Impact of Urbanization on Quality and Quantity of Groundwater in Nakhon-Nayok Province, Thailand

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Abstract

Groundwater has become an essential resource over the past few decades due to climate change, which highly increases the demand for using freshwater. The groundwater quality and quantity are then a significant criterion in matching water demand and supply. The objective of the study is to integrate the application of Geographic Information System (GIS) and Program R with the Water Quality Index (WQI) for the evaluation of groundwater quality and quantity in Nakhon-Nayok province, Thailand. The result of the study shows that the most community in western study area (Amphoe Ban Na) has WQI on average and below average levels. As a result, the urbanization can obviously impact on groundwater quality and quantity in the study area. Appropriate methods for monitoring and improving groundwater quality and quantity in affected areas should be suggested, especially in urban areas. In addition, this study indicates that the application of GIS and Program R with the WQI can be an effective tool and help more efficiently for groundwater management.

Keywords: groundwater quality, groundwater quantity, groundwater management, geographical information system, program r, water quality index

1. Introduction

Water security is a major challenge for many nations. This challenge can be attributed to climate change, which increases the demand for using freshwater and may induce significant environmental problems such as desertification and overexploitation of the existing water resources. More frequently, the insufficient availability of surface water makes people dependent upon groundwater resources to fulfill users' demands. Thus, over the past few decades, groundwater has become an essential resource due to the increase of domestic consumption, and irrigation and industrial uses. Unavoidably, it is important to ensure that not only a sufficient quantity, but also a standard quality of groundwater can be provided. Regular monitoring of the groundwater quality and quantity in wells is necessary to assess groundwater supplies for domestic, agriculture, industry, and ecosystem health. However, it is not easy to determine and assess the groundwater quality and quantity with huge samples containing concentrations for many parameters and different groundwater levels.

In general, there are several conventional methods to assess water quality. The Water Quality Index (WQI) is a preliminary assessment of water quality. The calculation of the WQI is based upon several physico-chemical and bacteriological parameters. Examples of different water quality indices developed worldwide are the US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), Oregon Water Quality Index (OWQI) (Poonam et al., 2013), and Indian Water Quality Index (Tiwari and Mishra, 1985). Interestingly, Ho (2012) presented the concept of indexing water with a numerical value to express groundwater quality, which was called as Total Water Quality Index (TWQI). In Thailand, Sungsitthisawad and Pitaksanurat (2013) developed Groundwater Quality Index (GWQI) by integrating the complex groundwater quality data into a numerical score, which was employed as a simple mathematical tool for planning water supply production in Khon Kaen city. Noticeably, the application of the WQI can be used as an efficient method for evaluating quality of groundwater. For the purpose of this study, the WQI developed by Tiwari and Mishra (1985), which was simplified from using weighting factors and standardized into a parameter (see details in section 2.2), is recognized and chosen as an appropriate application for evaluating groundwater quality in the study area.

The Geographical Information System (GIS) is widely known and can be used as an effective tool for water quality and quantity analysis and is useful for modeling and detecting environmental change (Asadi et al., 2007). Additionally, program R is a free software environment for statistical computing and graphics. It compiles and runs on a wide variety of UNIX platforms, Windows and MacOS. The Program R can be used as a tool to visualize, monitor and analyze scientific data. Therefore, the main objective of this study is to integrate GIS and Program R applications with the WQI for the evaluation of groundwater quality and quantity in order to answer the question of this study "Does urbanization significantly impact on groundwater quality and quantity in Nakhon-Nayok province, Thailand?".

2. Materials and Methods

2.1 Study area

Nakhon-Nayok is one of the eastern central provinces of Thailand. The total area of Nakhon-Nayok is 2,122 km^2 that is subdivided into four districts; namely, Mueang Nakhon Nayok, Ban Na, Pak Phli, and Ongkharak (Figure 1). The climate is temperate with a daily mean maximum temperature varying from a minimum of 24 ^{o}C in December to a maximum of 34 ^{o}C in April. The rainfall in Nakhon-Nayok is mainly from the southwest monsoon with the total annual average rainfall of about 193 mm. The population in 2018 was approximately 258,000. Most of the agriculture in Nakhon-Nayok is growing rice and tropical fruits, e.g. mangos, durians, mangosteens, and oranges. These agricultural products are the main commercial products of the area (Department of Nakhon-Nayok Province, 2016).

In terms of topography, the province is mostly flat, with some steep mountains in the east and the north of the province. The highest mountain, which is approximately 1,351 m. above mean sea level, is in the northeast. The central and southern regions are mostly flat and are parts of the Chao Phraya deltaic area, known as "the Great Central Plain". The soil is composed mainly of silty clay and clay, which benefit farming and fruit plantations in this region. The main river is Nakhon-Nayok River flowing from the mountain in the north to the southwest. The River merges with Bang Prakong River and flows southward out to the ocean in the Gulf of Thailand. As this region is a major rice growing area, the quantity and quality of water are very important. However, the water supply from Nakhon-Nayok River is frequently not enough for farming. Groundwater, thus, has continuously become an important source in this region, especially in the drought season (Department of Nakhon-Nayok Province, 2016; Department of Groundwater Resources, 2018).

