HUMAN HEALTH RISK ASSESSMENT ASSOCIATED WITH HEAVY METALS IN DRINKING SHALLOW GROUNDWATER WELLS AT UBON RATCHATHANI PROVINCE, THAILAND

Miss Pokkate Wongsasuluk

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
(Interdisciplinary Program)
Graduate School
Chulalongkorn University
Academic Year 2010

การประเมินความเสี่ยงสุขภาพจากการปนเปื้อนของโลหะหนักในน้ำดื่มจากบ่อบาดาลระดับตื้น จังหวัดอุบลราชธานี ประเทศไทย

นางสาวปกเกศ วงศาสุลักษณ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2553

Thesis Title	HUMAN HEALTH RISK ASSESSMENT ASSOCIATED WITH HEAVY METALS IN DRINKING SHALLOW GROUNDWATER WELLS AT UBON RATCHATHANI PROVINCE, THAILAND
By	Miss Pokkate Wongsasuluk
Field of Study	Environmental Management
Thesis Advisor	Srilert Chotpantarat, Ph.D.
Thesis Co-advisor	Wattasit Siriwong, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

……Dean of the Graduate School
(Associate Professor Pornpote Piumsomboon, Ph.D.)

THESIS COMMITTEE

…… Chairman
(Assistant Professor Ekawan Luepromchai, Ph.D.)

……Thesis Advisor
(Srilert Chotpantarat, Ph.D.)

……Thesis Co-advisor
(Wattasit Siriwong, Ph.D.)

……..…Examiner
(Tassanee Prueksasit, Ph.D.)

…… ……External Examiner
(Apaporn Siripornprasarn, Ph.D.)

5287544020 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: GROUNDWATER / RISK ASSESSMENT / HEAVY METAL CONTAMINATION / UBONRATCHATHANI

POKKATE WONGSASULUK: HUMAN HEALTH RISK ASSESSMENT ASSOCIATED WITH HEAVY METALS IN DRINKING SHALLOW GROUNDWATER WELLS AT UBON RATCHATHANI PROVINCE, THAILAND. ADVISOR: SRILERT CHOTPANTARAT, Ph.D., CO-ADVISOR: WATTASIT SIRIWONG, Ph.D.,

Most local people in an agricultural area of Ubon Ratchathani province generally consume groundwater from their farm wells that may cause an adverse health effects from contamination of heavy metals. This study aimed to assess human health risk related to heavy metals contamination in shallow groundwater wells at Ubon Ratchathani province. Water samples were randomly collected from 12 wells in wet and dry season and were quantified heavy metal concentrations by Inductive Coupled Plasma Spectrometry – Mass Spectrometry (ICP-MS). The exposure questionnaires were completed by face-to-face interviewing with 100 local people. The result showed that contaminated heavy metals (i.e., arsenic, cadmium, chromium, copper, mercury, lead, nickel, and zinc) were found in this agricultural area. Non-carcinogenic risk characterization showed that contaminations of cadmium, chromium, copper, mercury, lead, and nickel were not exceed an acceptable risk level (HQ<1) while arsenic and zinc were exceed an acceptable risk level (HQ≥1) in some locations of this area. For carcinogenic risk characterization, the local people in some locations of this area may be getting adverse health effects related to cancer from arsenic contamination more than 1 person in a million. This study suggested that local people should be more concerned about shallow groundwater drinking in this area regarding to avoid adverse health effects.

Field of Study: Environmental Management Student's Signature:.....

Academic Year: 2010 Advisor's Signature:.....

ปกเกศ วงศาสุลักษณ์: การประเมินความเสี่ยงสุขภาพจากการปนเปื้อนของโลหะหนักในน้ำดื่มจากบ่อบาดาลระดับตื้น จังหวัดอุบลราชธานี ประเทศไทย (HUMAN HEALTH RISK ASSESSMENT ASSOCIATED WITH HEAVY METALS IN DRINKING SHALLOW GROUNDWATER WELLS AT UBON RATCHATHANI PROVINCE, THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: อ.ดร.ศรีเลิศ โชติพันธรัตน์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: อ.ดร.วัฒน์สิทธิ์ ศิริวงศ์, 110 หน้า

