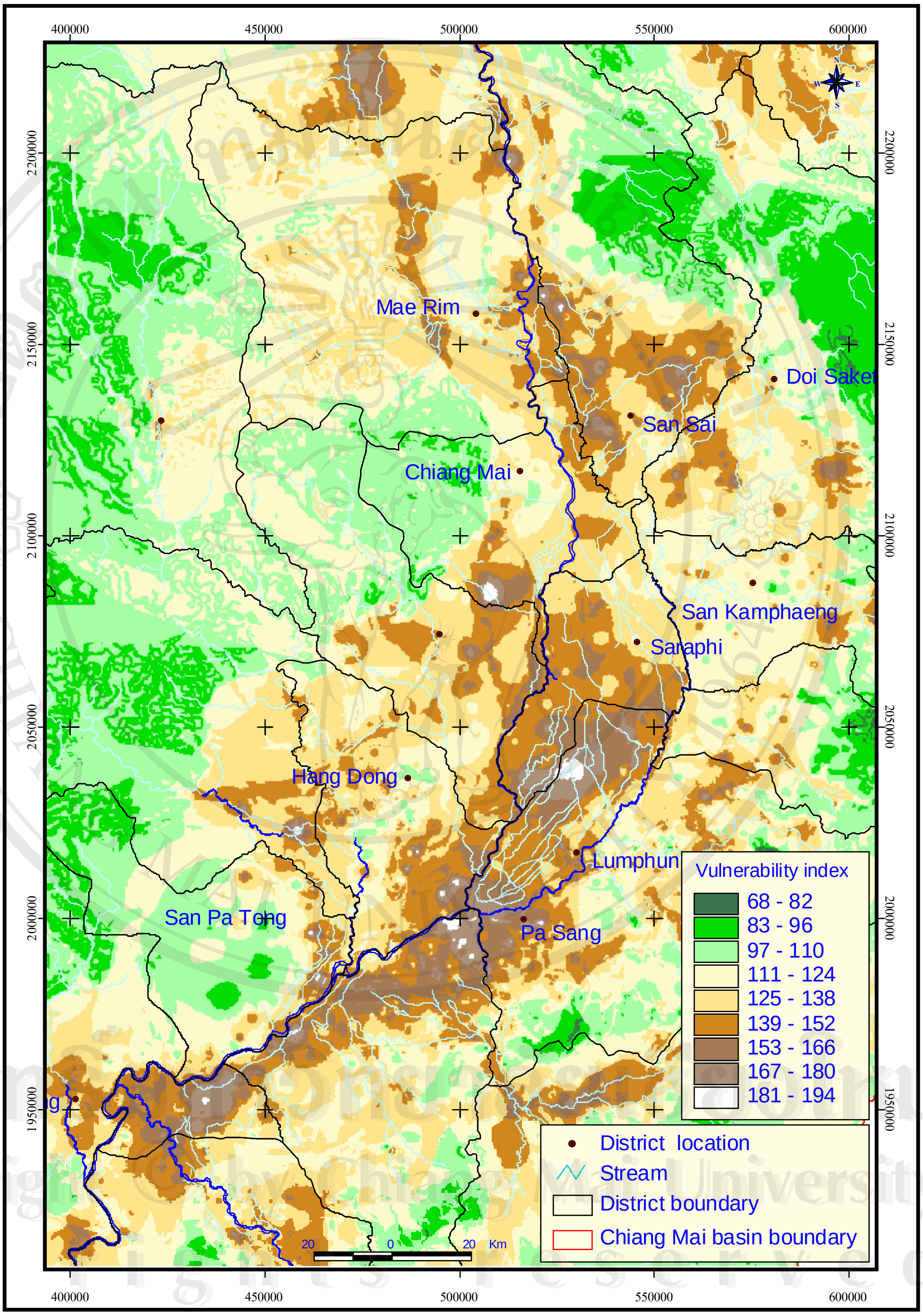

Figure 6.2 Vulnerability index map of Chiang Mai basin (in unconsolidated aquifers).