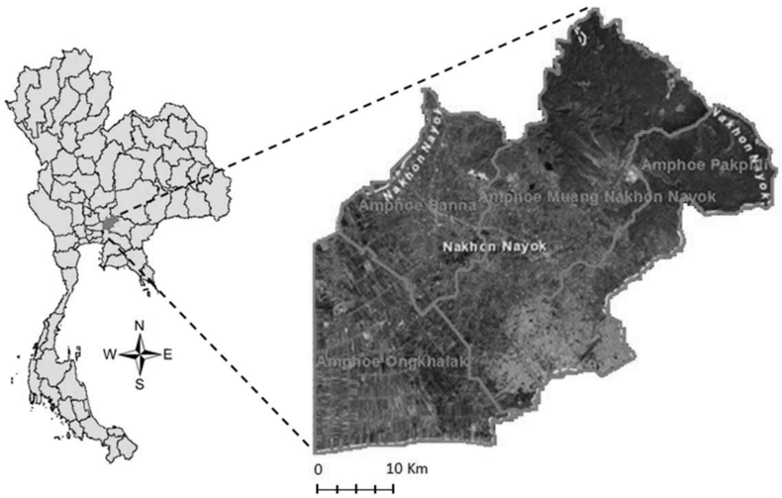

Figure 1. Nakhon-Nayok province in Thailand

2.2 Methodology

2.2.1 Data collection

The data of well and groundwater characteristics was collected for the study including the depth and water level in wells, water uses, pH, nitrate (NO_3^-), sulfate (SO_4^{2-}), chloride (Cl^-), fluoride (F^-), alkalinity, sodium (Na^+) hardness, and total dissolved solids (TDS). All data (413 domestic wells) in the study area were obtained for 2015-2017 from the Department of Groundwater Resources, Thailand. These data can be downloaded from the website http://app.dgr.go.th/newpasutara/xml/Krabi.files/show.php.

2.2.2 Assessment of groundwater level and flow by program R

In the study, program R was used for the visualization of groundwater quantity through water level in wells and estimation of groundwater flow direction. The R scripts were built with the Shiny framework and produced groundwater level maps using plotly, leaflet, highcharts, and ggplot2 which accessed through R packages.

For estimating groundwater flow, the Groundwater Spatiotemporal Data Analysis Tool (GWSDAT) which has been developed by Shell Global Solutions and the University of Glasgow based on program R language, was applied in the study. Vectors of groundwater flow strength and direction were calculated using the well coordinates and recorded groundwater elevations. The model is based on the simple premise that local groundwater flow will follow the local direction of steepest descent (hydraulic gradient). For a given well, a linear plane is fitted to the local groundwater level data (Jones et al., 2014):

$$L_i = a + bx_i + cy_i + e_i \qquad \text{(e.q.1)}$$

where L_i represents the groundwater level at location (x_i, y_i). Local data is defined as the neighboring wells as given by a Delaunay triangulation (Turner, 2012) of the monitoring well locations. The gradient of this linear surface in both x and y directions is given by the coefficients b and c. Estimated direction of flow is given by:

$$delta = tan^{-1}(\frac{c}{b}) \qquad \text{(e.q. 2)}$$

and the relative hydraulic gradient (a measure of relative flow velocity) is given by:

$$R = \sqrt{b^2 + c^2} \qquad \text{(e.q. 3)}$$

where *R* represents the relative hydraulic gradient. b and c are the coefficients.

An example of R scripts for the study is presented as following below (all R scripts is available in Appendix and on website http://thai-deutsch-civilengineering.blogspot.com):

```
      logo: Mholan00.png
      #favicon: Mholan00.png
      title: "Groundwater Management in Thailand"
      runtime: shiny
      output: flexdashboard::flex_dashboard:
              orientation: rows
              vertical_layout: fill
              social: menu
###########################
full_tracts<-full_tracts%>%  dplyr::mutate(waterdeep=cut(waterdeep
,c(0,50,100,150,200,250),
labels = c('> 0 & <= 50', '> 50 & <= 100', '> 100 & <= 150', '> 150 & <= 200',
'> 200 & <= 250')))
full_tracts.df <- split(full_tracts, full_tracts$waterdeep)
l <- leaflet() %>% addTiles()
names(full_tracts.df) %>%
      purrr::walk( function(df) {
l <<- l %>%
     addMarkers(data=full_tracts.df[[df]],
               lng=~long, lat=~lat,
              label=~as.character(waterdeep),
              popup=~as.character(waterdeep),
              group = df,
              clusterOptions=markerClusterOptions(removeOutsideVisibleB
ounds=F), labelOptions=labelOptions(noHide=F, direction= 'auto'))
})
l %>%
      addLayersControl(
      overlayGroups = names(full_tracts.df),
      options = layersControlOptions(collapsed = FALSE)
)
```

2.2.3 Assessment of groundwater quality in piper diagram

In this study, hydrochemical facies types were illustrated by piper plots for analyzing the alkalinity and salinization of groundwater quality. Frequently, the concept of hydrochemical facies has been used in hydrologic studies as an approach to identify dominant groundwater chemical types in many countries e.g. the US (Chaudhuri and Ale, 2014), Italy (Mongeli et al., 2013), Belgium (Vandenbohede and Lebbe, 2012), Algeria (Belkhiri et al., 2011), Iran (Aghazadeh and Mogadda, 2010), India (Sadashivaiah et al., 2008), and Ethiopia (Kebede et al., 2005). In Thailand, the hydrochemical facies concept has been used to identify the problem of soil and groundwater salinization by integrating with remote sensing (Wannakomol, 2005).