ชาวบ้านท้องถิ่นผู้อาศัยอยู่ในเขตพื้นที่เกษตรกรรมจังหวัดอุบลราชธานีสูบน้ำบาดาลจากบ่อบาดาลระดับตื้นที่ตั้งอยู่ในเขตพื้นที่เกษตรกรรมของตนขึ้นมาเพื่อใช้ในการอุปโภคบริโภคในชีวิตประจำวัน ซึ่งโลหะหนักที่ปนเปื้อนอยู่ในน้ำบาดาลอาจส่งผลกระทบที่อันตรายต่อสุขภาพได้ การศึกษานี้จึงมีจุดประสงค์ที่จะประเมินความเสี่ยงผลกระทบต่อสุขภาพจากการดื่มน้ำบาดาลปนเปื้อนโลหะหนักในจังหวัดอุบลราชธานี บ่อน้ำใต้ดินระดับตื้นในเขตพื้นที่เกษตรกรรม 12 บ่อ ถูกสุ่มเลือกเพื่อตรวจวัดปริมาณโลหะหนักปนเปื้อน (สารหนู, แคดเมียม, โครเมียม, ทองแดง, ปรอท, ตะกั่ว, นิกเกิล, สังกะสี) ด้วยเครื่อง Inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS) นอกจากนี้ข้อมูลส่วนบุคคลและอัตราการบริโภคน้ำจากการตอบแบบสอบถามของชาวบ้านท้องถิ่นจำนวน 100 คนในจังหวัดอุบลราชธานีที่บริโภคน้ำใต้ดินถูกรวบรวมมาเพื่อใช้ในการประเมินความเสี่ยงผลกระทบต่อสุขภาพด้วย ผลการศึกษาพบว่าการปนเปื้อนโลหะหนักแคดเมียม, โครเมียม, ทองแดง, ปรอท, ตะกั่ว, และนิกเกิลอยู่ในระดับที่ไม่ส่งผลกระทบต่อสุขภาพกรณี Non-carcinogenic effects ยกเว้นสารหนูและสังกะสี ซึ่งในบางบริเวณปนเปื้อนในระดับความเข้มข้นที่เสี่ยงต่อการก่อให้เกิดโรคและส่งผลกระทบต่อสุขภาพได้ สำหรับกรณี Carcinogenic effects นั้น ปริมาณสารหนูในบางบริเวณที่ศึกษามีค่าความเข้มข้นในระดับที่สามารถส่งผลกระทบต่อสุขภาพได้ ซึ่งผลกระทบนั้นอาจก่อให้เกิดโรคมะเร็งในชาวบ้านจำนวนมากกว่า 1 คนในจำนวนชาวบ้าน 1 ล้านคนที่บริโภคน้ำใต้ดินปนเปื้อนนี้ การศึกษาครั้งนี้ชี้ให้เห็นว่าชาวบ้านท้องถิ่นไม่ควรบริโภคน้ำใต้ดินจากบ่อบาดาลระดับตื้นในเขตพื้นที่เกษตรในอำเภอเมืองจังหวัดอุบลราชธานีเพื่อหลีกเลี่ยงความเสี่ยงผลกระทบต่อสุขภาพ

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต .....

ปีการศึกษา 2553 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก .....

ACKNOWLEDGEMENTS

The completion of this dissertation would not be accomplished without who helped me through gathering my goal. I would like to express my sincere gratitude to my advisor, Srilert Chotpantarat, PhD. and my co-advisor, Wattasit Siriwong, PhD. for their kindness supports, suggestions, constantly attention, invaluable knowledge, and encouragement all the time during this study.

To my thesis chairman and committees, Assistant Professor Ekawan Luepromchai, Ph.D., Tassanee Prueksasit, Ph.D., and Apaporn Siripornprasarn, Ph.D., I would like to gratefully acknowledge for their interest, comments, suggestions, and invaluable knowledge.

I gratefully thank to Mr. Sakchai at Ubonratchathani University. Also thank to Miss Sutisar and Miss Lalita my colleagues in National Center of Excellence for Environmental and Hazardous Waste Management (NCE-EHWM), Chulalongkorn University for their kind assistance, nice relationship, and encouragement. In addition, I would like to thank all local people at Muang district, Ubon Ratchathani province, Thailand who were participants in this study.

The research financial support, which was provided by the National Center of Excellence for Environmental and Hazardous Wastes Management (NCE-EHWM), Chulalongkorn University, Conference Grant For Master Degree Student, Thai Fogarty ITREOH Center (ITREOH, Fogarty International Center-National Institutes of Health-NIEHS: D43 TW007849-01), Cluster Aging Society (AS581A), National Research University, Chulalongkorn University and the 90th Anniversary of the Chulalongkorn University Fund Ratchadaphiseksomphot Endowment Fund.

Finally, I would like to gratefully thank my lovely family for their continuous financial support, all help and encouragement. I am very happy and proud to be a part of my lovely family.

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Overview

Water is one of the essentials that supports all forms of plant and animal life (Vanloon and Duffy, 2005) and it is generally obtained from two principal natural sources; Surface water such as fresh water lakes, rivers, streams and groundwater (i.e. borehole water and well water) (McMurry and Fay, 2004; Mendie, 2005). Water has unique chemical properties due to its polarity and hydrogen bonds which mean it is able to dissolve, absorb, adsorb or suspend many different compounds (WHO, 2007). Thus, in nature, water is not pure as it acquires contaminants from its surrounding and those arising from humans and animals as well as other biological activities (Mendie, 2005).

Nowadays, there are several problems which are concerned about environment. One of the most important environmental issues today is groundwater contamination (Vodela et al., 1997) and among the wide diversity of contaminants affecting water resources, heavy metals receive particular concern considering their strong toxicity even at low concentrations (Marcovecchio et al., 2007). Heavy metals are elements having atomic weights between 63.546 and 200.590. They exist in water in colloidal, particulate and dissolved phases (Adepoju-Bello et al., 2009) with their occurrence in water bodies being either of natural origin (e.g. eroded minerals within sediments, leaching of ore deposits and volcanism extruded products) or of anthropogenic origin (i.e. solid waste disposal, industrial or domestic effluents, harbour channel dredging) (Marcovecchio et al., 2007). Some of the metals are essential to sustain life-calcium, magnesium, potassium and sodium must be present for normal body functions. Also, Co, Cu, Fe, Mn, Mo and Zn are needed at low levels as catalyst for enzyme activities (Adepoju-Bello et al., 2009). However, excess exposure to heavy metals can result in toxicity.

Moreover, heavy metal can cause serious health effects with varied symptoms depending on the nature and quantity of the metal ingested (Adepoju-Bello and Alabi, 2005). They produce their toxicity by forming complexes with proteins, in which carboxylic acid (–COOH), amine ($–NH_2$), and thiol (–SH) groups are involved. These

modified biological molecules lose their ability to function properly and result in the malfunction or death of the cells. When metals bind to these groups, they inactivate important enzyme systems or affect protein structure, which is linked to the catalytic properties of enzymes. This type of toxin may also cause the formation of radicals which are dangerous chemicals that cause the oxidation of biological molecules (Momodu and Anyakora, 2009).

