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Groundwater recharge assessment using GIS approach in Chiang Mai basin

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Abstract

The geographic information system (GIS) techniques were used to groundwater recharge estimation and groundwater recharge potential map in Chiang Mai Basin. The groundwater recharge estimation use slope, rainfall and infiltration factor for calculation. Amount of groundwater recharge are 597.20 – 896.19 m^3/year. The study used lithology, land use, lineaments, drainage and slope gradient as influence factors to the groundwater recharge potential. The groundwater potentiality was integrated from thematic maps and derived from the sum of the weighted factor using weight overlay method in the GIS system. Almost of the study area is classified as the high groundwater recharge potential zone. The moderate groundwater recharge potential zone is located in the western part of study area and along with the Ping River.

Keywords: Ground water; Recharge; GIS; Weight overlay; Chiang Mai

1. Introduction

The groundwater recharge potential zone has been assessed by many researchers [1-8]. Accurate estimation of groundwater recharge is important for the appropriate management of groundwater system. Groundwater recharge is temporally and spatially distributed. Groundwater recharge potential depends upon many contributing factors, including topographical characteristics, meteorological, lithology, hydrological, depth of weathering, extent of fractures, porosity, slope, drainage patterns, landform, soil, land use and geologic characteristics [2, 5, 9-10].

Amount of recharge rated is one of component in groundwater temperature changes [11]. Many techniques are available for assessing groundwater recharge. The choice of methods partially depends on the available data, the hydrogeological system and the expected accuracy of the results. The geographic information system (GIS) techniques were used to groundwater recharge potential area estimation. Spatial analysis using the geographic information system (GIS) is useful to evaluate groundwater recharge estimation on a large-scale and complex area [6, 12]. The technique can be used for assessing groundwater recharge potential and calculated weighted of multiple factors such as lithologic characteristics, land use, drainage density, lineament and slope as the five significant factors affecting potential groundwater recharge. Therefore, the purpose of this research is focus on groundwater recharge potential map assessment using geographic information system techniques. The groundwater recharge potential map can be used to ensure sustainable groundwater resource management.

2. Material and methods

2.1. Chiang Mai Basin

Chiang Mai Basin is located in the northern part of Thailand, between latitude $18^{0}30'$ N and $19^{0}00'$N and longitudes $98^{0}45'$E and $99^{0}15'$E .It comprises of Chiang Mai and Lamphun Provinces .The topography of Chiang Mai Basin is

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classified into 3 major parts including high mountainous area, hilly and rolling area, and plain area in the middle .The study area is located within a plain area which covers about 2,841.45 km^2 (Figure 1). The climate of the basin is characterized by a tropical monsoon climate, which is southwest and northeast monsoons. The study area has 3 seasons consist of winter, summer and rainy season. Average meteorological data in thirty-year period (1981–2010) were provided by The Northern Meteorological Center [13]. The mean annual rainfall was 1,140.2 mm. Long–term temperature averages varies between 12.5–38.0 °C and mean annual temperature is 25.8 °C throughout the year .