2.2.4 Calculation and assessment for water quality index (WQI)

The WQI is a useful and efficient method for assessing the quality of water and communicating the information about overall water quality (Alam and Pathak, 2010; Jerome and Pius, 2010). Thus, the classification of groundwater quality in the study area was done more realistically and accurately by using the WQI and taking parameters such as pH, nitrate (NO_3^-), sulfate (SO_4^{2-}), chloride (Cl^-), fluoride (F^-), hardness, and total dissolved solids (TDS). The method for calculating the WQI is based upon the calculation as suggested by Tiwari and Mishra (1985) and Vandenbohede and Lebbe, (2012). There are two fundamental steps to calculate the WQI for the suitability of groundwater for the standard drinking purpose: (1) calculating a quality rate for each water quality parameter used in the indices and (2) aggregating these sub-indices into overall index. The WQI is computed as the following formula (Tiwari and Mishra, 1985).

$$WQI = \sum_{i=1}^{n} W_i \text{ x } q_i \qquad \text{(e.q.4)}$$

where WQI is the Water Quality Index [-], Wi is the weightage factor that is computed from the following equation in Table 1 [-] and q_i is the quality rate that is determined from Table 2 based on WHO (2008) [-].

$$W_i \propto \frac{1}{S_i} \quad \text{or} \quad W_i = K/S_i \qquad \text{(e.q.5)}$$

where K is the proportionality constant that is estimated from the equation (6) [-] and Si is the WHO standard values of the water quality parameter (Table 1). The value of K can be evaluated:

$$\sum_{i=1}^{n} W_i = 1 \text{ or } \sum_{i=1}^{n} K/S_i = 1 \text{ or } K\sum_{i=1}^{n} 1/S_i = 1 \quad \text{or} \quad K = [1/(\sum_{i=1}^{n} 1/S_i)] \qquad \text{(e.q.6)}$$

Based upon the above WQI values, the groundwater quality is rated as good, average, below average, poor or unfit for human consumption (Table 3).

Table 1. Water quality parameters of the WHO standard, and assigned unit weights (WHO, 2008)

Parameter	Standard (S_i)	Weightage (W_i)
pH	8.5	0.1417
Nitrate (NO_3^-)	50	0.0241
Sulfate (SO_4^{2-})	250	0.0048
Chloride (Cl^-)	250	0.0048
Fluoride (F^-)	1.5	0.8032
Total dissolved solids (TDS)	1000	0.0012
Total hardness	300	0.0040
Alkalinity	120	0.0100
Sodium	200	0.0060

(All units except pH are in mg/l)

Table 2. Water quality parameters and rating values based on WHO (2008)

Rating Scale					
Parameter	Rating Value (q_i)				
	100	75	50	25	0
pH	≥ 6.5 to ≤ 8.5	6.5 or 8.5	≥ 6.0 to < 6.5 or > 8.5 to ≤ 9.0	≥ 5.75 to < 6.0 or > 9.0 to ≤ 9.25	< 5.75 or > 9.25
Nitrate (NO_3^-)	≤ 45	45	> 45 to ≤ 67.5	> 67.5 to ≤ 135	>135
Sulfate (SO_4^{2-})	≤ 200	> 200 to ≤ 400	> 400 to ≤ 600	> 600 to ≤ 1200	>1200
Chloride (Cl^-)	≤ 250	> 250 to ≤ 1000	> 1000 to ≤ 1500	> 1500 to ≤ 3000	>3000
Fluoride (F^-)	≤ 1.0	> 1.0 to ≤ 1.5	> 1.5 to ≤ 2.2	> 2.2 to ≤ 4.5	>4.5
Total dissolved solids (TDS)	≤ 500	> 500 to ≤ 2000	> 2000 to ≤ 3000	> 3000 to ≤ 6000	>6000
Total hardness	≤ 300	> 300 to ≤ 400	> 400 to ≤ 500	> 500 to ≤ 600	>600
Alkalinity	≤ 200	> 200 to ≤ 600	> 600 to ≤ 900	> 900 to ≤ 1800	>1800
Sodium	≤ 200	> 200 to ≤ 400	> 400 to ≤ 600	> 600 to ≤ 1200	>1200

(All units except pH are in mg/l)

Table 3. Water quality index categories

Water Quality Index (WQI)	Description (Water Quality Rate)
0-49	Poor
50-74	Below Average
75-89	Average
90-100	Good

2.2.5 Attribute database and surface interpolation

The attribute database was generated with the selected parameters of the groundwater contamination for the piper diagram and WQI. The spatial distribution maps were prepared to simply identify the variation in concentrations of parameters in the groundwater at various locations of the study area by using a technique of ArcGIS 10.3.1 for Desktop. Although there are several spatial interpolation techniques available in GIS, the Inverse Distance Weighted (IDW) approach was selected to use in this study. This method uses a defined or selected set of sample points for estimating the output grid cell value. It determines cell values by using a linearly weighted combination of a set of sample points. It also controls the significance of known points upon the interpolated values based upon their distance from the output point for generating a surface grid (Arsalan, 2004). Selected parameters of the groundwater quality and well characteristics were analyzed in the study area with the help of the spatial interpolation technique in GIS. This technique enables us to investigate the relationship of cause and effect with a spatial map. Figure 2 shows the overall methodology for data analysis, interpolation, and interpretation in this study.