As known that Thailand is an agricultural country, there produced a large amount of agricultural products such as rice and fruits, especially the northeast of Thailand where is the high agricultural activities area that produced lots of rice and chillies. In addition, Muang district, UbonRachathani province is the largest area of chilli production in Thailand. For the purpose of highest product requirement, many loads of fertilizers were applied to add in farm soils and led to a widespread accumulation of heavy metals in agricultural soils. When water downward through soils, heavy metal might dissolve from such soils and released downward until reaching into shallow aquifer system.

As mentioned, some heavy metals are potentially toxic to human health as exceeding the standard level. Although some elements are actually necessary for humans in few amounts, on the other hand, some elements are carcinogenic or toxic which have an effect on the central nervous system, kidneys, liver, skin, bones, or teeth. However, long time ago until nowadays, people who have lived in this agricultural area generally consume groundwater from their wells located in their farm (Figure1.1) because they don’t concern about negative effects from heavy metal contamination in groundwater.

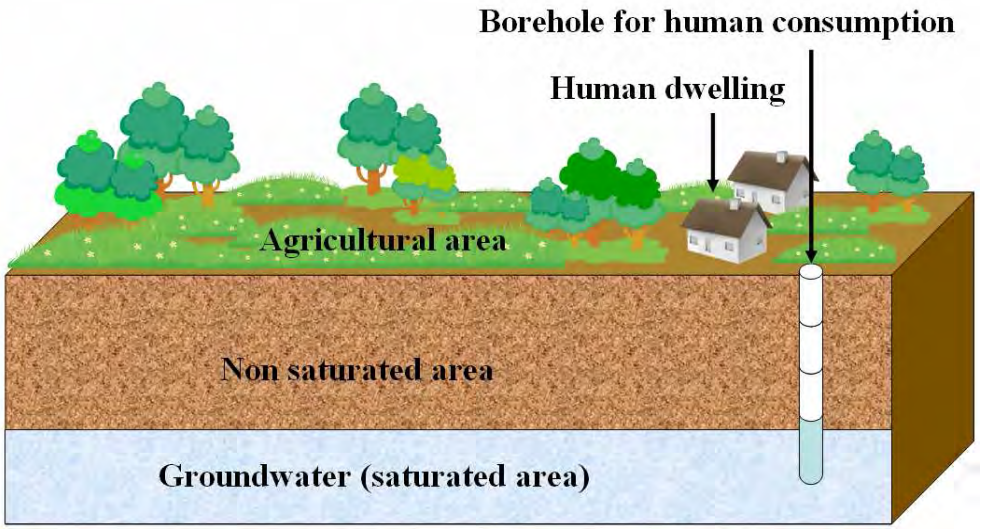

Figure1.1 Graphic representation of the scenario studied.

There is thus the need to assess the human health risk associated with heavy metal contaminated in shallow groundwater. Moreover, human health risk assessment can prevent the disease and adverse effect in order to local people who lived and consumed contaminated groundwater in such agricultural area.

1.2 Objective

The aims of this thesis were focused on human health risk assessment associated with heavy metals which were arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc that contaminated in drinking shallow groundwater. There were two objectives of this thesis as following.

1) To investigate heavy metal concentrations in shallow groundwater wells at Ubon Ratchathani province**.**

2) To assess the level of the human health risk from contaminated groundwater for the residence in the vicinity area.

1.3 Scope of Study

The study area was agricultural area at Muang district, UbonRachatani province, Thailand. This area was the largest areas of chilli farming in Thailand. The

twelve shallow groundwater wells in agricultural area were random by selected and contaminated shallow groundwater were collected. Sampling was carried out during two different seasons which were during the months of June, August, November, 2010 and January, 2011. All samples would be analyzed for concentrations of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn) by Inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS). For the purpose of human health risk assessment calculation, face-to-face interviews with local people who lived and consumed shallow groundwater at study area were used for collect personal information and rate of their groundwater consumption. Finally, human health risk assessment was done.

1.4 Expected Research Outcome

1. The concentration of heavy metals which were arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in shallow groundwater at Ubon Ratchathani province, Thailand.

2. Level of human health risk on local people who consume shallow groundwater at Ubon Ratchathani province, Thailand.

3. Risk map related to heavy metal contamination and local consumption between wet and dry season.

CHAPTER II

LITERATURE REVIEWS

2.1 Heavy Metals

2.1.1 Definition of Heavy Metals

"Heavy metals" are chemical elements with a specific gravity that is at least 5 times the specific gravity of water (Lide, 1992). The specific gravity of water is 1 at 4°C (39°F). Simply stated, specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Some well-known toxic metallic elements with a specific gravity that is 5 or more times that of water are arsenic, 5.7; cadmium, 8.65; iron, 7.9; and lead, 11.34 (Lide, 1992).

There are 35 metals that concern us because of occupational or residential exposure; 23 of these are the heavy elements or "heavy metals": antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc (Glanze, 1996). Interestingly, small amounts of these elements are common in our environment and diet and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning). Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Allergies are not uncommon and repeated long-term contact with some metals or their compounds may even cause cancer (International Occupational Safety and Health Information Centre, 1999). For some heavy metals, toxic levels can be just above the background concentrations naturally found in nature. Therefore, it is important for us to inform ourselves about the heavy metals and to take protective measures against excessive exposure. In most parts of the United States, heavy metal toxicity is an uncommon medical condition; however, it is a clinically significant condition when it does occur. If unrecognized or inappropriately treated, toxicity can result in significant illness and reduced quality of life (Ferner, 2001).

Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings (Roberts, 1999).