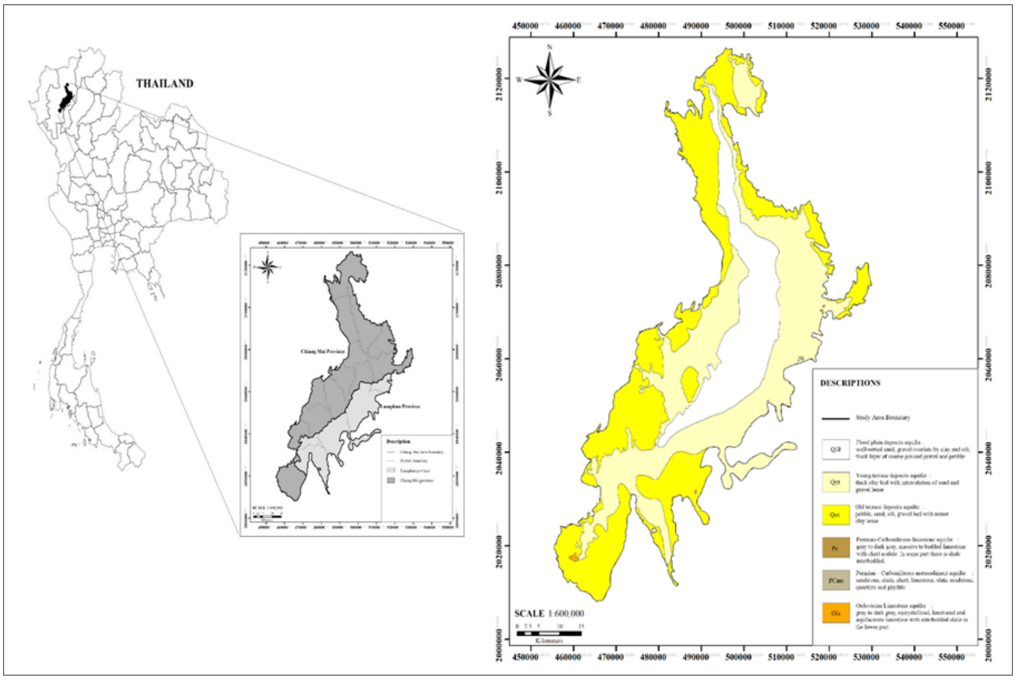

Figure 1 Chiang Mai Basin

Hydrogeology of Chiang Mai Basin consists of Tertiary to Quaternary deposits and it is apparent that consolidated rocks and unconsolidated rocks are the main aquifer of the study area. The consolidated rocks were forming a mountain area in the western part and divided into 3 hydrogeological units[14-19], namely;

- Permian-Carboniferous limestone aquifer
- Permian – Carboniferous metasediment aquifer and
- Ordovician limestone aquifer.

The unconsolidated rocks cover an approximately 2800 km^2 at the central and eastern parts of the study area. There were divided into 3 hydrogeologic units, namely;

- Flood plain deposits aquifer
- Young terrace deposits aquifer, and
- Old terrace deposits aquifer

Flood plain deposits aquifer were deposited along the flood plain and meander belt of Ping River. It consists of well-sorted sand and gravel overlain by clay and silt. A thick layer of coarse grained gravels and pebbles was deposited behind the natural levee. It is an average thickness of about 20 – 40 m and well yields is more than 20 m^3/hr.

Young terrace deposits aquifer were widely distributed along the narrow terrace next to the Ping River's flood plain. This consists of a thick clay bed with intercalation of sand and gravel lenses. Mostly the area was a relatively low flat surfaced terrace. The average thickness of sediment range from 30 – 100 m and well yield is 10 – 20 m^3/hr.

Old terrace deposits aquifer is distributed in the high terrain next to the young terrace sediments till the hilly. It consists of pebble, sand, silt, gravel bed with minor clay lenses. The part of the area formed a high dissected surface terrace but mostly area concealed under younger sediments. It deposited along area higher than young terrace deposit. The average thickness of old terrace sediment is 50– 250 m and 300 m. in some areas. Well yield is 2 – 10 m^3/hr.

Land use types of Chiang Mai Basin is described by the GIS Enterprise Access Database of Chiang Mai province and Lamphun province (2018) [20]. Land use types of the study area consist of building and village area, agricultural land, reservoir, industrial area, forest, wetland, park, bare land, and others.

2.2. The geographic information system (GIS) method

2.2.1. Groundwater recharge estimation

The geographic information system (GIS) has been used for assessing groundwater recharge and can calculated weighted of multiple factors including rainfall infiltration, slope and amount of rainfall. Amount of groundwater recharge estimation of this area can be calculated as follows:

$$R_C = A \times R_A \times I_F \times S_F \text{.............. (Equation 1)}$$

Where:
R_c = groundwater recharge (m^3)
A = area (m^2)
R_A = the average annual rainfall (m)
I_F = infiltration factor
S_F = the slope factor.

Precipitation is the main source of groundwater recharge. In the study area, it is in the form of rainfall. Amount of rainfall in research area were collected from meteorological observation computerized by Meteorological Department, Ministry of Information and Communication Technology [21]. Table 1 illustrates amount of annual rainfall in Chiang Mai and Lamphun provinces from 2003–2018. The average annual rainfalls is 2,287.09 mm/year for this period. The annual rainfalls is 2,109.90 mm/year in 2018.