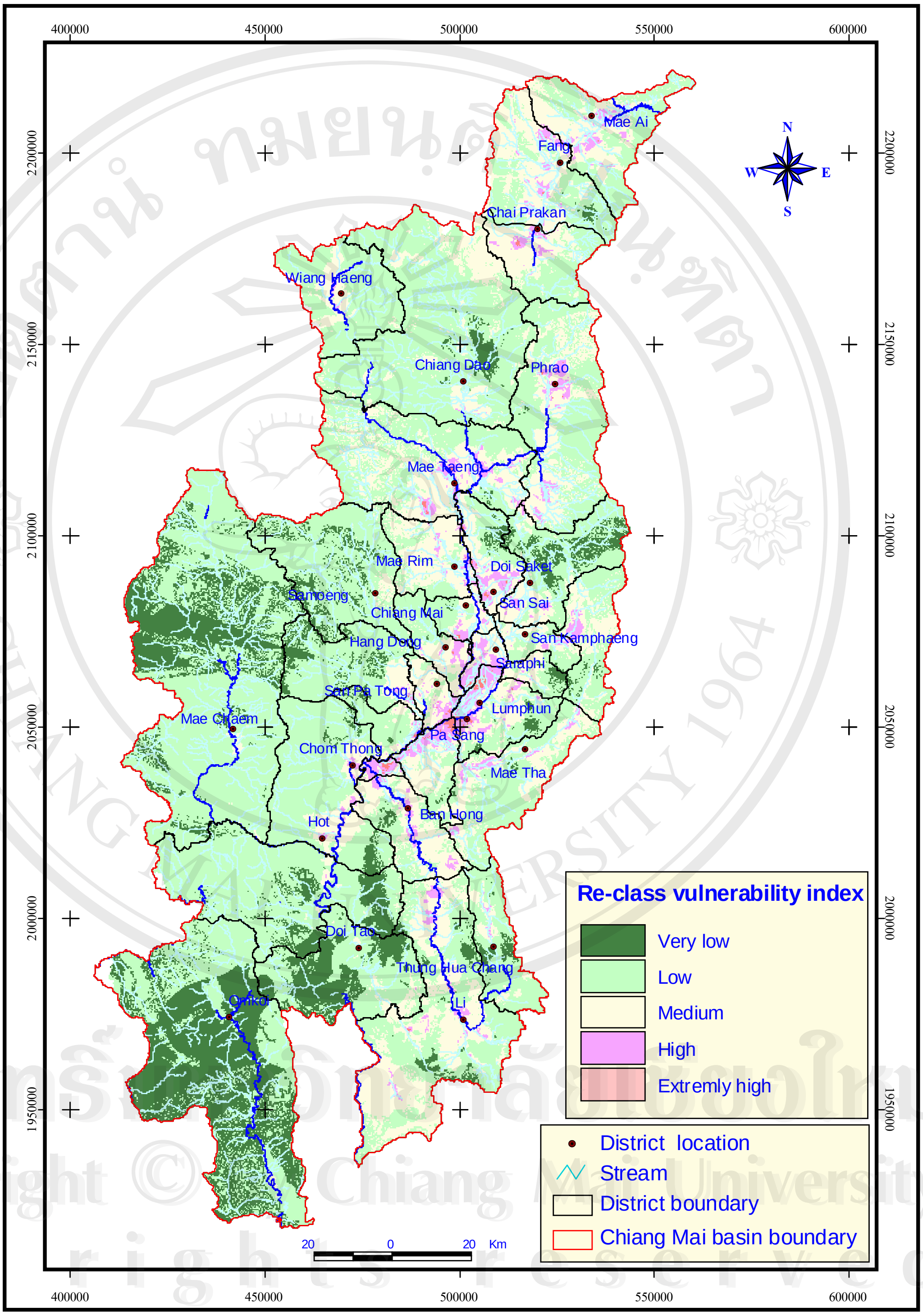

Figure 6.3 Re-class vulnerability index map of Chiang Mai basin.

