CHAPTER 4

GROUNDWATER VULNERABILITY MAP OF PHUKET ISLAND

The main features of groundwater vulnerability map of Phuket island resulted from a DRASTIC analysis include seven parameters: depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. Details of these parameters are described in the following sections.

4.1 Depth to water table

In preparing the vulnerability map of Phuket island, the data on depth to water table were taken from those of the Department of Mineral Resources, because these data are more extensive and are representatives of the depth of groundwater in the aquifers. The data from field observation collected from shallow dug-wells probably include some that represent non-real groundwater such as the water in vadose zone or perched aquifer. A depth to water table has the most significant effect to the DRASTIC analysis. This is the distance in meters, measured from the ground surface to the water table. This parameter determines the thickness of material through which a contaminant travels before reaching the aquifer. The weight of depth to water table is assigned as 5. The range and rating of the depth to water table is shown to be less than 3 m in the Holocene aquifers (Qbs, and Qfd), and more than 15 m in Pleistocene aquifers (Qcl) and weathered consolidated rocks. Due to the fact that this parameter is relatively important to the analysis, therefore it was given a highest weight. As a consequence, the resulting calculated values of the groundwater pollution potential are rather high, i.e. 50, 40, 30, 20, and 10.

4.2 Net recharge

From the investigation of the underground dam project by the Royal Irrigation Department in 1996 using a water balance method, groundwater recharge in Phuket island was estimated at about seven percent. The aquifers, mainly unconfined aquifers, receive a direct recharge from rain water. As the net recharge is proportional to rainfalls, therefore, annual rainfalls recorded during the period 1964 to 2003 were used in the DRASTIC analysis. On Phuket island, there are four meteorological stations located at Phuket Airport in the northwest, Thalang district in the northeast, Bang War Dam in the southwest, and Muang Phuket in the southeast. The weight of net recharge parameter is given as 4 (moderately high). The calculated values of this parameter are 40, 32, 24, and 16.

4.3 Aquifer media

The aquifer media was defined by hydrogeological map of the Department of Mineral Resource (1993). The aquifers in Phuket island were divided into five groups; including colluvium aquifers (Qcl), floodplain aquifers (Qfd), beach sand aquifers (Qbs), sedimentary or meta-sedimentary aquifers (PCms), and igneous rocks (Gr). The importance weight of the aquifer type parameter is assigned to be 3 (moderate). Calculated values of this parameter are 24, 21, 18, 12, and 9.

4.4 Soil media

Soils have a significant impact on the amount of recharge that infiltrates into the groundwater system. In Phuket island, the soil media map was compiled by approximating soil permeability and the map was produced using for soil landform information. The soil media map has been classified into ranges where high permeability is associated with higher pollution potential and low permeability is associated with lower pollution potential. The soil type parameter was assigned a weight of 2. The index values from the calculation are low, i.e. 20, 16, 12, 8, and 4, depending on the soil groups.

4.5 Topography

A north-south trending mountainous area occupies the western part of Phuket island. Slope steepness expressed in percent were calculated using in ArcView software and slope steepness was then classified and ranked for the later use in the topographic component map. The topographic index values are still low compared with the indices of other parameters. The weight of this parameter was assigns as 1. The slope steepness ranges from 0 to 67 percent and the majority of the slopes range from 0-10 percent. The index values of topography are 10, 8, 6, 4, 2, and 1.

4.6 Impact of vadose zone

A process for interpreting the impact of vadose zone by DRASTIC was defined by hydrogeological conditions. The hydrogeological units were grouped into six groups, including colluvium deposits (Qc), floodplain deposits (Qf), beach sand deposits (Qb), mangrove deposits (Qm), sedimentary or meta-sedimentary rock (PC) and igneous rocks (K). The weight of the impact of vadose zone parameter is assigned as 5 (high). The calculated values of this parameter are 40, 35, 30, 25, 20, and 15.

4.7 Hydraulic conductivity

The hydraulic conductivity is significant such that it controls the rate at which water flows horizontally through an aquifer. The hydraulic conductivity map of Phuket island is based on the pumping test data conducted by the Royal Irrigation Department. It is noted that the higher the hydraulic conductivity the higher the vulnerability of that particular aquifer. The hydraulic conductivity parameter was assigned a weight of 3. The index values from the calculation are moderate, i.e. 30, 24, 18, 12, 6, and 3.

4.8 DRASTIC analysis of Phuket island

In case of Phuket Island, the seven parameters, which were deemed important in the construction of the groundwater vulnerability map, were analyzed and shown as the maps of depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity, respectively. The DRASTIC indices in terms of weight, range, and rating of seven parameters are shown in Table 4.1. The seven prepared maps of the DRASTIC analysis are shown in Figure 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, and 4.7, respectively.

Table 4.1 DRASTIC indices of Phuket island.

Parameter	Description	Range	Rating	Weight	Value
D: Depth to water table		<3 m	10	5	50
		3-6 m	8	5	40
		6-9 m	6	5	30
		9-12 m	4	5	20
		>12 m	2	5	10
R: Net recharge	Phuket Airport	2,627 mm/y	10	4	40
	Bang War Dam	2,394 mm/y	8	4	32
	Muang Phuket	2,291 mm/y	6	4	24
	Thalang	2,237 mm/y	4	4	16
A: Aquifer media	sand, coarse to fine grained, well sorted	Qbs	8	3	24
	gravel, sand, silt, clay, and minute size of rock debris	Qfd	7	3	21
	gravel, sand, clay, laterite, and rock fragment, poorly sorted	Qcl	6	3	18
	pebbly mudstone, mudstone, siltstone, graywacke, quartzitic sandstone, phyllitic shale, and slaty shale.	PCms	4	3	12
	granite	K	3	3	9
S: Soil media	rapid to very rapid	>3 m/day	10	2	20
	moderately rapid	1.50-3 m/day	8	2	16
	moderate	0.48-1.50 m/day	6	2	12
	moderately slow	0.12-1.50 m/day	4	2	8
	very slow to slow	<0.12 m/day	2	2	4
T: Topography	slope steepness (%)	<10 %	10	1	10
		10-20 %	8	1	8
		20-30 %	6	1	6
		30-40 %	4	1	4
		40-50 %	2	1	2
		>50 %	1	1	1
I: Impact of vadose zone	sand	Qb	8	5	40
	sand and gravel	Qf	7	5	35
	sand and gravel with significant silt and clay	Qc	6	5	30
	pebbly mudstone, mudstone, siltstone	PC	5	5	25
	weathered granite	K	4	5	20
	sand and clay	Qm	3	5	15
C: Hydraulic conductivity		>0.083 mm/day	10	3	30
		0.066-0.083 mm/day	8	3	24
		0.050-0.066 mm/day	6	3	18
		0.033-0.050 mm/day	4	3	12
		0.017-0.050 mm/day	2	3	6
		<0.017 mm/day	1	3	3