Table 1 Annual rainfall in Chiang Mai and Lamphun provinces (2003 – 2018)

Year	Meteorology Station	
	Chiang Mai	Lamphun
2003	889.6	823.2
2004	1,208.9	1,008.7
2005	1,393.4	1,253.8
2006	1,500.0	1,142.3
2007	1,125.3	890.2
2008	1,141.0	1,226.7
2009	1,070.2	737.2
2010	1,156.0	1,355.1
2011	1,449.5	1,706.7
2012	925.6	896.5
2013	1,288.0	1,137.0
2014	1,064.4	788.0
2015	831.8	1,076.1
2016	1176	1,313.4
2017	1419.5	1,489.5
2018	984.2	1125.7
Average	1164.0	1123.1

Infiltration factor is the maximum of rainfall that can infiltrate into and though soil and rocks. Hydrogeologic characteristic is one of factors that affect infiltration. In unconsolidated rocks, infiltration depends on primary porosity while infiltration depends on secondary porosity in mostly consolidated rocks. Infiltration factor of rock which has high porosity and high hydraulic conductivity, is higher than infiltration factor of the rock which has low porosity and low hydraulic conductivity. Previous study, they had many define an infiltration factor (I_F) to each rock [22-25]. This study assigns the infiltration factors into 3 types (Table 2). The infiltration factor I (I_{F1}) is divided by hydrogeologic units. The infiltration factor II (I_{F2}) and the infiltration factor III (I_{F3}) are divided by type of rock and type of aquifer, respectively.

Table 2 Infiltration factor (I_F)

Hydrogeologic unit	**Infiltration factor (% of rainfall)**		
	I_{F1}*	**I_{F2}****	**I_{F3}*****
Recent alluvial deposits	12	15	10
Young terrace deposits	10		
Old terrace deposits	12		
Limestone/Carbonate rock	6	6	5
Metasedimentary and Metamorphic rock	3	6	2-3
Volcanic rock	3	3	-
Granitic rock	2	3	-

*[22, 25]; **[23, 24]; *** [22]

The slope is one factor that affects the recharge and slop relates to lateral flow and infiltration. The lateral flow on the steeply sloped land is less infiltration than the lateral flow on the flat land. The slope factor relates to the amount of rainfall that remains after water loss due to the lateral flow. Almost of study area is a plain area in the middle. The result calculated by GIS, presented in terms of the spatial raster. The flowchart for groundwater recharge estimation using GIS is shown in Figure 2.

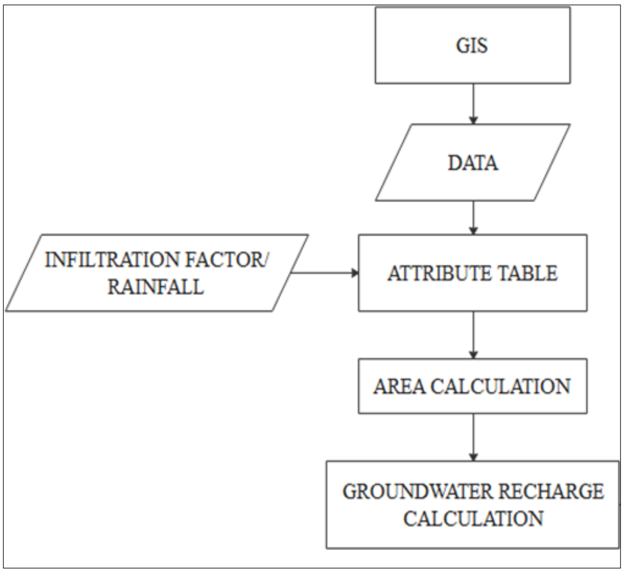

Figure 2 Work flow of groundwater recharge estimation using GIS method

2.2.2. Groundwater recharge potential map

The geographic information system (GIS) is used to provide a groundwater recharge potential map. The groundwater recharge potential map can be used to ensure sustainable groundwater resource management. The factors that affect the groundwater recharge in the study are following sections;

Lithology

The lithology with fracture systems, joints, and dykes influences the capacity and specific storage of groundwater [26]. Unconsolidated rocks are main source of aquifer in Chiang Mai Basin. Based on the known infiltration factor of each rock type, were classified into 5 categories including unconsolidated rocks, sedimentary rocks, limestone rocks, the metamorphic complex and igneous rocks.