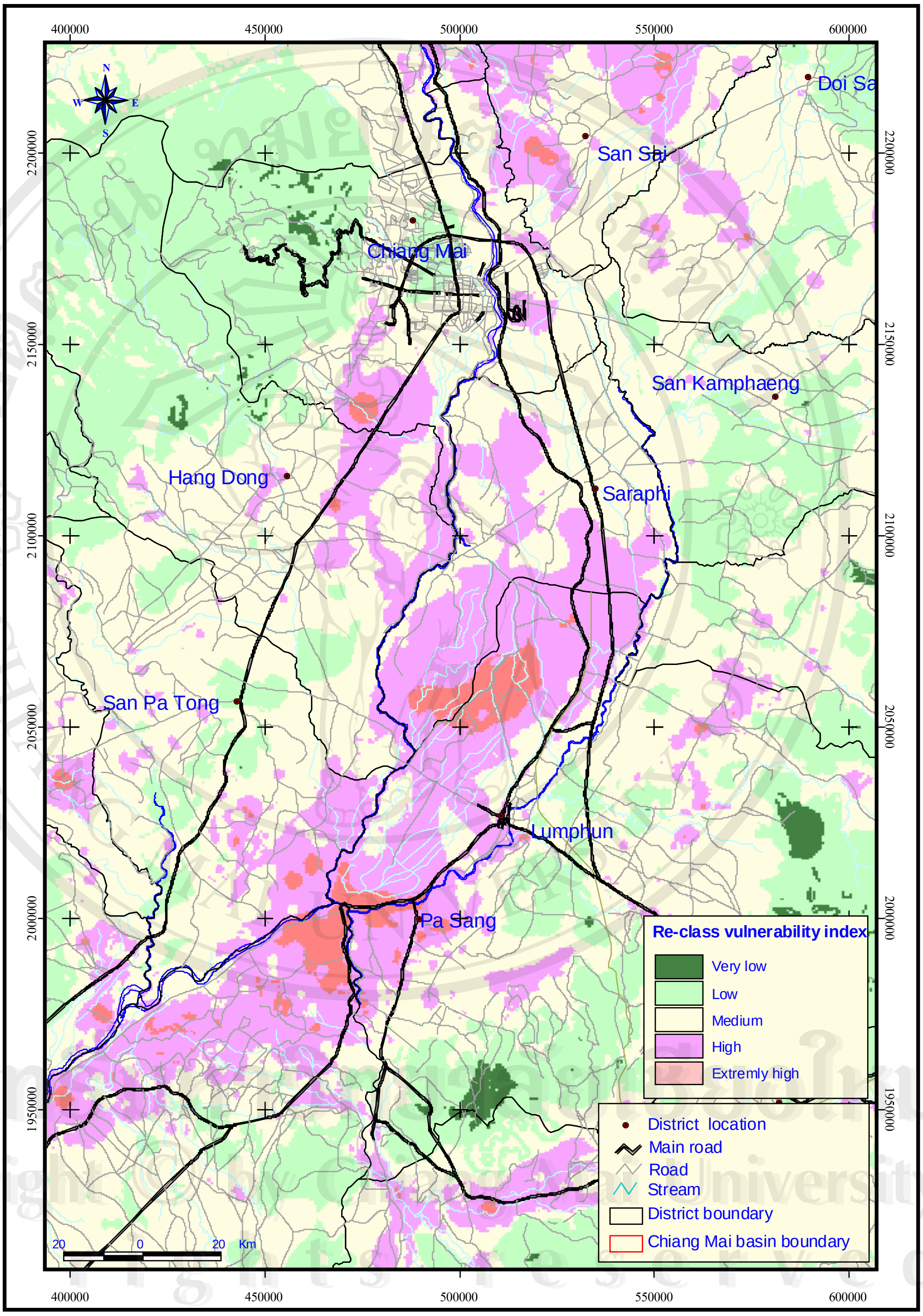

Figure 6.4 Re-classed vulnerability index map of Chiang Mai basin (in unconsolidated aquifers).

6.1 Vulnerability map

The vulnerability to contamination map shows high to extremely high vulnerable areas, from the north of Mae Ai district along the main rivers, especially Mae Ping River, and from Muang district, the central plain of Chiang Mai Province, downward to Pa Sang district of Lumphun Province. Most of the high vulnerable areas were in alluvium flood plains and low terrace aquifers the in San Sai and Sara Phi districts of Chiang Mai Province down to Pa Sang district of Lumphun Province. It can be seen that such areas met the criteria stated in the DRASTIC method, where high hydraulic conductivity (gravel and sand aquifers), flat terrain, high rate of recharge (high rainfall intensity), and low level of groundwater are present. The medium vulnerability areas are situated in high terrace aquifers which have a gentle slope, low permeability, and a lower intensity of rainfall. The other areas, low and very low vulnerability, are in mountainous areas (steep slope), deep groundwater levels, hard rock aquifers, and low hydraulic conductivity, all of which are characterized as having low vulnerability to contaminants.