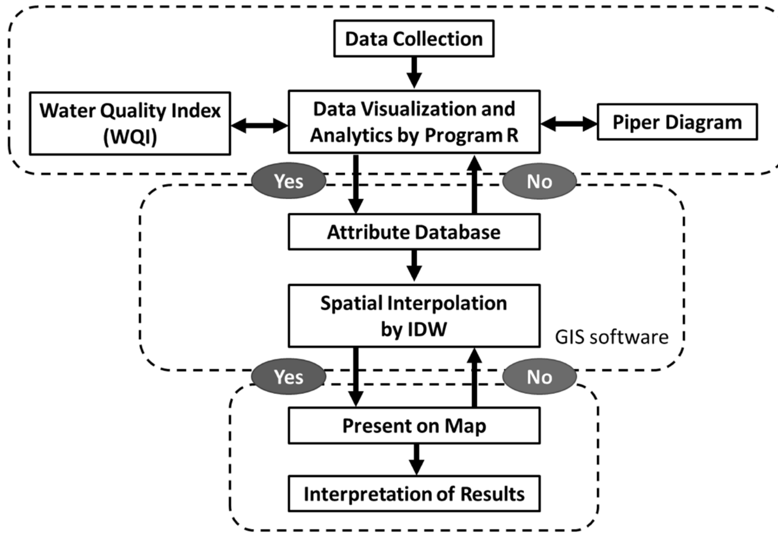

Figure 2. Flow chart for the methodology

3. Results and Discussion

3.1 Showing collected data for the study

After collecting data of landscape, soil texture and well characteristics with groundwater chemical parameters in the study area, it shows that the most of wells are located in domestic areas. These selected data are used in ArcGIS to create spatial maps. Obviously, higher landscape slope is in northern study area as shown in Figure 3. Figure 3 shows spatial maps with collected data as the following.

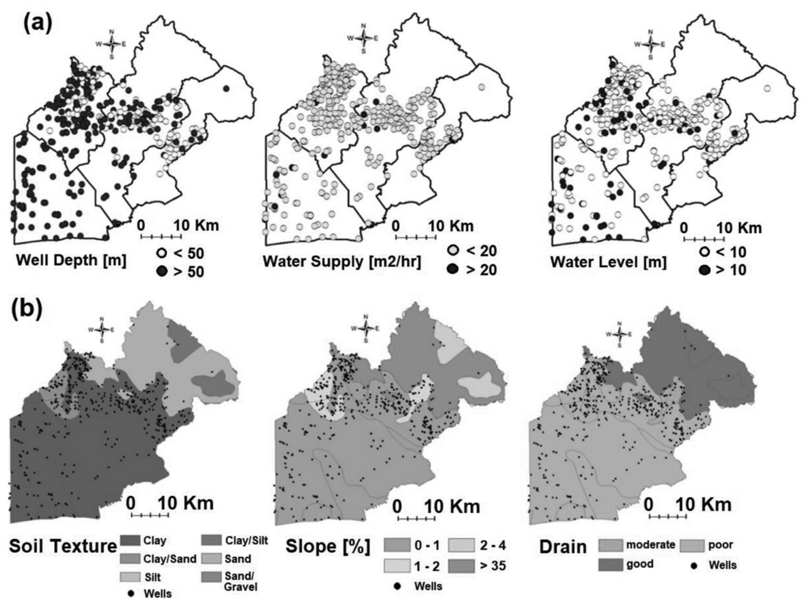

Figure 3. (a) well depth, water supply and water level from 413 wells and (b) soil texture, slope and drain abilities (Department of Groundwater Resources, 2018)

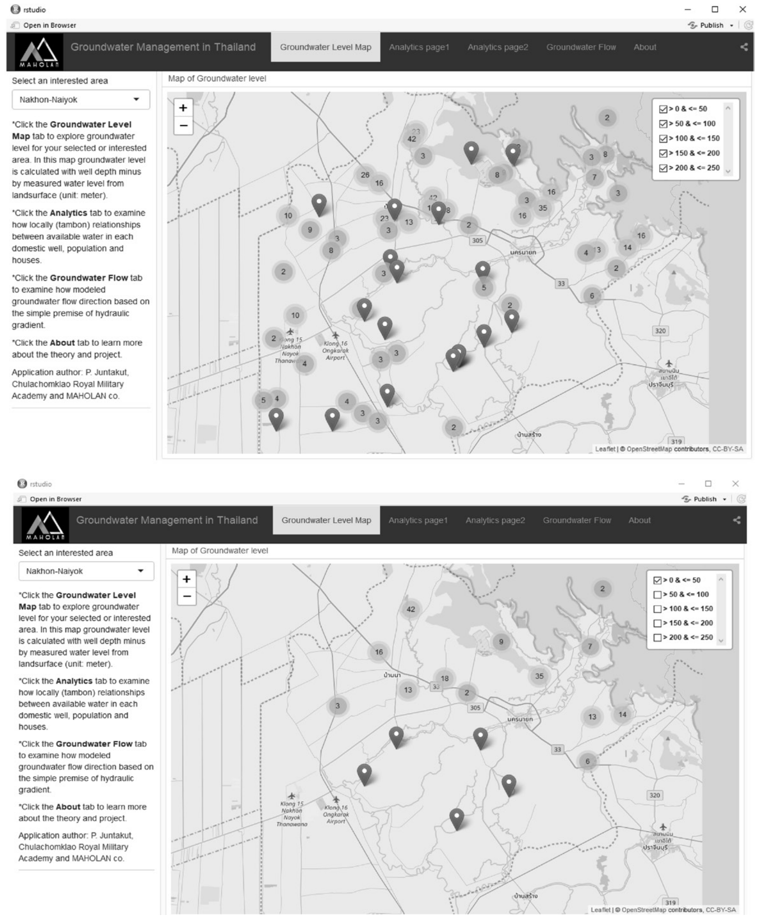

Figure 4. Showing all wells in the study area with five groups of different groundwater levels (above) and the group of lowest groundwater level in 0-50 meter (bottom)