Land use

Land use types of the study area consist of building and village area, agricultural land, reservoir, industrial area, forest, wet land, park, bare land and other. The rate of infiltration is directly relationship with density of vegetation cover. Reservoir and wet land were assigned highest rank for groundwater recharge while agricultural land with village and built up area is lower rank for groundwater recharge.

Lineaments

Lineaments influence on groundwater recharge potential area because they increase secondary permeability and porosity of rock and so accelerate the rate of water percolation to recharge the aquifers [26-27]. The linear geological features of the study area were derived from the Department of Mineral Resources [23] and incorporated into the GIS. The resulting was classified into 5 classes with each class according to a range of lineament density.

Drainage

Drainage density is the total length of streams per unit area. The spatially different of a drainage density depends on lithology, climatic conditions, topographic characteristic and land use impacts [6, 28]. The drainage of study area was categorized into 4 ranges of drainage density value. Drainage density was classified into 5 classes as <0.5429, 0.5429 - 1.1782, 1.1782 - 2.0493, 2.0493 - 2.9931 and >2.9931 km/km^2. The highest drainage density appeared in the southern part of the study area.

Slope

Slope of study area was classified into 5 classes as <5, 5 - 10, 10 – 15, 15 - 20 and >20 degree.

Each relationship of various factors is weighted according to its strength impact on groundwater recharge potential. The relationship of factors influence concerning the recharge property is shown in Figure 3. The factor are interdependent although each factor may influence the groundwater recharge at different rating. The relative weightage values based on interrelationship between groundwater recharge potential factors [5]. Reclassified values of the value ranges of each factor are presented in Table 3.

The methodology to identify the potential groundwater recharge zone of Chiang Mai Basin is shown in Figure 3.

3. Results and discussion

3.1. Groundwater recharge estimation

Groundwater recharge estimation using GIS method was divided into 56 sub-area. Table 4 illustrates groundwater recharge estimation in Chiang Mai Basin using GIS calculation. This study use 3 types of infiltration factor for groundwater recharge calculation. The result of groundwater recharge calculation was shown in Table 5. Groundwater recharge calculation of Chiang Mai Basin are 597.20 – 896.19 m^3/year as a percentage of 9.98 – 14.97% of the annual rainfall. The result using infiltration factor II (I_{F2}) is given amount of recharge rate more than other.

3.2. Groundwater recharge potential

The thematic maps for all factors with respect to groundwater recharge was then prepared using a spatial analysis method and is shown in Figure 4.

According to Table 3, the relative weightage values based on interrelationship between groundwater recharge potential factors presented. The factors of main influence were assigned as 29 percent and the minor influence were assigned as 14 percent. The rank assignment of each factor was integrated and prepare groundwater recharge potential using spatial analysis.

Table 3 Reclassified values of the value ranges of each factor

Factor	Description	Reclassified value	Class	Weight (%)
Lithology	Igneous rocks	1	Poor	29
	Metamorphic complex	2	Fair	
	Limestone	3	Moderate	
	Sedimentary rocks	4	High	
	Unconsolidated rocks	5	Very high	
Land use	Built up area	1	Poor	24
	agricultural land with village	2	Fair	
	agricultural land	3	Moderate	
	forest	4	High	
	reservoir and wet land	5	Very high	
Lineament density	no lineament	1	Poor	19
	< 0.1126	2	Fair	
	0.1126 - 0.2151	3	Moderate	
	0.2151 - 0.3781	4	High	
	> 0.3781	5	Very high	
Drainage density	>2.9931	1	Poor	14
	2.0493 - 2.9931	2	Fair	
	1.1782 - 2.0493	3	Moderate	
	0.5429 - 1.1782	4	High	
	<0.5429	5	Very high	
Slope gradient	> 20	1	Poor	14
	15 -20	2	Fair	
	10 - 15	3	Moderate	
	5 - 10	4	High	
	< 5	5	Very high	