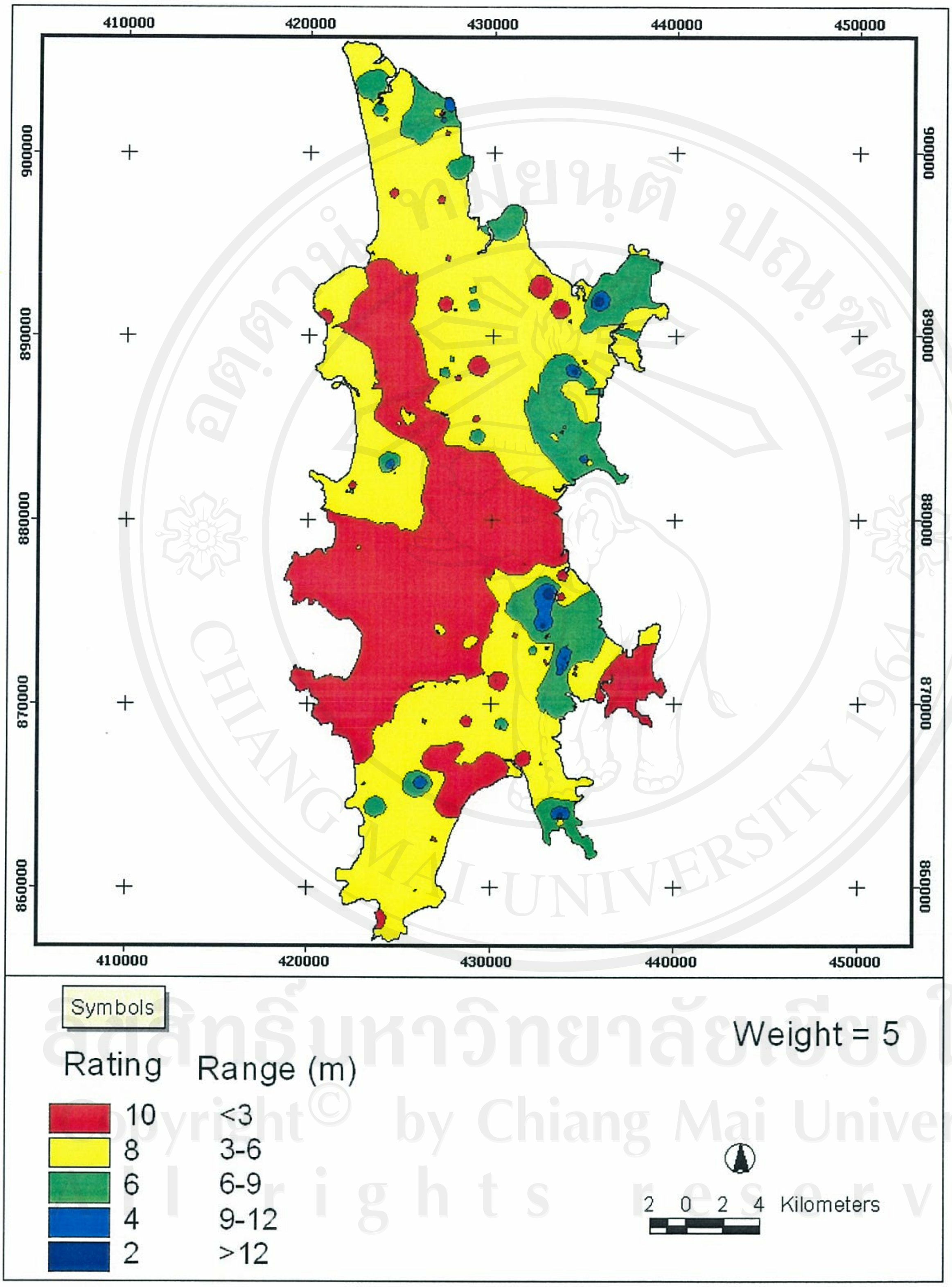

Figure 4.1 Depth to water table map of Phuket island (modified after Department of Mineral Resources, 2001).

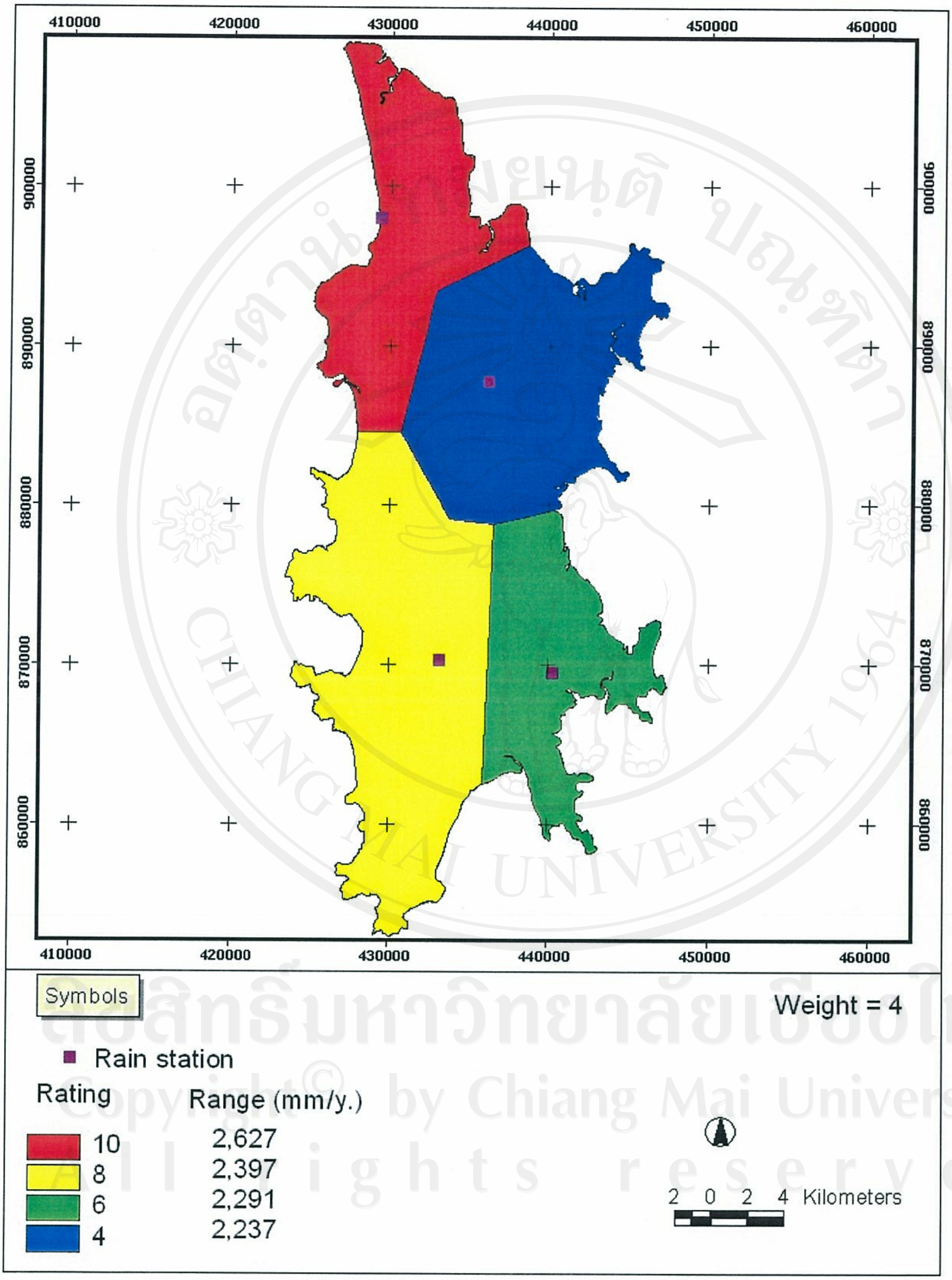

Figure 4.2 Net recharge map of Phuket island (modified after Royal Irrigation Department, 1996; Department of Mineral Resources, 2001).