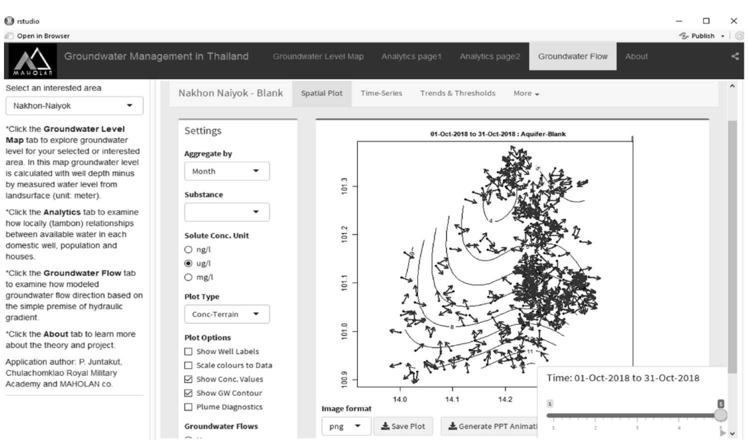

Figure 5. Showing directions of groundwater flow in the study area using GWSDAT software in Program R

3.3 Groundwater level and flow

Figure 4 and Figure 5 present maps of groundwater quantity by considering on groundwater level and flow in the study area. On the maps, a number means the amount of wells and a circle with orange color is higher density of wells in an area. The results show lower groundwater level are found in Amphoe Ban Na where is a community or urban area of the study area (Figure 4). Probably, less groundwater recharge areas occur in the area of communities in Amphoe Ban Na due to less green areas. Although estimated groundwater flow is not clear about the direction of groundwater flow in the study area, but groundwater level contours show that the direction of groundwater flow is generally from northern to southern area of the study area due to slope of landscape (Figure 5).

3.4 Spatial variability of groundwater quality

The analysis of depth, water discharge, and water level of wells in the study area is essential comparatively for a proper understanding of groundwater quality. On spatial maps, the major water discharge is observed in the southern parts of urban area (Amphoe Ban Na) with 48 m^2/hr. This discharge is from wells with a depth of approximately 245 m as shown in Figure 6 (a) and (b). On the other hand, the high groundwater quantity is mostly located in the middle area of Amphoe Ban Na, where there is a high density of wells as presented in Figure 6 (c) and (d).

High concentrations of nitrate (2-10 mg/l) are found in the western and middle of the study area (Amphoe Ban Na and Muang Nakhon-Nayok). In the same areas, high concentrations of fluoride, more than 2 mg/l (higher than 1.5 mg/l WHO standard drinking water), are also found. Fluoride, the most commonly occurring form of fluorine, is a natural contaminant of water. Groundwater usually contains fluoride dissolved from geological formations in the western study area. Granitic rocks in this study area which are a typical source of fluoride rich rocks contain higher fluoride than any other rock type (Krauskopf and Bird, 1995; Brindha and Elango, 2011). The weathering of these rocks results in increased fluoride content in groundwater. Both nitrate and fluoride are significant parameters affecting the suitability of groundwater for human consumption. Interestingly, high concentrations of nitrate and fluoride are observed in the depth of wells less than 50 m as shown in Figure 6 (e) and (f). Recent studies indicated that the depth of wells is an influenced factor of groundwater nitrate concentrations. Shallower wells are likely to have higher contamination levels in groundwater than deeper wells (Nolan and Hitt, 2006; Juntakut et al., 2019).

Differences in extent of groundwater salinization across the study area are aptly reflected by contrasting hydrochemical concentrations and groundwater chemical parameters in the piper diagram (Figure 7). Lower salinity (TDS < 500 mg/l) is accompanied by predominant Ca-HCO_3 facies with minor contribution from the Ca-SO_4, Na-HCO_3, and Na-Cl facies (Figure 7 in (a)). Abundance of the HCO_3^- facies in Amphoe Ban Na, Muang Nakhon-Nayok, and Pakphi signified fresh groundwater recharge and/or lesser salinization. Source of Ca^{2+}, Mg^{2+}, and HCO_3^- in the northern parts of the study area can partly be attributed to the dissolution of carbonate minerals presented as cement within the caliche layers, which are abundant in the upper soil horizons of Nakhon-Nayok province. Commonly, the formation of Ca^{2+} and HCO_3^- ions can lead to generation of acidity, as shown by following reactions (Bohlke et al., 2002):

$$CaCO_3 + H^+ <=> Ca^{2+} + HCO_3^- \quad \text{(e.q. 7)}$$

Higher salinization (TDS > 500 mg/l) in the study area is probably accompanied by (i) the predominance of Cl- and SO_4^{2-} over HCO_3^-, and (ii) the emergence of mixed cation-SO_4-Cl, and Na-Cl facies by replacing the HCO_3^- facies that were found in the lower salinity observations (Figure 7 in (b) and (c)). The abundance of HCO_3^- across