6.2 Vulnerability map with Total Dissolved Solids from subsurface water

In order to compare the vulnerability index map with subsurface water, water samples of dug wells were taken for analyzing conductivity. Extremely high vulnerability area and low vulnerability areas in Sara Phi district; south of Chiang Mai Province, and Pa Sang district; north-west of Lumphun Province, were selected to check the degree of subsurface water contamination in the extremely high vulnerability and low to very low vulnerability areas. Forty two water samples from dug wells of those areas were measured in-situ for water conductivity, water acidity or water alkalinity (pH) by using conductivity and pH meters (Table 6.1).

Table 6.1 Conductivity and pH measurement locations.

Location	District	Province	Conductivity meter/day	pH	East	North
Wat Bo Haew	Pasang	Lumphun	1400	6.6	498368	2052021
Wat Bo Haew	Pasang	Lumphun	1068	7.2	498368	2052021
Wat Bo Haew	Pasang	Lumphun	1065	7.2	498035	2051627
Ban Bo Haew	Pasang	Lumphun	1055	7.6	498044	2051643
Sri yoi School	Pasang	Lumphun	350	7.2	497325	2050861
Wat Pan Ta Hoen	Pasang	Lumphun	766	7.3	495834	2050309
Pa Sang School	Pasang	Lumphun	954	7.1	492840	2047590
Ban Nong Hoi	Pasang	Lumphun	772	7.5	492250	2047564
Mae Rang Health Center	Pasang	Lumphun	876	7.2	491371	2047018
Wat Pa Haeng	Pasang	Lumphun	1123	7.5	490721	2046740
Wat Dham Sang Vech	Pasang	Lumphun	1083	7.8	489757	2048281
Wat Tha Ko Ngui	Pasang	Lumphun	1440	7.6	490735	2048867
Wat Chang Kao Nua	Pasang	Lumphun	817	7.7	493996	2046248
Wat Pa Tan	Pasang	Lumphun	408	6.8	493324	2043530
Wat Chang Kham	Pasang	Lumphun	695	6.9	490969	2041372
Ban Ban Nakhon Jedi 1	Pasang	Lumphun	295	7.5	488331	2040222
Ban Ban Nakhon Jedi 2	Pasang	Lumphun	295	7.2	488331	2040222
Wat Rong Ha	Pasang	Lumphun	560	7.9	488331	2040222
Wat Ban Ruan	Pasang	Lumphun	1176	8.3	487949	2045984
Wat ban Khu	Pasang	Lumphun	570	8.3	488941	2047762
Wat Sai Mun	Pasang	Lumphun	271	8.0	492705	2051365
Wat Mong Kon	Pasang	Lumphun	380	8.0	491584	2053638
Ban Ma Kham Luang	Pasang	Lumphun	904	7.0	491755	2053861
Wat Ton Kaew	Pasang	Lumphun	717	7.6	491200	2055370
Wat Kuan Nimit	Pasang	Lumphun	620	7.5	490121	2057699
Ban Hua Lim	Muang	Lumphun	580	7.7	500735	2065023
Nong Chang Kun	Muang	Lumphun	2300	8.8	501407	2064198
Ban Lam chang	Muang	Lumphun	1212	7.7	500897	2061239
Ban Pratu Pa	Muang	Lumphun	1467	7.9	500109	2059604
Wat Pratu Pa	Muang	Lumphun	579	7.6	500346	2059012
Wat Hua Luk	Muang	Lumphun	815	8.1	500136	2059840
Wat Nam Khong	Muang	Lumphun	974	7.8	500659	2061372
Wat Sri Sai Mun	Muang	Lumphun	621	7.5	501147	2062409
Wat Hua Fai	Muang	Lumphun	785	7.9	501359	2064316
Wat Pratu Pa	Muang	Lumphun	480	7.6	499511	2060792
Ban Wang Mui (1)	Muang	Lumphun	888	7.9	497692	2060085
Wat Chai Mong Kon	Muang	Lumphun	945	7.5	497436	2059686
Ban Wang Mui (2)	Muang	Lumphun	1041	7.3	496953	2058861
Wat Pa Kae	Muang	Lumphun	540	7.8	496451	2058172
Wat Bub Pha Ram	Sa Ra Phi	Chiang Mai	321	7.3	495710	2059427
Ban San Sai	Sa Ra Phi	Chiang Mai	572	8.0	496084	2060515
Wat Pa Sa	Sa Ra Phi	Chiang Mai	802	8.4	496339	2063892
Wat Hua Dong	Sa Ra Phi	Chiang Mai	323	7.8	497199	2063892
Ban Kua Mung	Sa Ra Phi	Chiang Mai	346	7.9	498387	2064568