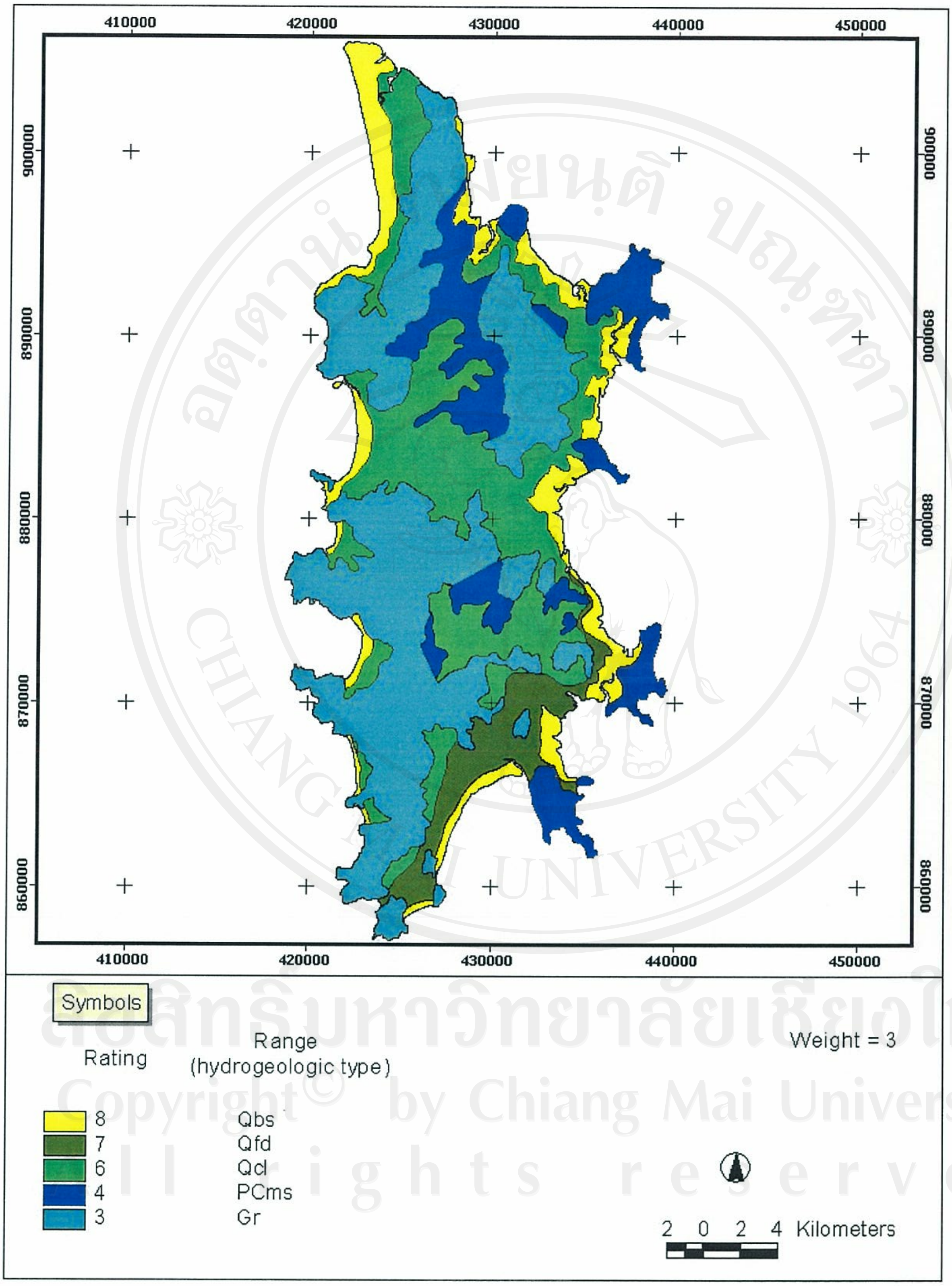

Figure 4.3 Aquifer media map of Phuket island (modified after Department of Mineral Resources, 2001).

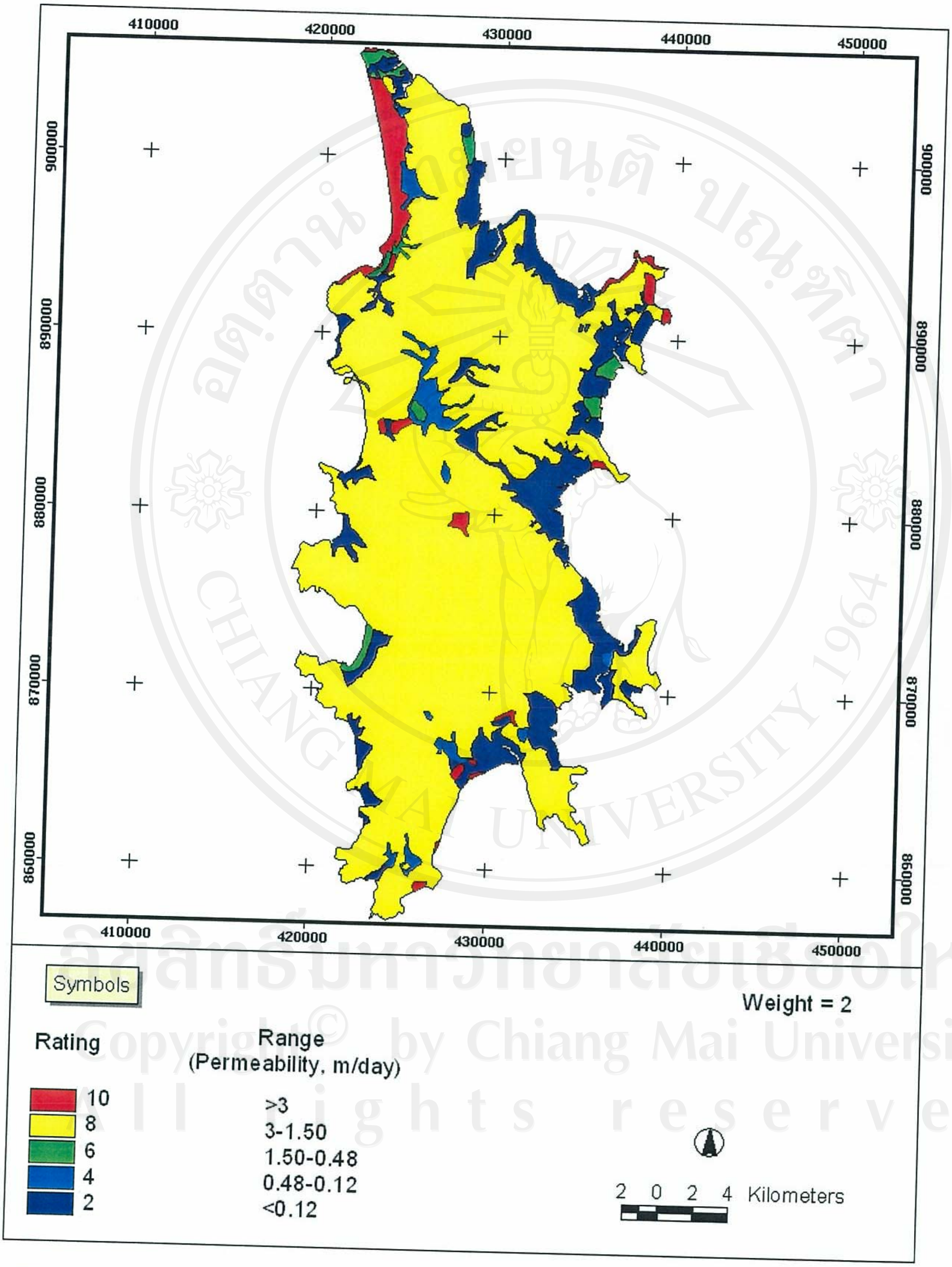

Figure 4.4 Soil media map of Phuket island (modified after Department of Land Development,1992; Department of Mineral Resources, 2001).