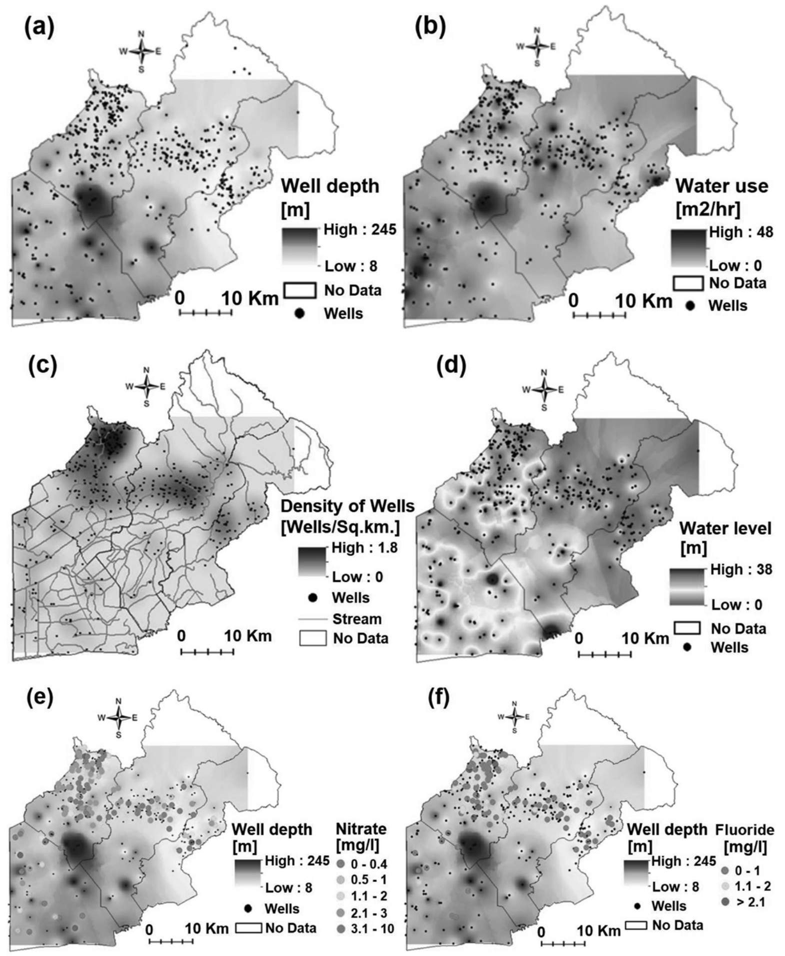

Figure 6. Spatial Distribution of (a) depth of wells, (b) water discharge, (c) density of wells, (d) water level of wells, (e) nitrate contamination compared with the depth of wells, and (c) fluoride contamination compared with the depth of wells

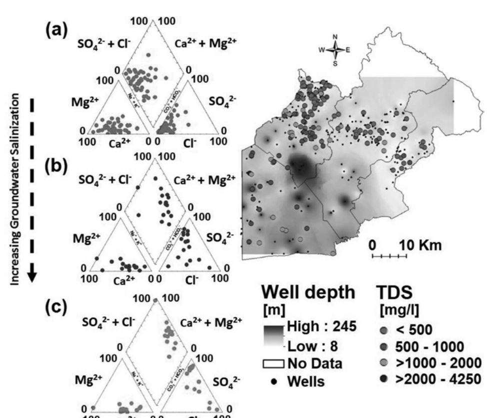

Figure 7. The piper diagram for analyzing the alkalinity and salinization of the groundwater quality in the study area

the northern area (Amphoe Ban Na, Muang Nakhon-Nayok, and Pakphi) suggested relatively freshwater recharge in this region and the lesser HCO_3^- values in the southern parts of the study area indicated more saline recharge.

Overall, the major analysis of groundwater chemical parameters indicates that (i) there are distinct regional differences of groundwater quality between the northern parts (Amphoe Ban Na, Muang Nakhon-Nayok, and Pakphi) and southern parts (Amphoe Ongkhalak) of Nakhon-Nayok province, (ii) strong acids (Cl- and SO_4^{2-}) dominate over weak acids (HCO_3^-) in the southern parts of the study area with an opposite trend in the northern parts, (iii) the high groundwater salinization is more apparent in the southern parts and is most likely to be associated with high level of Cl- and SO_4^{2-} species with mixed cation composition, and (iv) although HCO_3^- is the dominant anion, at the low salinization, the identity of contributing chemical species is yet unclear and warrants further site-specific investigation.

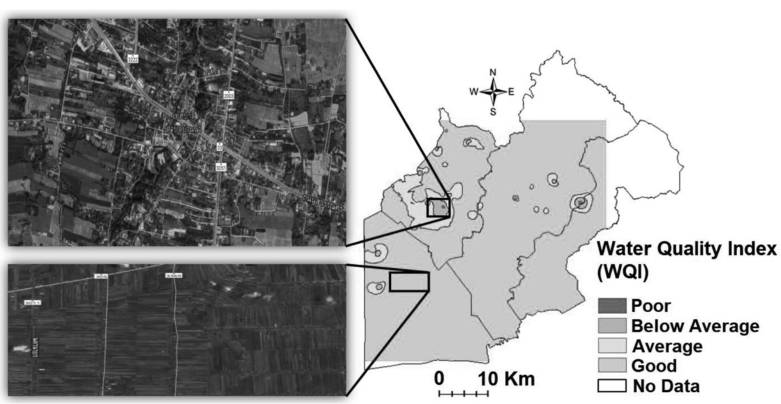

Figure 8. The WQI map for groundwater management of Nakhon-Nayok province in Thailand

3.5 Spatial distribution of water quality index (WQI)

The WQI is calculated to determine the suitability of potable water by showing on the WQI map. The WQI values reveal that the groundwater quality in Amphoe Muang Nakhon-Nayok, Pakphi, and Ongkhalak is mostly of good quality with the WQI ranging between 90-100. Therefore, it can be used for drinking as well as agricultural uses. Interestingly, the groundwater quality in Amphoe Ban Na is of average and below average quality with the WQI ranging between 50-89. As a result, it should be carefully considered before using groundwater for drinking and domestic purposes in urban areas of Amphoe Ban Na. The WQI map is presented in Figure 8.