Water conductivity results were then converted to TDS by multiplying by 0.65 (DGR, 2002). The TDS of subsurface dug wells was interpolated to grid-cell basis in three classes, 0-500 ppm, 500-750 ppm, and 750-1500 ppm, respectively (DGR, 2002). The TDS distribution map shows a significantly high TDS concentration (>750 ppm) in the areas from south of Sara Phi district and San Pa Tong district of Chiang Mai Province to Muang Lumphun district and Pa Sang district of Lumphun Province. TDS and vulnerability maps were overlaid on each other in order to compare the results (Figure 6.5).

The TDS map shows the high TDS area coincided with high and extremely high vulnerability areas of the vulnerability index map, except in the north-east of Pa Sang district where high TDS (750-1500 ppm) concentrations occured in medium vulnerability areas. This means that shallow aquifers were contaminated. The low concentration of TDS from dug wells were found outside the boundary of medium vulnerability area where these areas had low permeability and low recharge water.The areas of low TDSwas also a non-populated area with little human activity, hence a low TDS was to be expected.

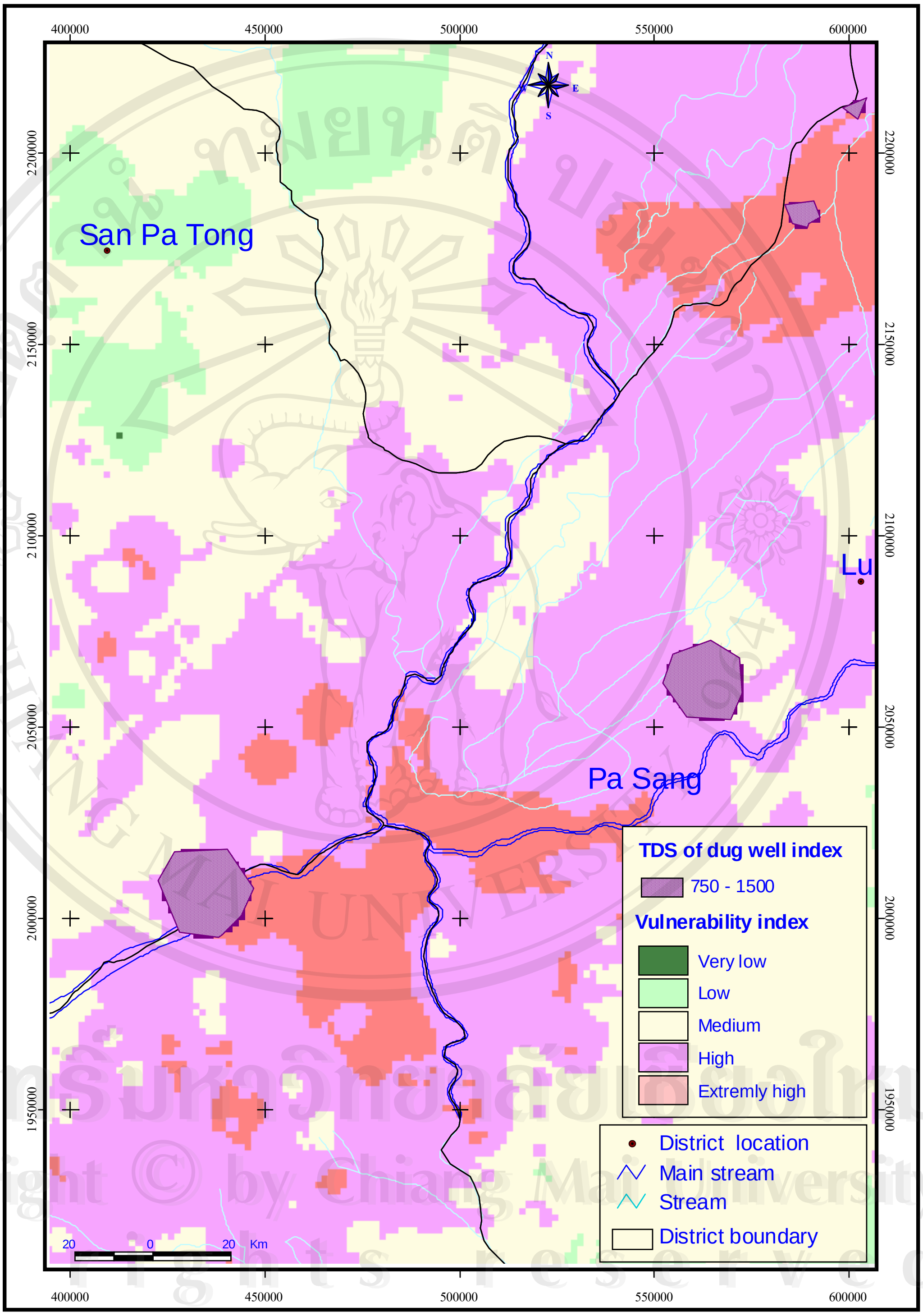

Figure 6.5 Vulnerability index map and TDS of dug wells of Chiang Mai basin.

6.3 Vulnerability map with Total Dissolved Solids from groundwater

Vulnerability maps from drilled depths <100 meters and net recharge from the wet period of rainfall were compared with the TDS distribution map. The TDS map from the depth <100 meter shows a slightly different result from the TDS from dug wells, TDS distribution from groundwater wells were scattered outside of the central of alluvium flood plain (Figure 6.6) where high vulnerability indices were located. The distribution of high TDS (750-1,500 ppm) was found mainly in the area outside of the flood plain of the Ping River and its tributaries in the medium vulnerability areas, from the south of San Sai district to Sara Phi district of Chiang Mai Province down to Pa Sang district of Lumphun Province.

High TDS groundwater was contaminated in low terrace aquifers and some parts of the flood plain aquifers. The TDS in flood plain aquifers had a lower concentration than in low terrace aquifers due to the fact that the drilled depths of low terrace aquifers were deeper than the flood plain aquifers. Consequently the contaminant took a longer time to percolate to low terrace aquifers and allow the contaminant to become absorbed and diluted. Moreover high recharge water from rainfall and direct recharge from rivers to flood plain aquifers was much greater than in low terrace aquifers, which causes shallow aquifers to be contaminated more rapidly than low terrace aquifers.