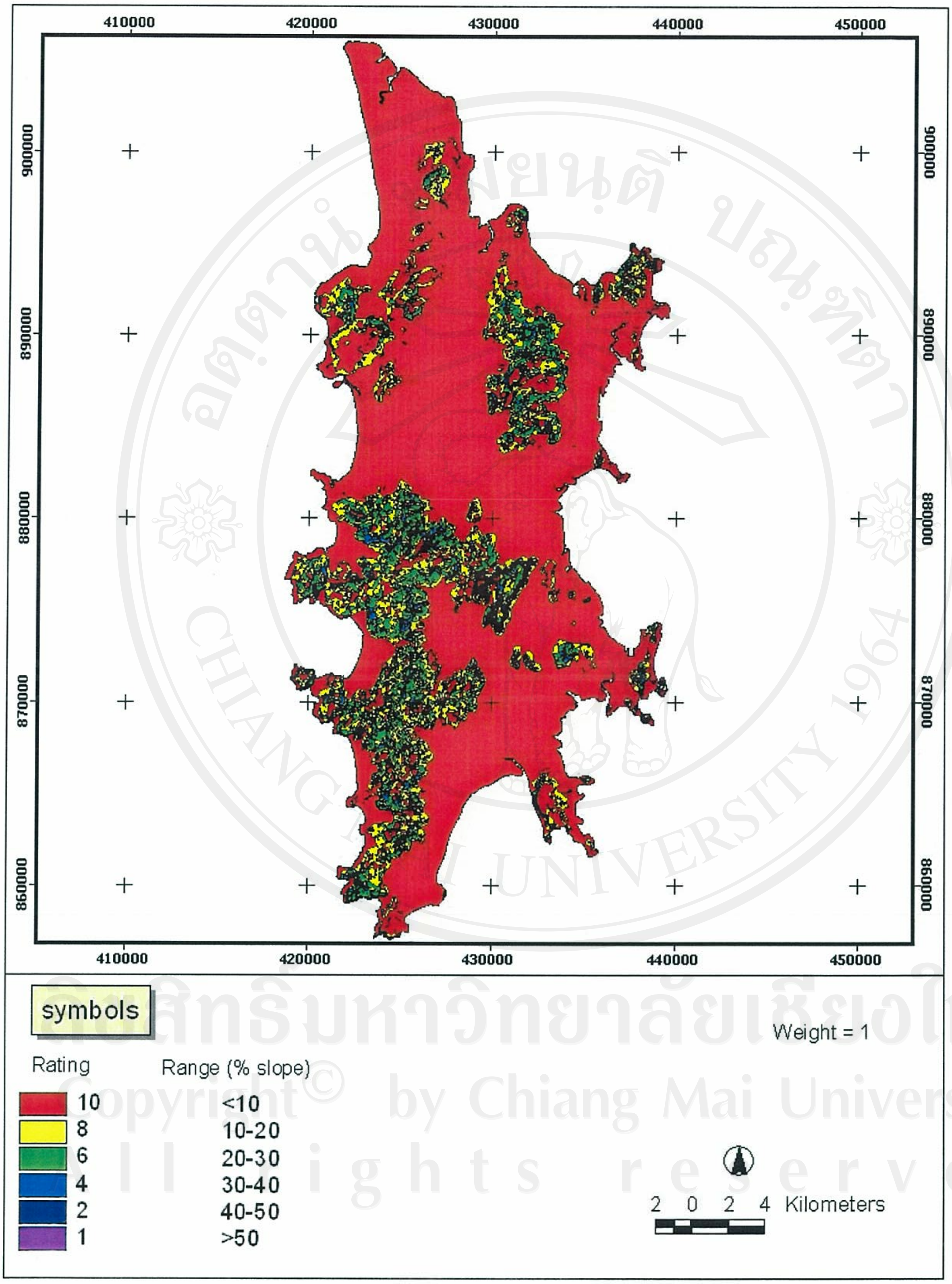

Figure 4.5 Topographic map of Phuket island (modified after Department of Mineral Resources, 2001).

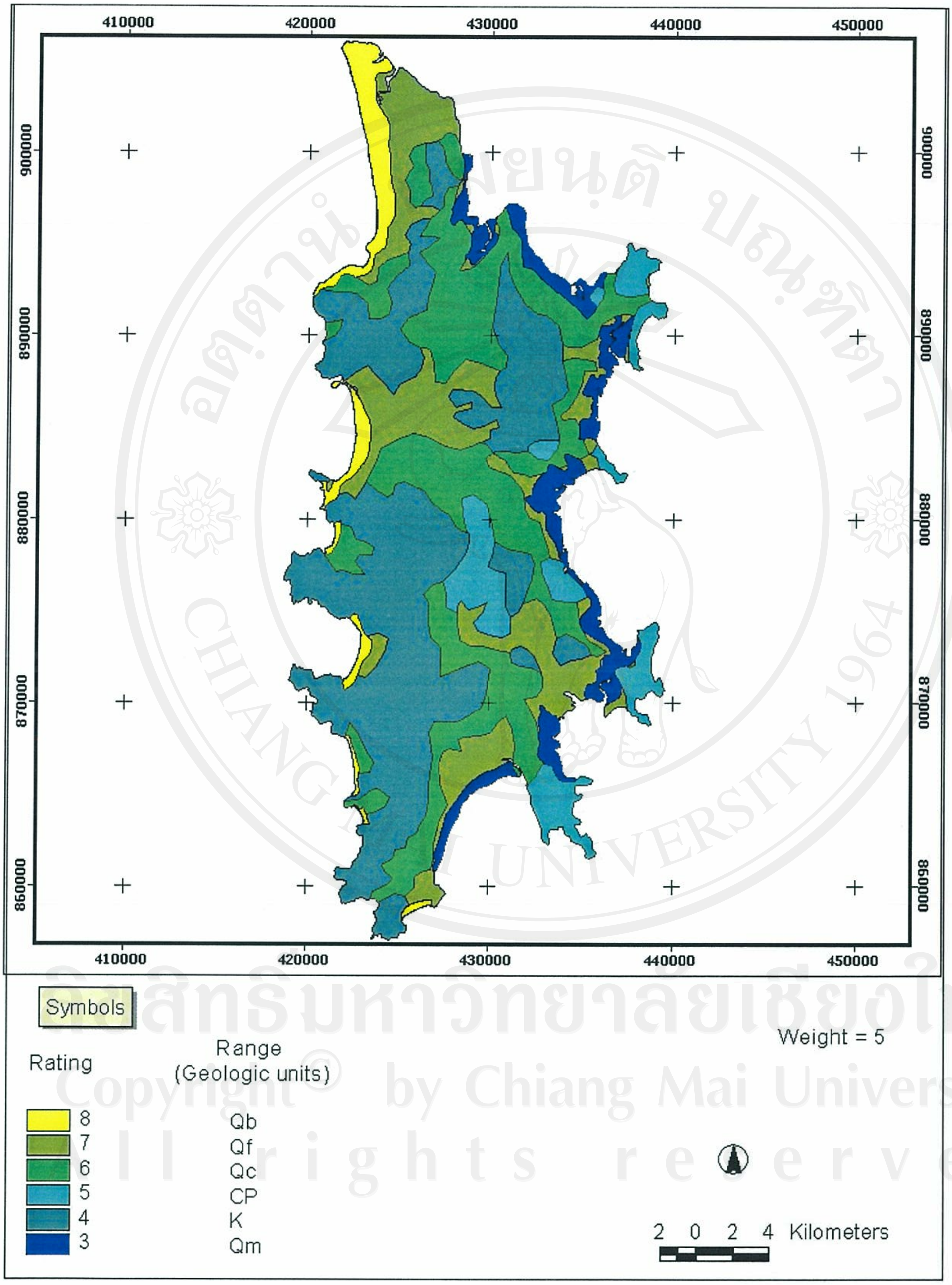

Figure 4.6 Impact of vadose zone map of Phuket island (modified after Department of Mineral Resources, 2001).