2.1.2 Symptoms of Heavy Metal Toxicity:

2.1.2.1 Acute and Chronic

Exposure to toxic heavy metals is generally classified as acute, 14 days or less; intermediate, 15-354 days; and chronic, more than 365 days (Agency for Toxic Substances and Disease Registry (ATSDR), 2005) Additionally, acute toxicity is usually from a sudden or unexpected exposure to a high level of the heavy metal (e.g., from careless handling, inadequate safety precautions, or an accidental spill or release of toxic material often in a laboratory, industrial, or transportation setting). Chronic toxicity results from repeated or continuous exposure, leading to an accumulation of the toxic substance in the body. Chronic exposure may result from contaminated food, air, water, or dust; living near a hazardous waste site; spending time in areas with deteriorating lead paint; maternal transfer in the womb; or from participating in hobbies that use lead paint or solder. Chronic exposure may occur in either the home or workplace. Symptoms of chronic toxicity are often similar to many common conditions and may not be readily recognized. Routes of exposure include inhalation, skin or eye contact, and ingestion (Anon. 1993; WHO 1998; International Occupational Safety and Health Information Centre, 1999; Roberts, 1999; Dupler, 2001; Ferner, 2001).

2.1.2.2 Non-Carcinogenic Effects and Carcinogenic Effects

Non-carcinogenic effects are the symptoms or diseases from non-carcinogen which are some kinds of the heavy metals that can cause diseases but can not cause cancer. On the other hand, carcinogen can cause cancer.

Non-Carcinogen: Cadmium (Cd)

Cadmium can be found in soils because insecticides, fungicides, sludge, and commercial fertilizers that use cadmium are used in agriculture. Inhalation accounts for 15-50% of absorption through the respiratory system; 2-7% of ingested cadmium is absorbed in the gastrointestinal system. Target organs are the liver, placenta, kidneys, lungs, brain, and bones (Roberts, 1999).

Symptoms of acute cadmium exposure are nausea, vomiting, abdominal pain, and breathing difficulty. Chronic exposure to cadmium can result in chronic obstructive lung disease, renal disease, and fragile bones. Symptoms of chronic exposure could include alopecia, anemia, arthritis, learning disorders, migraines, growth impairment, emphysema, osteoporosis, loss of taste and smell, poor appetite, and cardiovascular disease (Roberts, 1999).

Non-Carcinogen: Copper (Cu)

Copper, as native copper, is one of the few metals to occur naturally as an un-compounded mineral. Copper is a reddish brown nonferrous mineral which has been used for thousands of years by many cultures. The body needs trace amounts of copper in order to function properly but too much exposure to copper can cause a number of health problems. The most routine exposures to copper involved in contact with it through the air, drinking water and from foods. It can also enter the body through the skin. The places where copper accumulates are the liver first, then the brain and the reproductive organs. Copper may affect any organ or system of the body. However, it usually affects about four or five major systems of the body. These are the nervous system, the female and male reproductive system, connective tissues such as hair, skin and nails and organs like the liver. In conclusion, simply breathing in copper can cause irritation to your nose and throat. If you ingest copper orally, it may cause Nausea, vomiting, diarrhea, liver damage, and kidney damage (Eck and Wilson, 1989).

Non-Carcinogen: Pb : Lead

Lead accounts for most of the cases of pediatric heavy metal poisoning (Roberts, 1999). It is a very soft metal and was used in pipes, drains, and soldering

materials for many years. Millions of homes built before 1940 still contain lead (e.g., in painted surfaces), leading to chronic exposure from weathering, flaking, chalking, and dust. Every year, industry produces about 2.5 million tons of lead throughout the world. Target organs are the bones, brain, blood, kidneys, and thyroid gland (International Occupational Safety and Health Information Centre, 1999; ATSDR ToxFAQs for Lead).

Acute exposure to lead is also more likely to occur in the workplace, particularly in manufacturing processes that include the use of lead (e.g., where batteries are manufactured or lead is recycled). Symptoms include abdominal pain, convulsions, hypertension, renal dysfunction, loss of appetite, fatigue, and sleeplessness. Other symptoms are hallucinations, headache, numbness, arthritis, and vertigo. Chronic exposure to lead may result in birth defects, mental retardation, autism, psychosis, allergies, dyslexia, hyperactivity, weight loss, shaky hands, muscular weakness, and paralysis (beginning in the forearms). In addition to the symptoms found in acute lead exposure, symptoms of chronic lead exposure could be allergies, arthritis, autism, colic, hyperactivity, mood swings, nausea, numbness, lack of concentration, seizures, and weight loss (International Occupational Safety and Health Information Centre, 1999).

Non-Carcinogen: Nickel (Ni)

Nickel is a very abundant element. In the environment, it is found primarily combined with oxygen (oxides) or sulfur (sulfides). It is found in all soils and is emitted from volcano. Pure nickel is a hard, silvery-white metal that is combined with other metals to form alloys. Nickel and its compounds have no characteristic odor or taste. Nickel is required to maintain health in animals. A small amount of nickel is probably essential for humans, although a lack of nickel has not been found to affect the health of humans. Much of the nickel in the environment is found with soil and sediments because nickel attaches to particles that contain iron or manganese, which are often present in soil and sediments.

The most common adverse health effect of nickel in humans is an allergic reaction. People can become sensitive to nickel when things containing it are in direct contact with the skin, when they eat nickel in food, drink it in water, or breathe dust

containing it. Once a person is sensitized to nickel, further contact with it will produce a reaction.

Chronic exposure to nickel can reduce lung function. Although a soluble nickel compound in body did not cause cancer but nickel compounds that were hard to dissolve caused cancer. The acute toxicity of *nickel carbonyl* by inhalation is high. Acute toxic effects occur in two stages, immediate and delayed. Headache, dizziness, shortness of breath, vomiting, and nausea are the initial symptoms of overexposure; the delayed effects (10 to 36 hours) consist of chest pain, coughing, shortness of breath, bluish discoloration of the skin, and in severe cases, delirium, convulsions, and death. Recovery is protracted and characterized by fatigue on slight exertion. Workers who accidentally drank water containing 100,000 times more nickel than in normal drinking water had stomach aches and effects to blood and kidneys (Natural Healing Site Natural Healing Site, 2010).