4. Conclusions

From the analysis of groundwater level, urban areas can likely impact on groundwater quantity due to less groundwater recharge. Thus, community areas in Amphoe Ban Na have lower groundwater level than other areas (non-urban). In addition, based on the WQI map and the analysis of the alkalinity and salinization of groundwater quality in the piper diagram, the groundwater quality in the study area (Nakhon-Nayok province) is identified by considering on chemical parameters as pH, nitrate (NO_3^-), sulfate (SO_4^{2-}), chloride (Cl^-), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), sodium (Na^+), alkalinity, hardness, and total dissolved solids (TDS). These parameters are investigated between years 2015-2017, which are collected by the Department of Groundwater Resources, Thailand. The result presents that the community area in Amphoe Ban Na should be closely monitored in groundwater quality because of below average quality based on the WQI map. As a result, decision makers should plan a project for improving and managing groundwater in this region. Moreover, the study shows that the integration of GIS and program R with the WQI can be an effective tool for evaluating groundwater quality and quantity.

The classification of the groundwater quality in the study area has been done more realistically and accurately by using the WQI method. However, in order to reach a goal of sustainable groundwater management, there is a need to regularly monitor the groundwater quality and quantity for detecting its trends and causes, especially in urban areas which can impact on groundwater quality and quantity.

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Appendix

```
################################################################
###########
------------------------------------------------------------------------------------------------
---------------------
logo: Mholan00.png
#favicon: Mholan00.png
title: "Groundwater Management in Thailand"
runtime: shiny
output:
  flexdashboard::flex_dashboard:
    orientation: rows
    vertical_layout: fill
    social: menu
    #source_code: https://github.com/walkerke/neighborhood_diversity
    #theme: simplex
    theme: bootstrap
------------------------------------------------------------------------------------------------
----------------------
library(shiny)
library(leaflet) # devtools::install_github('rstudio/leaflet')
library(highcharter) # devtools::install_github('jbkunst/highcharter')
library(plotly) # devtools::install_github('ropensci/plotly')
library(ggplot2) # devtools::install_github('hadley/ggplot2')
library(sp)
library(dplyr)
library(flexdashboard) # devtools::install_github('rstudio/flexdashboard')
library(rgeos)
library(mapproj)
library(maptools)
library(readr)
library(ggthemes)
library(viridis)
library(raster)
library(rgdal)
################################################################
############
# Define the list of available metros
lookup <- structure(c(30001L, 30002L, 30003L, 30004L), .Names =
c("Lopburi", "Nakhon-Naiyok", "Phetchaboon", "Pracheenburi"))
# Read in data, and subset for the selected metro
#full_tracts <- readRDS('full_simp2.rds')
full_tracts <- read.csv('F:/neighborhood_diversity-num/data/3nakhon_
naiyok00.csv')
```

```
Sidebar {.sidebar}
========================================================
==========
# Define inputs
selectInput('metro_name', label = 'Select an interested area', choices =
lookup, selected = 30002L)
#sliderInput('span', label = 'Span Parameter', min = 0.1, max = 0.9, value
= 0.3,
 #         step = 0.1)
```

```
*Click the __Groundwater Level Map__ tab to explore groundwater
level for your selected or interested area.  In this map groundwater
level is calculated with well depth minus by measured water level from
landsurface (unit: meter).
*Click the __Analytics__ tab to examine how locally (tambon)
relationships between available water in each domestic well, population
and houses.
*Click the __Groundwater Flow__ tab to examine how modeled
groundwater flow direction based on the simple premise of hydraulic
gradient.
*Click the __About__ tab to learn more about the theory and project.
Application author: [P. Juntakut](http://thai-deutsch-civilengineering.
blogspot.com/),
[Chulachomklao Royal Military Academy](http://www.crma.ac.th) and
[MAHOLAN co.](https://www.maholan.co.th/)
------------------------------------------------------------------------------------------------
--------------------------
Groundwater Level Map
==========================================================
===========
Row
------------------------------------------------------------------------------------------------
--------------------------
### Map of Groundwater level
```{r}
full_tracts <- full_tracts %>%
  dplyr::mutate(waterdeep = cut(waterdeep,c(0,50,100,150,200,250),
                        labels = c('> 0 & <= 50', '> 50 & <= 100', '> 100 & <=
150', '> 150 & <= 200', '> 200 & <= 250')))
full_tracts.df <- split(full_tracts, full_tracts$waterdeep)
l <- leaflet() %>% addTiles()
names(full_tracts.df) %>%
  purrr::walk( function(df) {
    l <<- l %>%
      addMarkers(data=full_tracts.df[[df]],
                 lng=~long, lat=~lat,
                 label=~as.character(waterdeep),
                 popup=~as.character(waterdeep),
                 group = df,
                 clusterOptions = markerClusterOptions(removeOutsideVis
ibleBounds = F),
                 labelOptions = labelOptions(noHide = F,
                                   direction = 'auto'))
  })
l %>%
  addLayersControl(
    overlayGroups = names(full_tracts.df),
```
```

```
  options = layersControlOptions(collapsed = FALSE)
 )
```
Analytics page1
==
=================
Row