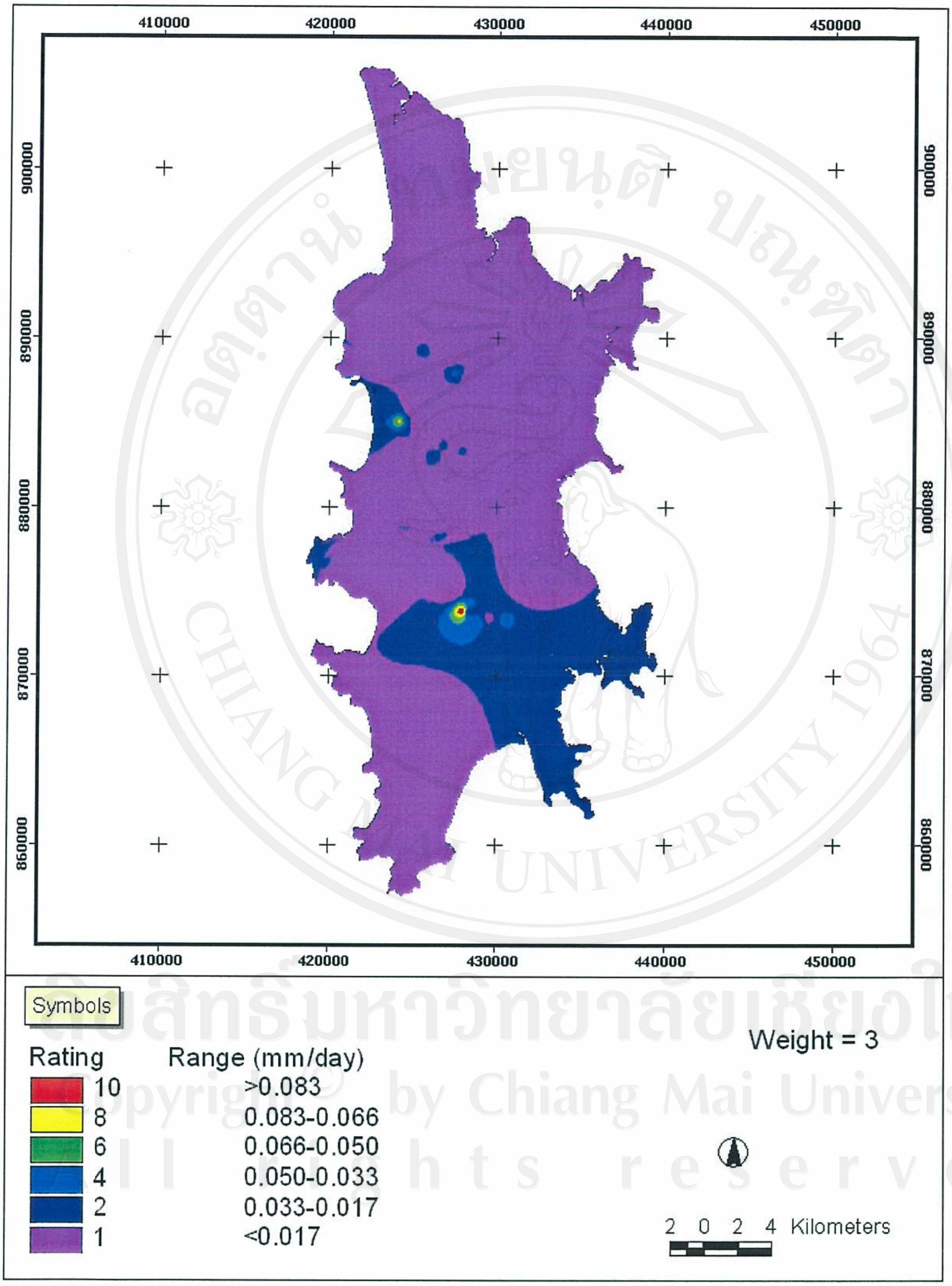

Figure 4.7 Hydraulic conductivity map of Phuket island (modified after Royal Irrigation Department, 1996; Department of Mineral Resources, 2001).

In this study, map calculation was carried out using the spatial analyst extension of the ArcView geographic information system to compile the geospatial data, to compute the DRASTIC indices, and to generate the final vulnerability map. After computing the groundwater vulnerability index ranges, they were reclassified to be five classes, i.e. high, moderately high, moderate, moderately low, and low as shown in Table 4.2. A regional scale is useful for comparing the relative vulnerability. DRASTIC indices range from 110 for the slight vulnerable to 171 for the most vulnerable. The highest vulnerability area was colored by red, and the lower areas were yellow, green, blue, and violet, respectively (Figure 4.8).

Table 4.2 Range, rating, and average areas of groundwater vulnerability map by DRASTIC method.

Feature	Name	Range	Rating	Area		
				Rais	Acres	Percent (%)
DRASTIC	Groundwater vulnerability in Phuket Island	>171	High	8,853	3,541	3
		170-151	Moderately high	56,880	22,752	17
		150-131	Moderate	141,920	56,768	44
		130-111	Moderately low	112,908	45,163	35
		<110	Low	5,110	2,044	2

The five classes of groundwater vulnerability of Phuket Island are described in more details as follows:

High

High vulnerability ranked groundwater resources are predominantly found in a few areas in the sandy beaches in the northwestern portion of the island. These areas are also characterized by shallow water table, high rainfall, beach sand aquifer, and relatively high soil permeability which suggest good surface water to groundwater connection in these areas. These areas of high vulnerability in the northwestern and western part of the island include Tha Chat Chai, Suan Maphrao, Mai Khao, Nai Yang, Khok Tanot village, and in the eastern part, Bang Tong village.

Moderately high

The moderately high vulnerability rank is slightly higher than moderate and moderately low vulnerability ranks. This vulnerability rank is characterized by unconfined and shallow groundwater systems in the lowland areas. This vulnerability class is not limited to one geological group, and in fact reflects the importance of depth to water table, soil media, and the impact of vadose zone on groundwater vulnerability. Recharge potential and topography have important roles to the sensitivity of these areas. In Phuket island, the moderately high vulnerability rank is found in many areas of urban area, build-up land, industrial land, and perennial lakes (former tin mines).

Moderate

The moderate vulnerability rank is the dominant class and found to associate with the largest area of vulnerability in Phuket island. They are predominantly characterized by terrains that have moderately deep water table, colluvial porous deposits of weathered granite with moderate soil permeability, moderately steep slope, and moderate recharge potential. However, the depth to water table is relatively deep in the weathered deposits underlain the agricultural land, urban area, and build-up land.

Moderately low

The moderately low vulnerability class comprises the second largest area of vulnerability in Phuket island. It includes weathered granite or weathered sedimentary or meta-sedimentary rocks that underlie the mountainous areas, mangrove clay in near shore areas, and floodplain deposits of low energy environment in the eastern part of Phuket island. It invariably is associated with high relief and steep slopes, moderate to low recharge potential, deep or absent water table, and moderate to low soil permeability. In Phuket island, some aquifers are protected by the presence of low permeability top layers such as clay and fine sand of the mangrove areas.

Low

Low vulnerability ranked groundwater resources are predominantly found in in the eastern part of Phuket island. These areas are characterized by deep water table, low to moderate recharge potential, very steep slopes, low soil permeability, and low hydraulic conductivity. In the Phuket island, the low vulnerability rank is shown in southeastern upland areas of Tut, Khat, To Sae, Sapam, and Phonthurat hill. Other areas include the mangrove area of Ao Kung in the northeast, and Chi Lao, and Khok Chang village in the southeast.

There are a relation between the DRASTIC index and type of aquifer. The Qbs aquifer unit (Holocene unconsolidated sediments) consists of beach sands that are coarse to fine grained, and well sorted. The aquifer in this unit is highly permeable. This aquifer has moderately high to high DRASTIC indices. The Qfd aquifer unit (Holocene unconsolidated sediments) consists of gravel, sand, silt, and clay, that area moderately well sorted. They have moderately high depth to water table and moderate DRASTIC indices. The Qcl aquifer unit (Pleistocene unconsolidated sediments) is composed of gravel, sand, silt, clay and lateritic material, which are poorly sorted. They have moderate to moderately low DRASTIC indices. The consolidated aquifers that include granite (Gr) and sedimentary or meta-sedimentary aquifers (PCms) are characterized by weathered rocks in the mountainous areas. They have moderately low to low DRASTIC indices. In some areas in the eastern part that are covered by mangrove clay, the DRASTIC indices are moderately low to low. As the major aquifer of this area is the granitic rocks, therefore, the large area of the Phuket island has a moderate to moderately low vulnerability rank.