Both Non-Carcinogen and Carcinogen: Arsenic (As)

Arsenic is the most common cause of acute heavy metal poisoning in adults. Arsenic may be also be found in water supplies worldwide, leading to exposure of shellfish, cod, and haddock. Target organs are the blood, kidneys, and central nervous, digestive, and skin systems (Roberts, 1999; ATSDR ToxFAQs for Arsenic).

Symptoms of acute arsenic poisoning are sore throat from breathing, red skin at contact point, or severe abdominal pain, vomiting, and diarrhea, often within 1 hour after ingestion. Other symptoms are anorexia, fever, mucosal irritation, and arrhythmia. Cardiovascular changes are often subtle in the early stages but can progress to cardiovascular collapse. Chronic or lower levels of exposure can lead to progressive peripheral and central nervous changes, such as sensory changes, numbness and tingling, and muscle tenderness. A symptom typically described is a burning sensation ("needles and pins") in hands and feet. Neuropathy (inflammation and wasting of the nerves) is usually gradual and occurs over several years. There may also be excessive darkening of the skin (hyperpigmentation) in areas that are not exposed to sunlight, excessive formation of skin on the palms and soles (hyperkeratosis), or white bands of arsenic deposits across the bed of the fingernails (usually 4-6 weeks after exposure) (Roberts, 1999; ATSDR ToxFAQs for Arsenic).

2.2 Drinking Water Standards

There are difference standards of heavy metal concentrations contaminated in groundwater for drinking. The standards of groundwater for drinking in Thailand are higher concentrations than those of others organization. The standards of heavy metals contaminated in groundwater established by Pollution Control Department of Thailand (PCD, 2000), World Health Organization (WHO, 1993), and European Union (EU, 1998) are shown in table 2.1.

Table 2.1 Drinking Groundwater Standards

Drinking Groundwater Standards			
Heavy metals	**Pollution Control Department, Thailand, 2000 (mg/L)**	**WHO,1993 (mg/L)**	**EU, 1998 (mg/L)**
As	0.01	0.01	0.01
Cd	0.003	0.003	0.005
Cr	0.05	0.05	0.05
Cu	1.0	2	2
Hg	0.001	0.001	0.001
Pb	0.01	0.01	0.01
Ni	0.02	0.02	0.02
Zn	5.0	3	Not mentioned

2.3 Related Studies

Anita et al. (2010) studied about risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. They studied waste water from Dinapur sewage treatment plant which is used for irrigating vegetable plots. They quantified the concentrations of heavy metals, Cd, Cr, Cu, Ni, Pb and Zn in soil, vegetables and the waste water used for irrigation. The waste water used for irrigation had the highest concentration of Zn followed by Pb, Cr, Ni, Cu and Cd. Continuous application of waste water for more than 20 years has led

to accumulation of heavy metals in the soil. Consequently, concentrations of Cd, Pb and Ni had crossed the safe limits for human consumption in all the vegetables. Percent contribution of fruit vegetables to daily human intake for Cu, Ni, Pb and Cr was higher than that of leafy vegetables, while the reverse was true for Cd and Zn. Target hazard quotient showed health risk to the local population associated with Cd, Pb and Ni contamination of vegetables. Therefore, to reduce the health risk and the extent of heavy metal contamination, steps must be taken for efficient treatment of sewage. Regular monitoring of heavy metals in the vegetables grown in waste water irrigated areas is also necessary.

Evens et al. (2009) studied about groundwater contamination by microbiological and chemical substances released from hospital wastewater: health risk assessment for drinking water consumers. They found that contamination of natural aquatic ecosystems by hospital wastewater is a major environmental and human health issue and the discharge of chemical compounds from hospital activities into the natural environment could lead to the pollution of water resources and risks for human health. The aim of their study are (i) the steps of a procedure intended to evaluate risks to human health linked to hospital effluents discharged into a septic tank equipped with a diffusion well; and (ii) the results of its application on the effluents of a hospital in Port-au-Prince. The procedure is based on a scenario that describes the discharge of hospital effluents, via septic tanks, into a karstic formation where water resources are used for human consumption. A risk of infection of 10^{-5} infection per year was calculated. Major chemical risks, particularly for children, relating to Pb(II), Cr(III), Cr(VI) and Ni(II) contained in the ground water were also characterized. Certain aspects of the scenario studied require improvement, especially those relating to the characterisation of drugs in groundwater and the detection of other microbiological indicators such as protozoa, enterococcus and viruses

Hye-Sook Lim et al. (2008) studied about the contamination levels and dispersion patterns of As and heavy metals, the bioaccessible fraction of the metals in soil and crop plant, and the risk of health effects on the residence in the vicinity of the abandoned Songcheon Au–Ag mine, Korea. They found that the levels of As, Cd and Zn in drinking water were higher than the permissible level standard regulated in

Korea. Maximum levels of As, Cd and Zn in stream water were 0.71 mg/L, 0.19 mg/L and 5.4 mg/L, respectively. In addition, the results of risk assessment, the toxic risk (HI) value of heavy metals in the mine area was 16. Especially, HQ value of only As was 15. The carcinogenic risk for As in this mine area was estimated as 2.7E−03. Thus the daily intake or contact of soil, crop plant and water by the local residents can pose a potential health threat due to long-term arsenic exposure.