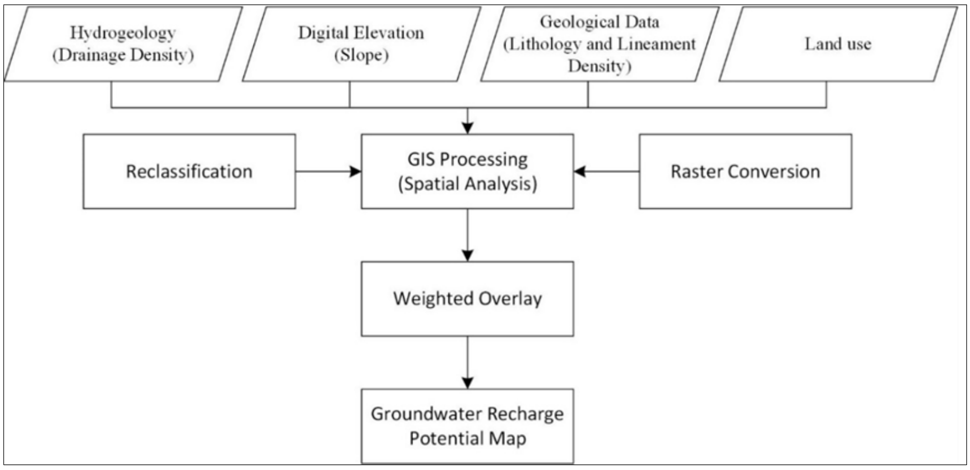

Figure 3 Work flow of groundwater recharge potential zone using GIS method

Table 4 Groundwater recharge estimation in Chiang Mai Basin using GIS calculation

Code	Unit	Area (km²)	I_{F1}	I_{F2}	I_{F3}	Quantity	R1	R2	R3
1	Pc	0.11	0.06	0.06	0.05	0.23	0.27	0.27	0.14
2	Pc	0.23	0.06	0.06	0.05	0.48	0.01	0.01	0.01
3	Pc	0.18	0.06	0.06	0.05	0.38	0.01	0.01	0.01
4	Pc	0.13	0.06	0.06	0.05	0.27	0.02	0.02	0.01
5	Pc	0.04	0.06	0.06	0.05	0.08	0.00	0.00	0.00
6	PCms	0.08	0.03	0.06	0.02	0.17	0.02	0.02	0.01
7	PCms	0.01	0.03	0.06	0.02	0.01	0.01	0.01	0.00
8	PCms	0.02	0.03	0.06	0.02	0.04	0.01	0.01	0.01
9	PCms	0.30	0.03	0.06	0.02	0.64	0.01	0.01	0.01
10	PCms	0.13	0.03	0.06	0.02	0.27	0.00	0.00	0.00
11	PCms	0.04	0.03	0.06	0.02	0.08	0.02	0.02	0.01
12	PCms	0.14	0.03	0.06	0.02	0.29	0.01	0.01	0.00
13	PCms	0.12	0.03	0.06	0.02	0.26	0.01	0.01	0.01
14	PCms	0.00	0.03	0.06	0.02	0.01	0.03	0.03	0.02
15	PCms	0.09	0.03	0.06	0.02	0.18	0.02	0.02	0.02
16	PCms	0.64	0.03	0.06	0.02	1.35	0.02	0.02	0.01
17	PCms	0.29	0.03	0.06	0.02	0.61	0.00	0.00	0.00
18	PCms	0.14	0.03	0.06	0.02	0.30	0.01	0.01	0.00
19	Qyt	3.40	0.10	0.15	0.10	7.16	0.00	0.00	0.00
20	Qyt	49.82	0.10	0.15	0.10	105.11	0.00	0.00	0.00
21	Qot	3.33	0.12	0.15	0.10	7.04	0.02	0.04	0.01
22	Qot	13.78	0.12	0.15	0.10	29.08	0.01	0.02	0.01
23	Qot	3.39	0.12	0.15	0.10	7.15	0.00	0.00	0.00
24	Qot	201.57	0.12	0.15	0.10	425.29	0.01	0.02	0.01
25	Qot	21.38	0.12	0.15	0.10	45.11	0.01	0.02	0.01
26	Qot	209.73	0.12	0.15	0.10	442.51	0.00	0.00	0.00
27	Qot	51.35	0.12	0.15	0.10	108.35	0.01	0.01	0.00
28	Qot	41.04	0.12	0.15	0.10	86.59	0.04	0.08	0.03
29	Qot	1.61	0.12	0.15	0.10	3.39	0.02	0.04	0.01
30	Qot	31.73	0.12	0.15	0.10	66.95	0.01	0.02	0.01
31	Qot	91.94	0.12	0.15	0.10	193.98	0.01	0.02	0.01
32	Qot	5.84	0.12	0.15	0.10	12.31	0.07	0.14	0.05
33	Qot	7.53	0.12	0.15	0.10	15.88	0.10	0.21	0.07
34	Qot	220.24	0.12	0.15	0.10	464.68	133.09	166.36	110.91
35	Qot	4.99	0.12	0.15	0.10	10.54	0.84	1.06	0.70