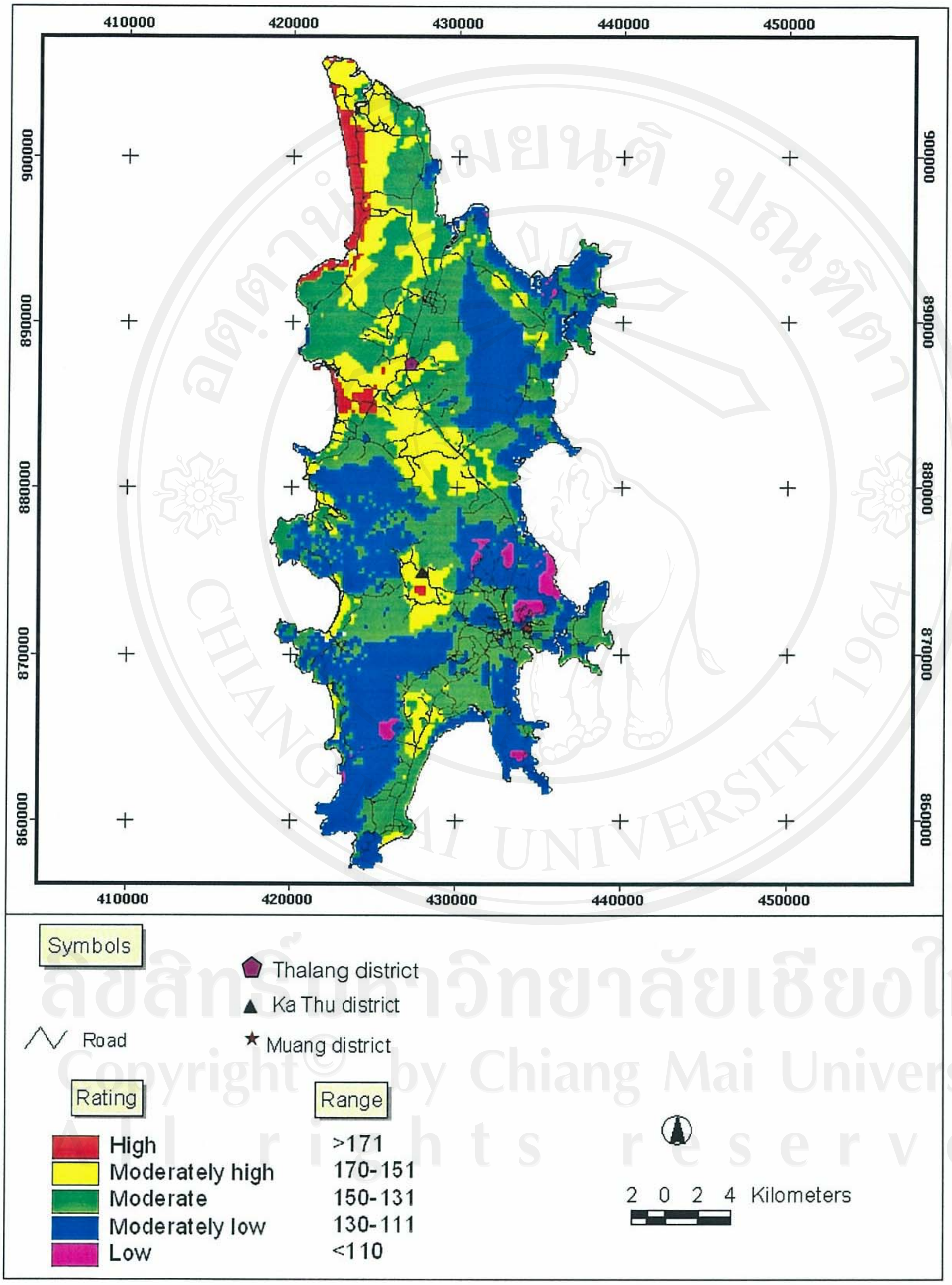

Figure 4.8 Groundwater vulnerability map of Phuket island.

4.9 Impact of the tsunami disaster to groundwater in Phuket island

The tsunami of 26 December 2004 (Figure 4.9) hit six provinces along the Andaman coast of Thailand, including Ranong, Phang Nga, Phuket, Krabi, Trang, and Satun (Figure 4.10). The level of devastation in these six provinces varies significantly depending upon a number of natural parameters including bathymetry, slope, elevation and presence of natural barriers, as well as man-made factors such as coastal land use and development. The impact of the tsunami disaster caused catastrophic loss of life and damage to the coastal environment and infrastructures of Thailand's southwestern coast. The Phuket island was also severely impacted.

Soon after the disaster, government agencies initiated rapid assessments of the impacts on most of the natural resources. In case of surface water and groundwater, the tsunami flooded coastal areas up to two to three kilometers inland. The tsunami has affected groundwater systems in the low-lying coastal zone of the stricken areas. Figure 4.11 gives a sketch of possible impacts on freshwater resources in coastal aquifers. Schematic representation of the possible effects of the tsunami on coastal groundwater systems: upconing of brackish groundwater under abstraction wells, intrusion of brackish or saline water from ponds, fingering of brackish water from pools, reduction in freshwater volume due to shoreline retreat (International Groundwater Resources Assessment Centre, 2005). The impact on groundwater condition by tsunami is shown in Figure 4.12. In Thailand the impact on groundwater by tsunami to be affect for coastal aquifer. It is less vulnerable groundwater.

In the inundated area, surface water is likely to have been contaminated significantly with sea water. The Department of Mineral Resources assessed surface water quality and the Department of Health of the Ministry of Public Health began assessing groundwater quality. The Department of Mineral Resources carried out an assessment of the impact of sea water intrusion into surface water bodies. Short duration flooding is likely to have caused negligible infiltration of saline water into groundwater. However, water that remained in pools, lakes or depressions after the tsunami, could lead to saline infiltration, especially in areas with permeable soils and sediments, hence impacting on groundwater. In addition, the destructive force of the tsunami has removed coastal sediments resulting in a landward shift of the coastline in some areas. The intrusion of sea water in the coastal aquifers is expected to shift landwards over a similar distance, which may affect some nearby groundwater wells. In the longer term, salinization of groundwater might also occur by deposited salts leaching from unsaturated zones into the groundwater. The problem of groundwater quality is further compounded by the potential contamination from sewage and the large amount of waste generated by the Tsunami. The Department of Health, Ministry of Public Health analyzed the quality of well water in the six tsunami affected provinces for coliform bacteria, chloride, and suspended matter. In Phuket, coliform bacteria contamination was affected 55 wells severely and 44 wells slightly. The quality of the water in twelve of these wells has already been restored with the addition of chloride (United Nations Environment Programme, 2005). The way for restore water supplies by re-leveling and where salts will be naturally flushed from topsoil by the seasonal monsoon rains. The Department of Groundwater Resources has made an effort to restore water supplies by drilling new wells or rehabilitating the contaminated wells (Figure 4.13 and 4.14). Figure 4.15 shows the map of groundwater zone of Phuket island that was affected by the tsunami in beach sand.

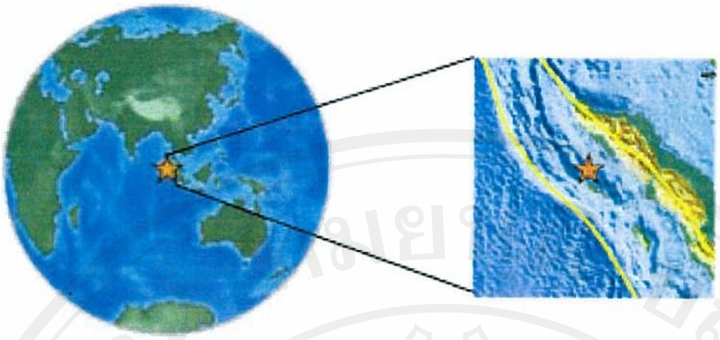

Figure 4.9 Map showing the source of the tsunami on 26 December 2004 that is located at 3.298°N, 95.778°E (United State Geological Survey, 2005).