Jaipieam et al. (2009) studied about organophosphate pesticide residues in drinking water from artesian wells and health risk assessment of agricultural communities, Thailand. Organophosphate pesticide (OPPs) concentrations in artesian wells located in Thai agricultural and non-agricultural communities were studied during both wet and dry seasons. A total of 100 water samples were collected and subjects were asked to complete a survey. Gas chromatography flame photometric detector was used for OPP analysis. The average OPP concentration in the agricultural communities (0.085 and 0.418 μg/l in dry and wet season) was higher than in the non-agricultural communities (0.004 μg/l in both seasons). Ingestion of OPPs in contaminated water in the agricultural communities were estimated to be 0.187 and 0.919 μg/day during the dry and wet seasons, respectively, and 0.008 μg/day during both seasons in the non -agricultural communities. Agricultural communities were exposed to pesticide residues under the oral chronic reference dose. They suggests that people in agricultural communities may be exposed to significantly greater levels of pesticides than non-agricultural populations during the dry and wet seasons

Limpakanwech (2009) studied about sorption and modeling transport of Chlorpyrifos through shallow groundwater aquifer in an agricultural area: a case study of Hua Rua area, Changwat Ubon Ratchathani.This study found that most of agricultural areas in Tambon Hua Rua, Changwat Ubon Ratchatani have long been intensively applied agrochemicals in agricultural activities that may in turn impact negatively to the environment including human health. Soil water characteristic curve (SWCC), relationship between water contents (θ) and suction pressures head (ψ) of soil core samples were measured at variable suction pressure heads to carry out properties of unsaturated soil. RETC program was applied to estimate unsaturated

parameters; consequently, Van Genuchen (VG) could explain SWCC with high correlation coefficient (R > 0.99) that is clearly better than Brooks and Corey (BG). The batch experiment was designed to derive Freundlich sorption coefficient (Kf) value yielding 157.398 L/kg (n = 4.4) at certain mass to solution ratio of 1:15 with contact time of 24h at 25°C. Finally, HYDRUS-1D modeling showed that chlorpyrifos transported through the topsoil with an approximate depth of 100 cm.

Momodu and Anyakora (2009) found that heavy metals contamination of the groundwater in middle class neighbourhood of Lagos were high above WHO specified Maximum Contaminant Level (MCL). About forty nine well and borehole water samples were analyzed using Atomic Absorption Spectrophotometer for their Aluminium, Cadmium and Lead content and their levels compared with WHO specified maximum contaminant level. According to the WHO, the Maximum Contaminant Level (MCL) for Aluminium, Cadmium and Lead are 0.2, 0.003 and 0.01mg/L respectively. From the results obtained, none of the samples analyzed contained Aluminium in concentrations above the MCL, however, the metal was found to be present in 93.88% of the samples analysed. Over 38% of the samples had Cadmium present in them and 32.65% of the samples had Cadmium concentrations above the MCL. Almost 60% of the samples had detectable level of Lead while 36.73% of the sample had Lead concentration above the MCL. In general 97.96% of all samples analysed contained one or more of the three heavy metals studied each in varying concentrations. The results obtained from this study suggest a significant risk to this population given the toxicity of these metals and the fact that for many, hand dug wells and bore holes are the only sources of their water supply in this environment.

Nouri et al. (2006) studied for evaluate and map regional patterns of heavy metals (Cu, Cd, Ni, and Zn) occurrence in south of Iran. The Flame Atomic Absorption Spectrometry (AAS-Flame) was used to measure the heavy metals concentration in water samples. The results demonstrated that all of the samples, Cu, Zn and Ni concentrations were below the EPA MCLG, EPA secondary standard and EPA MCL, respectively, but Cd, contents of 4.8% of all samples was higher than EPA MCL. Moreover, they found that agricultural practices, especially cultivation,

fertilization in farm lands was principal causes of heavy metal contaminated in groundwater because chemical contaminants discharged into the groundwater.

Rattan et al. (2005) studied at peri-urban agricultural lands under Keshopur Effluent Irrigation Scheme (KEIS) of Delhi, India. There were selected because there are various cereals, millets, vegetable and fodder crops had successfully been grown. Sewage effluents, ground water, soil and plant samples were collected and analysed mainly for metal contents. Results indicated that sewage effluents contained much higher amount of P, K, S, Zn, Cu, Fe, Mn and Ni compared to groundwater. While, there was no significant variation in Pb and Cd concentrations in these two sources of irrigation water and metal content were within the permissible limits for its use as irrigation water. There was an increase in organic carbon content ranging from 38 to 79% in sewage-irrigated soils as compared to tubewell water-irrigated ones. On an average, the soil pH dropped by 0.4 unit as a result of sewage irrigation. Sewage irrigation for 20 years resulted into significant build-up of DTPAextractable Zn (208%), Cu (170%), Fe (170%), Ni (63%) and Pb (29%) in sewage-irrigated soils over adjacent tubewell waterirrigated soils, whereas Mn was depleted by 31%. Soils receiving sewage irrigation for 10 years exhibited significant increase in Zn, Fe, Ni and Pb, while only Fe in soils was positively affected by sewage irrigation for 5 years. Among these metals, only Zn in some samples exceeded the phytotoxicity limit. Fractionation study indicated relatively higher build-up of Zn, Cu, Fe and Mn in bioavailable pools of sewage-irrigated soils. By and large, tissue metal concentrations in all the crops were below the generalized critical levels of phytotoxicity. Based on the soil to plant transfer ratio (transfer factor) of metals, relative efficiency of some cereals, millet and vegetable crops to absorb metals from sewage and tubewell water-irrigated soils was worked out. Risk assessment in respect of metal contents in some vegetable crops grown on these sewage-irrigated soils indicated that these vegetables can be consumed safely by human.