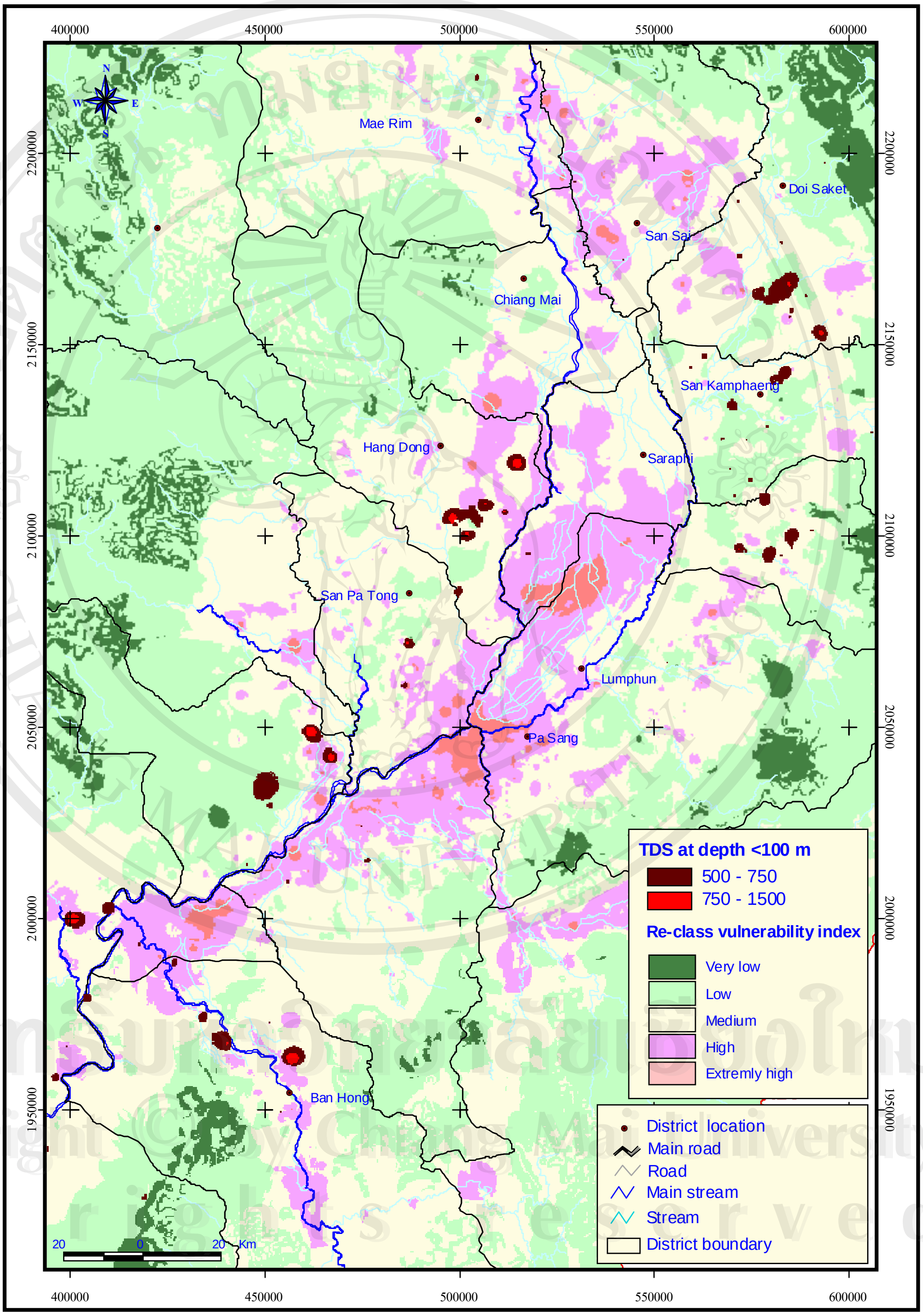

Figure 6.6 Vulnerability index map and TDS of drilled well of Chiang Mai basin.

6.4 Conclusions and recommendations

6.4.1 Conclusions

The vulnerability mapping by DRASTIC method employed seven hydrogeological parameters for generating a vulnerability map. The purpose of the DRASTIC method is to give a very general descriptions of hydrogeologic settings based on existing data and knowledge. The weight, range and rating of each parameter (Chapter 4) was assigned according to degree of vulnerability to contaminants.

The GIS computer base is an effective tool for analyzing and delineating vulnerability mapping. The vulnerability map is a relative for a partiuclar area compared with its vicinity area, thus it is not an absolute number. The map is applicable to the first encountered aquifers of alluvium flood plain deposits where the depth to groundwater level is the surface.High rainfall intensity, gently sloping terrain, and high permeability also influence vulnerability to contaminants.

The extremely high and high vulnerable areas in the Chiang Mai basin are situated along the Ping River and its tributaries which include the alluvium flood plain aquifers from the north, San Sai district, Meuang Chiang Mai district and Sara Phi district of Chiang Mai Province, and in the south, Meuang district and Pa Sang of Lumphun Province. The medium to very low vulnerable areas are located peripheral to the high vulnerable areas up to the rolling hills and mountainous areas with low groundwater yield, a very steep slope, and very low permeability.

The extremely high vulnerable areas were defined by a high concentration of Total Dissolved Solids of subsurface water from dug wells (shallow aquifers), while high TDS from deep groundwater wells were found only in the high vulnerable areas. This evidence shows that shallow aquifers are at high risk for contamination; therefore, groundwater protection and reservation is urgently needed in these areas and also in areas with extremely high vulnerability indices such as Sara Phi district of Chiang Mai Province and Pa Sang of Lumphun Province.