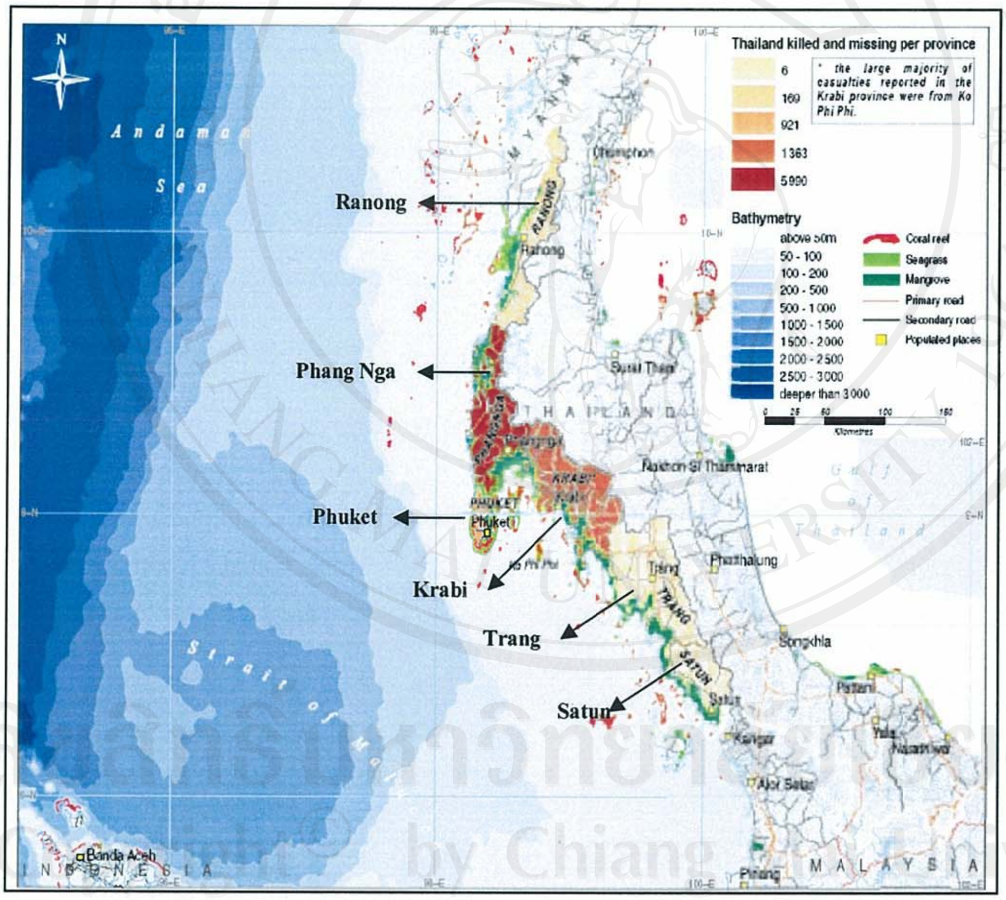

Figure 4.10 Map showing six provinces in the Andaman coast affected by the tsunami disaster (United Nations Environment Programme, 2005).

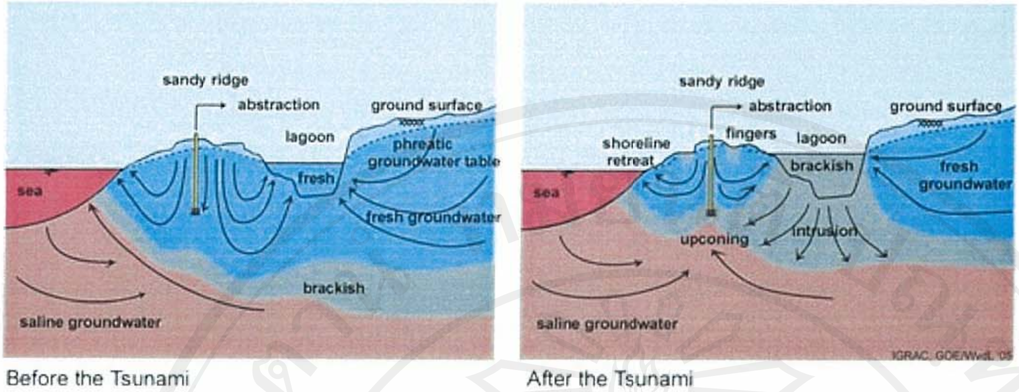

Figure 4.11 Schematic diagram showing the possible effects of the tsunami on coastal groundwater systems (International Groundwater Resources Assessment Centre, 2005).

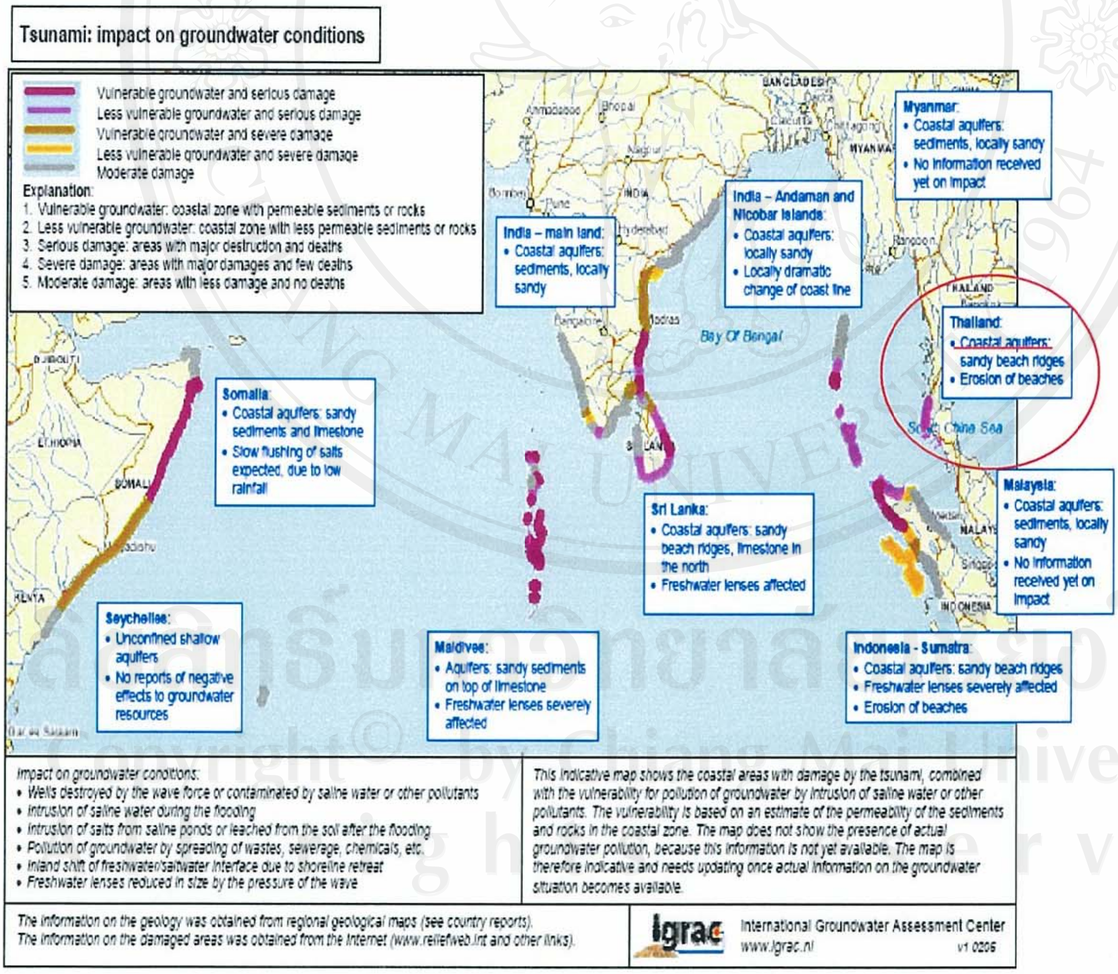

Figure 4.12 Map showing the impact on groundwater condition by tsunami (International Groundwater Resources Assessment Centre, 2005).