Srithongdee (2009) studied about Distribution of Pesticide and Nitrate Concentrations in a Shallow Groundwater Aquifer in an Agricultural Area: A Case Study of Hua Rua Area, Changwat Ubon Ratchatani. The study found that pH values in an agricultural area were ranged from 3.68 to 4.88, which is not proper for

drinking. This area had intensively applied pesticides and nitrogen (N) fertilizers in agricultural activities, particularly for planting chilli and rice. By the way pesticide concentrations were generally less than detection limit thus not found in shallow groundwater. Increasing nitrate concentrations in the groundwater had adversely impact to human and animals drinking such groundwater.

Stanislav and Katarína (2007) studied about health risk assessment maps for arsenic groundwater content: application of national geochemical databases. There investigation assessed the feasibility of calculating and visualizing health risk estimates from exposure to groundwater contaminated with arsenic (As) using data from national geochemical databases. The potential health risk associated with As-contaminated groundwater was assessed based on an elaboration of existing geochemical data in accordance with accepted methodological procedures established for human health risk assessment. A screening analysis approach was used for estimating the contribution of As to the total chronic health risk from exposure to groundwater contaminated with potentially toxic elements, including As, Ba, Cd, Cu, Hg, Pb, Sb, Se and Zn, and the results indicated that As contributes significantly (>50%) to this total health chronic risk in about 10% of Slovak territory. Their study areas characterized by high health risk levels are mainly those geogenically contaminated. High and very high carcinogenic risk was determined in 34 of 79 districts and in 528 of 2924 municipalities.

Williamson et al. (1989) studied about groundwater hydrology and salinity in a valley in Northeast Thailand. In addition, they showed that land use change in the Khorat Plateau has been associated with recent salinization of land and water resources. An intensive study was made of water and salt flow in the surficial aquifer of an area of 50 km near Khorat. The agriculturally developed uplands provide the water source which, in its path to the valley discharge areas, passes through evaporite (mainly halite) beds deposited in the Cretaceous. Parameterization of a flow model provides the basis on which strategies for management of the problem could be tested. Moreover, they found that salinity of groundwater were different between wet season and dry season which wet season (rainfall) of northeast of Thailand are during May until September period.

Yang et al. (2006) studied about cadmium in soil–rice system and health risk associated with the use of untreated mining wastewater for irrigation in Lechang, China. They found that all soil samples were extremely contaminated by cadmium, soil Cd occurred primarily in the residual fraction. Using synthetic stomach fluid simulating gastrointestinal condition, result showed that 28.4% of the total soil cadmium concentration would be ingested in human/animal gastrointestinal tract. Mean Cd concentrations in plant tissues (DW) ranged from 0.24 (unpolished rice) to 8.21 mg/g (root). Dietary intake of cadmium through contaminated rice consumption was calculated to be 2.2 and 1.5 mg/kg body weight per day for a 60-kg adult and 40-kg child, respectively. The values were much higher than the provisional tolerable daily intake (PTDI; 1 mg/kg bodyweight by FAO/WHO in 1989). They indicated that the paddy soil–rice system irrigated with untreated mining wastewater in Lechang lead/zinc mine area was heavily contaminated by Cd and would pose a human/animal health risk through Cd mobility in the food chain. Therefore, local mine wastewater should be decontaminated before being irrigated to surrounding farmland.

CHAPTER III

METHODOLOGY

3.1 Study area

The study area was Muang district, Ubonratchathani Province, Thailand (Figure 3.1). This area was located on the northeast of Thailand and this area was one of the largest areas of chili farming in Thailand. The flow chart of methodology of this study showed in figure 3.3.