Data uncertainty is inherent in the process of groundwater vulnerability mapping. Many factors influence vulnerability indices, i.e. groundwater level, distribution of data, and methods of interpolation, extrapolation, and validating data.

To minimize data uncertainty, appropriate data and methods of analyzing data were carefully selected. The DRASTIC method states that the first encountered aquifer was more vulnerable than deeper ones. Thus, shallow groundwater wells of less than 100 meters were selected. Other parameters were used as modified data sets.

6.4.2 Recommendations

The DRASTIC method employes seven parameters for vulnerability index mapping which are relatively simple and straightforward. However,the range and rating of each parameter is scored relative to the degree of contaminantion which is assigned based on certain conditions in an area. To assure that the interrelations between parameters are valid the rating scales for the parameters have to be sensitive enough to display variations in each parameter between different hydrogeologic settings. However, they cannot be too detailed as they must be developed with incomplete hydrogeological information and the groundwater vulnerability to contaminant classification. This rating scores must be assigned by hydrogeologists familiar with the area of investigation.

Data used in GIS is digital form, a shape file of the ArcView@program with spatial analyst function and 3-D modules were employed in groundwater vulnerability assessments. Large amounts of data sets and differing sources of data are problems in the use of the DRASTIC method. Hydrogeological information systems and database systems must be well designed and easy to retrieve.

The DRASTIC method is not popular in Thailand due to the lack of appropriate digital data maps. Hardcopy maps are time consuming to convert to digital form and result in inaccurate data. Therefore large amounts of same scale digital data is needed to analyze accurate vulnerability map locations.

Uncertainty in input data affects groundwater vulnerability mapping. Range and rating of parameters were modified from standard guide books which were carefully determined as following:

Groundwater level is the most sensitive parameter while net recharge and hydraulic conductivity also play a major role in DRASTIC vulnerability mapping. Groundwater monitoring of identical aquifers was required in order to get more accuracy in vulnerability mapping. Seasonal groundwater level fluctuation is a major cause of data uncertainty. To overcome this, the same period for groundwater sampling was used. More frequent groundwater data collection is also useful for following up groundwater contamination mapping.

Net recharge is derived on the basis of annual rainfall. It plays a major role in the DRASTIC vulnerability mapping method. Due to limited rain gauge stations, only 60 rain gauge stations were used to evaluate the distribution of net recharge in the Chiang Mai basin. This may introduce error in interpolation to the areas with no available data. More rain gauges and proper locations are needed in order to get better resolution. Monthly or seasonal rainfall may be used to evaluate sensitivity of the vulnerability index, especially in the high and extremely high vulnerability areas. The net recharge depends on elevation, geology and vegetation of the area. As a result, the mathematical interpolation method is not suitable for determining the net recharge of the area. More accurate methods should be considered to evaluate recharge.

Detailed mapping of the governing parameters in DRASTIC method, such as hydrogeological maps and soil maps, should be converted into the same scale. The hydrogeological map was derived from the geological map at the scale of 1:500,000 and was simplified to the hydrogeological map at the scale of 1:100,000. This may have caused error in ranges and ratings of vulnerability areas.

Hydraulic conductivity is based on the results of groundwater pumping tests of aquifers and also may have caused uncertainty in groundwater vulnerability assessments. The production wells used were the same as the pumping wells and no available observation wells from the same aquifer was used in calculation. This data was used to estimate hydraulic conductivity. Most of the pumping test wells were measured using the Aquitest software which is automatically calculated for transmissivity and hydraulic conductivity. There is some uncertainty in calculation due to improper data sampling during manual groundwater table collection. More expertise is needed for more accurate results. The same aquifer or the same depth should be used in conducting groundwater vulnerability assessment mapping. Fully penetrating aquifer thickness is preferable to partial penetrating thickness in order to get more accurate meausures of hydraulic conductivity where thickness of aquifer is involved.

The extremely high and moderately high vulnerability area warrant immediate action whereas low and moderate vulnerability areas require detailed site investigation and monitoring. A groundwater protection program should be initiated in at risk areas with large populations.