36	Qot	0.91	0.12	0.15	0.10	1.92	3.49	4.36	2.91
37	Qot	4.25	0.12	0.15	0.10	8.96	0.86	1.07	0.71
38	Qot	56.20	0.12	0.15	0.10	118.57	51.03	63.79	42.53
39	Ols	2.14	0.06	0.06	0.03	4.51	5.41	6.77	4.51
40	Ols	0.10	0.06	0.06	0.03	0.22	53.10	66.38	44.25
41	Ols	0.10	0.06	0.06	0.03	0.22	13.00	16.25	10.84
42	Ols	0.13	0.06	0.06	0.03	0.26	10.39	12.99	8.66
43	Ols	0.02	0.06	0.06	0.03	0.04	0.41	0.51	0.34
44	Ols	0.15	0.06	0.06	0.03	0.31	8.03	10.04	6.69
45	Ols	0.06	0.06	0.06	0.03	0.12	23.28	29.10	19.40
46	Ols	0.08	0.06	0.06	0.03	0.17	1.48	1.85	1.23
47	Ols	0.12	0.06	0.06	0.03	0.24	1.91	2.38	1.59
48	Ols	0.00	0.06	0.06	0.03	0.00	55.76	69.70	46.47
49	Ols	0.14	0.06	0.06	0.03	0.30	1.26	1.58	1.05
50	Qfd	525.66	0.12	0.15	0.10	1109.09	0.23	0.29	0.19
51	PCms	0.19	0.03	0.06	0.02	0.39	1.08	1.34	0.90
52	PCms	1.10	0.03	0.06	0.02	2.32	14.23	17.79	11.86
53	PCms	1.65	0.03	0.06	0.02	3.49	36.60	45.75	30.50
54	Qyt	1133.99	0.10	0.15	0.10	2392.61	0.72	1.07	0.72
55	Qot	144.54	0.12	0.15	0.10	304.97	10.51	15.77	10.51
56	Ols	0.08	0.06	0.06	0.03	0.16	239.26	358.89	239.26

I_F = infiltration factor ; R1 = Recharge estimation from I_{F1}; R2 = Recharge estimation from I_{F2}; R3 = Recharge estimation from I_{F3}

Table 5 Summarize groundwater recharge estimation in Chiang Mai Basin

Unit	Area (km²)	I_{F1}	I_{F2}	I_{F3}	Quantity	R1	R2	R3
Ols	3.11	0.06	0.06	0.03	6.56	0.39	0.39	0.20
Pc	0.69	0.06	0.06	0.05	1.45	0.09	0.09	0.07
PCms	4.93	0.03	0.06	0.02	10.41	0.31	0.62	0.21
Qfd	525.66	0.12	0.15	0.10	1109.09	133.09	166.36	110.91
Qot	1115.35	0.12	0.15	0.10	2353.27	282.39	352.99	235.33
Qyt	1187.20	0.10	0.15	0.10	2504.88	250.49	375.73	250.49
Total					5985.66	666.76	896.19	597.20
%					100	11.14	14.97	9.98

I_F = infiltration factor ; R1 = Recharge estimation from I_{F1}; R2 = Recharge estimation from I_{F2}; R3 = Recharge estimation from I_{F3}