NAKHON NAIYOK (1)
```{r}
# showing plot3D-NEwest_01
col1 <- colorRamp(c(“blue”, “yellow”, “red”))
plot_ly(full_tracts, x = ~people, y = ~houses, z = ~water) %>%
 add_markers(color = ~water, colors = col1) %>%
 colorbar(title = “Available Water (m3/hr)”)
```
NAKHON NAIYOK (2)
```{r}
# showing plot3D-NEeast_02
col2 <- colorRamp(c(“blue”, “yellow”, “red”))
plot_ly(full_tracts, x = ~male, y = ~female, z = ~water) %>%
 add_markers(color = ~water, colors = col2) %>%
 colorbar(title = “Available Water (m3/hr)”)
```
Analytics page2
==
============
Row

NAKHON NAIYOK - Available Water vs Well Depth
```{r}
plot1 <- ggplot(full_tracts, aes(x = water, y = welldeep)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot1)
```
NAKHON NAIYOK - Available Water vs People
```{r}
plot2 <- ggplot(full_tracts, aes(x = water, y = people)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot2)
```
Row

NAKHON NAIYOK - Available Water vs People
```{r}
plot3 <- ggplot(full_tracts, aes(x = water, y = people)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot3)
```
NAKHON NAIYOK - Available Water vs Male
```{r}
plot4 <- ggplot(full_tracts, aes(x = water, y = male)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot4)
```
Row

NAKHON NAIYOK - Available Water vs Female
```{r}
plot5 <- ggplot(full_tracts, aes(x = water, y = female)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot5)
```
NAKHON NAIYOK - Available Water vs Houses
```{r}
plot6 <- ggplot(full_tracts, aes(x = water, y = houses)) +
 geom_point(alpha = 0.5) +
 geom_density_2d() +
 theme(panel.background = element_rect(fill = ‘#ffffff’))
ggplotly(plot6)
```
Groundwater Flow
==
=================
```{r}
GWSDAT_Options <- list()
GWSDAT_Options[[‘Aggby’]] <- ‘Month’   # ‘Day’, ‘Month’, ‘Quarter’, 
‘Year’
GWSDAT_Options[[‘AggMethod ‘]] <- ‘Mean’
GWSDAT_Options[[‘NDMethod’]] <- ‘Half of ND Value’
GWSDAT_Options[[‘cross’]] <- 10
GWSDAT_Options[[‘Tune’]]  <- TRUE
GWSDAT_Options[[‘gamma’]] <- c(0)
GWSDAT_Options[[‘cost’]]  <- 2^c(0,1,2,3,4,5)
# fitPSplines()
GWSDAT_Options[[‘ModelMethod’]] <- ‘pspline’  # not used, fitData() 
assumes ‘pspline’ as default because no other method works
GWSDAT_Options[[‘PSplineVars’]] <- list()
GWSDAT_Options[[‘PSplineVars’]][[‘NIG.a’]] <- 0.0001
GWSDAT_Options[[‘PSplineVars’]][[‘NIG.b’]] <- 0.0001
GWSDAT_Options[[‘PSplineVars’]][[‘pord’]]  <- 1
GWSDAT_Options[[‘PSplineVars’]][[‘bdeg’]]  <- 2
GWSDAT_Options[[‘PSplineVars’]][[‘Trial.Lambda’]] <- 10^seq(-6, 0, 
length = 30)
GWSDAT_Options[[‘PSplineVars’]][[‘nseg’]] <- 6
GWSDAT_Options[[‘smThreshSe’]] <- 1.1512  # calcTrafficLights()
GWSDAT_Options[[‘smMethod’]] <- ‘aicc’    # calcTrafficLights()
GWSDAT_Options[[‘DefContThresh’]]  <- 500
GWSDAT_Options[[‘DefPlumeThresh’]] <- 10
GWSDAT_Options[[‘DefPorosity’]] <- 0.25
GWSDAT_Options[[‘Version’]] <- ‘2.11’
GWSDAT_Options[[‘Version’]] <- as.numeric(GWSDAT_
Options[[‘Version’]])
GWSDAT_Options[[‘ShapeFileNames’]] <- NULL
# ‘Nakhon Naiyok’
GWSDAT_Options[[‘SiteName’]] <- ‘Nakhon Naiyok’
#GWSDAT_Options[[‘WellDataFilename’]]   <- ‘F:/neighborhood_
diversity-num/data/BasicExample_WellData.csv’
#GWSDAT_Options[[‘WellCoordsFilename’]] <- ‘F:/neighborhood_
diversity-num/data/BasicExample_WellCoords.csv’
#GWSDAT_Options[[‘ShapeFileNames’]]     <- c(‘F:/GWSDAT-master - 
Num/data/GIS_Files/GWSDATex2.shp’)
GWSDAT_Options[[‘WellDataFilename’]]   <- ‘F:/neighborhood_diversity-
num/data/nakhonnaiyok_WellData.csv’
```

```
GWSDAT_Options[['WellCoordsFilename']] <- 'F:/neighborhood_
diversity-num/data/nakhonnaiyok_WellCoords.csv'
#GWSDAT_Options[['ShapeFileNames']]     <- c('F:/GWSDAT-master -
Num/data/GIS_Files/London_Borough_Excluding_MHW.shp')
#GWSDAT_Options[['ShapeFileNames']]     <- c('F:/neighborhood_
diversity-num/data/GIS_Files/m_tambon.shp')
library(GWSDAT)
devtools::load_all()
launchApp(GWSDAT_Options)
```

```
#################################################################
##############
```