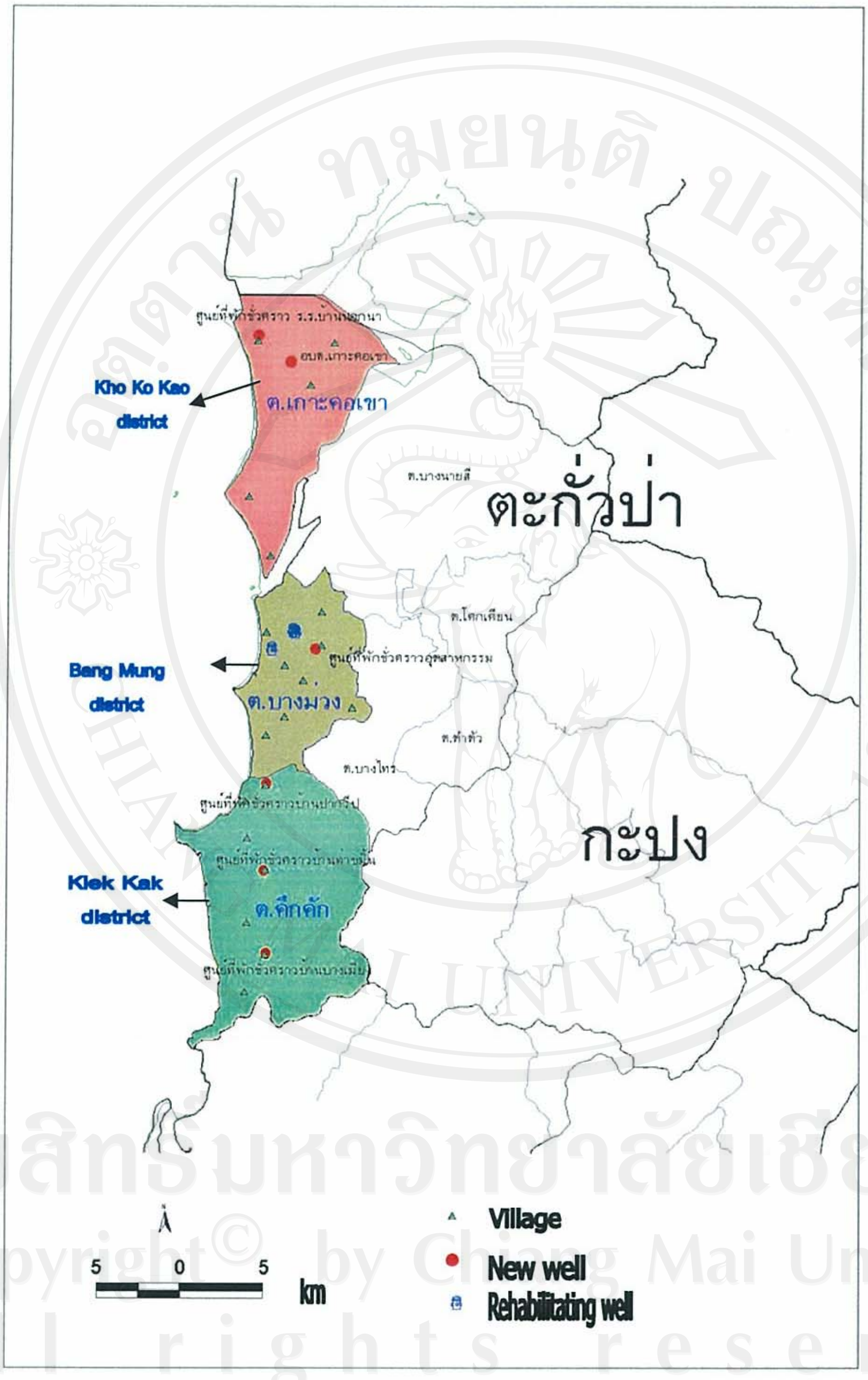

Figure 4.13 Map showing new drilled wells and rehabilitating wells in six provinces along the Andaman coast affected by the tsunami (Department of Groundwater Resources, 2005).

Figure 4.14 Photographs of Rehabilitating groundwater well (The Department of Groundwater Resources, 2005).

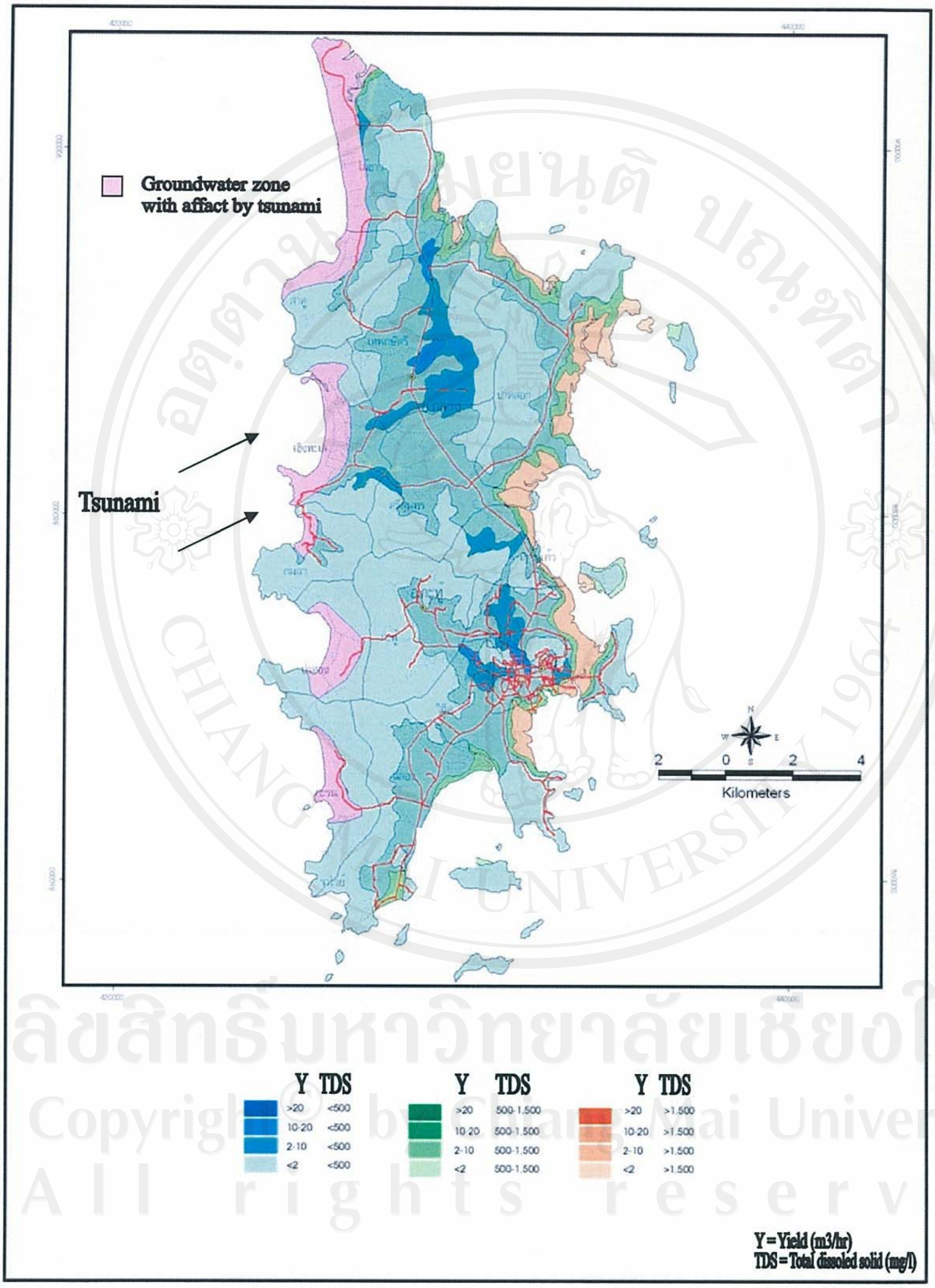

Figure 4.15 Map of Phuket island showing the groundwater zone affected by the tsunami (Department of Groundwater Resources, 2005).