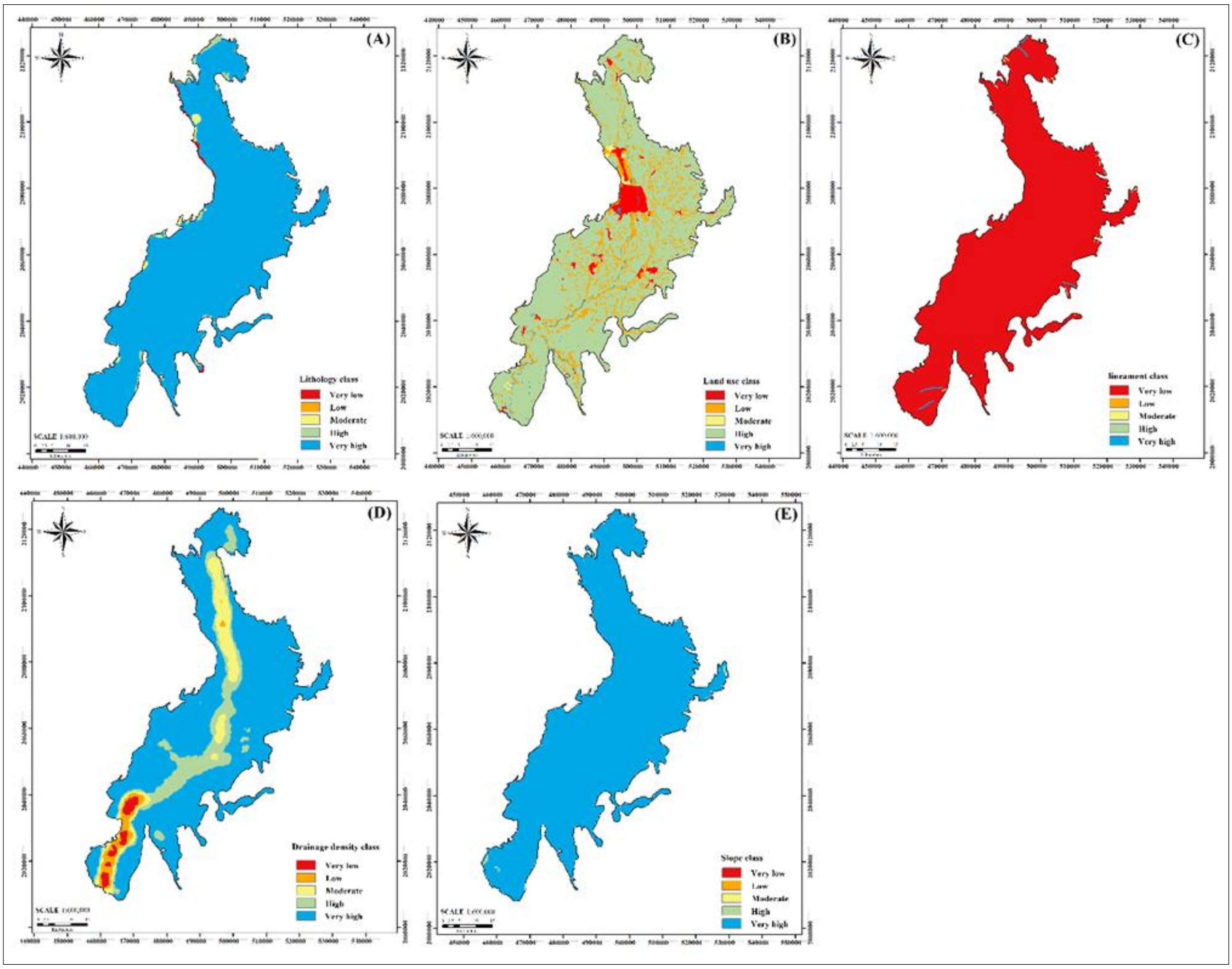

Figure 4 The thematic maps for all factors; (A) lithology, (B) land use, (C) lineament, (D) drainage density and (E) slope

The final map was derived from the sum of the weighted factor using weight overlay method in the GIS system. The result of groundwater recharge potential were classified into 5 classes as very high potential, high potential, moderate potential, low potential and very low potential recharge zones. Figure 5 illustrate groundwater recharge potentiality map of the study area. Almost of the study area is classified as the high groundwater recharge potential zone. This area is covered by the unconsolidated rocks and low slope gradient. The rapid densely urban area, where is located in the western part of study area, and along with Ping river were found the moderate groundwater recharge potential zone. Groundwater recharge estimation and groundwater recharge potential map can be applied further to develop appropriate guidelines for sustainable groundwater resource management and help design the groundwater potential map for vapor compression refrigeration system installation in this study area.

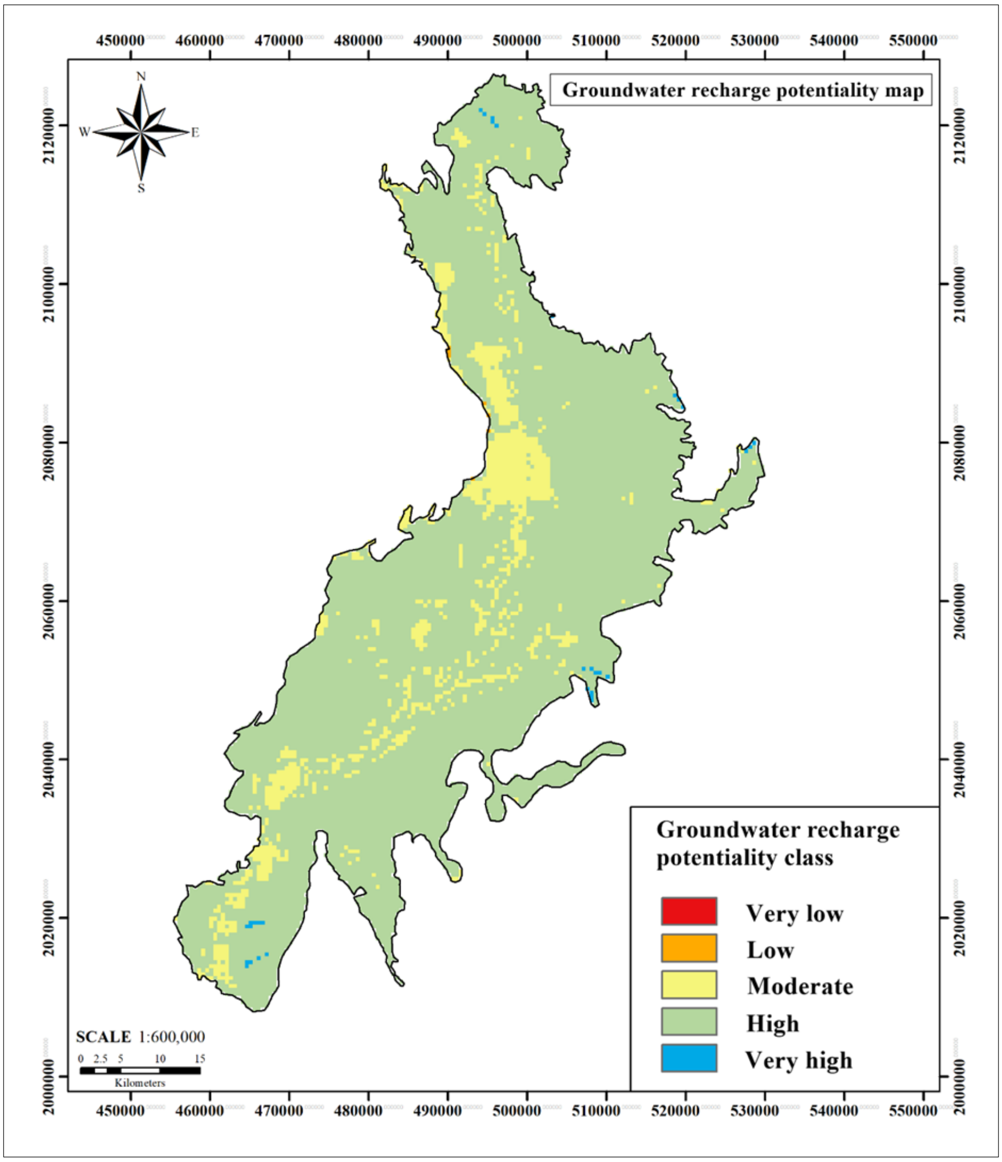

Figure 5 Groundwater recharge potential zone in Chiang Mai Basin

4. Conclusion

The geographic information system (GIS) techniques were used to groundwater recharge estimation and groundwater recharge potential map in Chiang Mai Basin. The groundwater recharge estimation is based on the multiple factors including rainfall infiltration, slope and rainfall. Amount of groundwater recharge are 597.20 – 896.19 m^3/year.

The groundwater potentiality was integrated from thematic maps and derived from the sum of the weighted factor using weight overlay method in the GIS system. Almost of the study area is classified as the high groundwater recharge potential zone. The moderate groundwater recharge potential zone is located in the western part of study area and along with the Ping River.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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