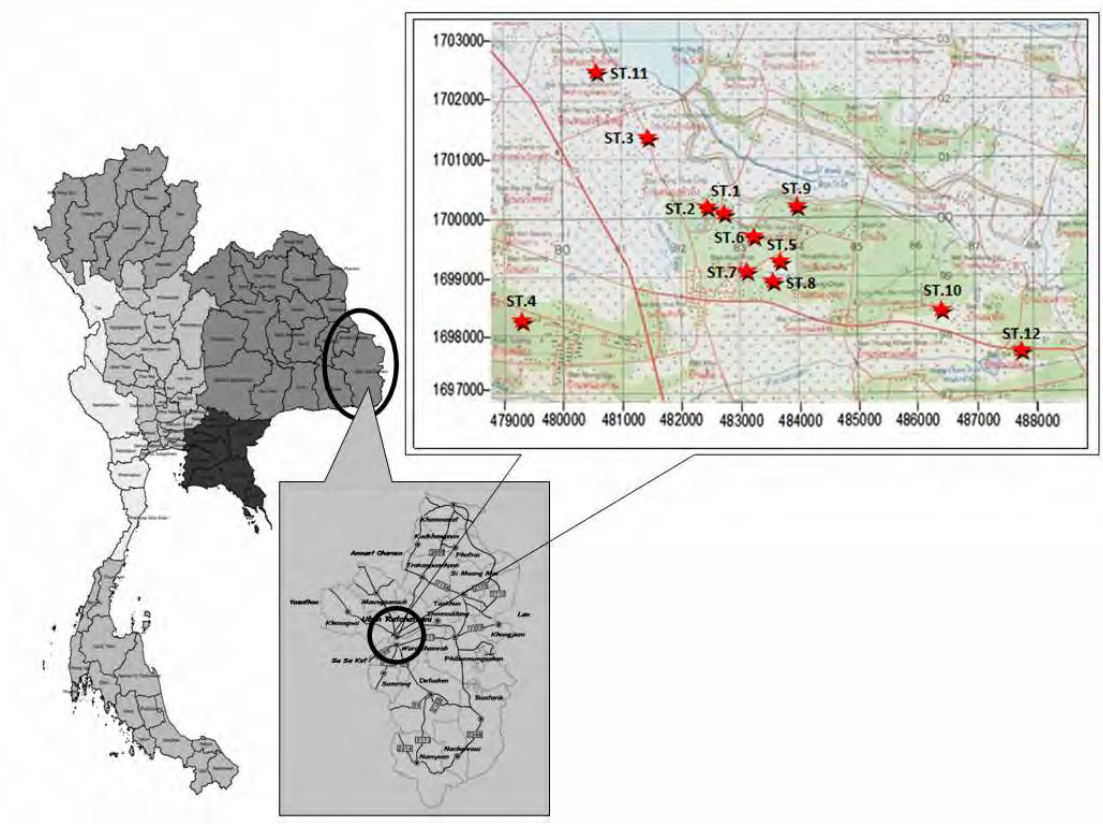

Figure 3.1 The study area at Muang district, UbonRachathani province, Thailand

★ = Shallow Groundwater Wells

3.2 Sampling and chemical analysis

The twelve shallow groundwater wells in agricultural area at Muang district, Ubon Ratchathani province were random selected to sample the groundwater.

Sampling would be collected during two different seasons which are during the months of June, August, November, 2010 and January, 2011. June and August were represent for wet season while November and January were represent for dry season. Shallow groundwater samples were pumped up and pH measured by pH meter in situation. Samples were acidified with nitric acid (conc. HNO_3) to low pH for dissolve all heavy metal and prevent crystallization. After nitric acid applied on collection sites then transported to laboratory with prevented evaporation bottles. The groundwater level were calculated from the difference between elevation and well depths.

All shallow groundwater samples were analyzed for heavy metals concentrations which were arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc by Inductively Coupled Plasma Spectrometry-Mass Spectrometry (ICP-MS). Finally, the concentration of each heavy metal that contaminated in shallow groundwater would be found out.

3.3 Face-to-Face Interviews

For the purpose of human health risk assessment calculation, Face-to-face interviews with local people who lived and consumed shallow groundwater at Muang district, UbonRachathani province would be used to find the intake rate of shallow groundwater consume. This study was focused on local people who consume shallow groundwater at Muang district, Ubon Ratchathani province. The interview questionnaire study consists of two main parts. The first part was about the general information and personal background of the local people who consumed shallow groundwater. Name, age, body weight, gender, education level, and occupation were obtained. The second part was focused on the consumption behavior. As a result, the intake rate, frequency and quantity of groundwater consumption were obtained. The results of Face-to-face interviews were used to assess the human health risk.

3.4 Risk Assessment

Health risk assessment was defined as a function of hazard and exposure. In general, there were four steps for health risk assessment i.e. (1) hazard identification; (2) dose-respond; (3) exposure assessment; and (4) risk characteristics (Robson and Ellerbusch, 2007) (Figure 3.2).

3.4.1 Step 1 Hazard Identification

The first step in the risk assessment process is to identify the potential health effects cause from each chemical which is difference according to type of heavy metals. In addition, harmful effects can be divided into two types: carcinogen and non-carcinogen. Hazard identification was the process of determining when expose to chemical can cause of increasing in human health effects. This step use some data to support the health effect and chemical (i.e. statistically controlled clinical studies on humans), providing the best evidence that link between chemical and health effect. During this step we should answer questions as shown below:

- What is the chemical of concern?
- What have been spilled, leaked, emitted, contaminated?
- Do the chemical undergo transformation?
    - Biotic – Microorganisms
    - Abiotic – Chemistry
- If transformed, which product is the most concern?
- If mixture, which chemical is the most toxic?
- What kinds of toxic, carcinogen or non-carcinogen?

3.4.2 Step 2 Dose-Response Assessment

This step use information that presented in the first step to estimate the amount of chemical that can be affected to human health. The association between level of exposure and health effect will be classified in this step (Robson and Ellerbusch, 2007). In this step non-carcinogen and carcinogen are separated.

3.4.2.1 Reference Dose of Non-Carcinogen

Non-Carcinogenic effects resulting from multiple exposures occurring over a significant period of time are also termed chronic exposure effects. To protect against chronic toxicity resulting from exposure to contaminants, EPA has developed Reference Doses (RfDs). The RfD is defined as “an estimate (with uncertainty perhaps spanning an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime”. RfDs are generally expresse in terms of mg of

contaminant per kg consumer body weight per day (mg/kg-d) (US EPA, 2000b). In addition, the Reference Dose (RfD) is depended on the assumption that thresholds of certain toxic effects. RfD is showed in units of mg/kg-day (Table 3.1) and derives for the non-carcinogenic health effects of substances that were also carcinogens.

Table 3.1 Critical effect and reference dose of heavy metal

Heavy Metals	**Critical Effect**	**Oral RfD**
As	Hyperpigmentation, keratosis and possible vascular complications (chronic effect)	$2.3x10^{-6}$ mg/kg-day
Cd	Fragile bones, alopecia, anemia, migraines, growth impairment, and cardiovascular disease (chronic effect)	$5.0x10^{-4}$ mg/kg-day
Cr	Gastroenteritis, yellow-green vomitus, hematemesis, hepatic necrosis, renal failure (acute effect)	$3.0x10^{-3}$ mg/kg-day
Cu	Nausea, vomiting, diarrhea, liver damage, and kidney damage (chronic effect)	40 mg/kg-day
Hg	Digestive disturbances (acute effect) brain and kidney damage (chronic effect)	$3.0x10^{-4}$ mg/kg-day
Pb	Mood swings, nausea, numbness, seizures, and weight loss (chronic effect)	3.5 mg/kg-day
Ni	Decreased body and organ weights (Chronic effect)	$2.0x10^{-2}$ mg/kg-day
Zn	Stomach cramps, nausea, and vomiting (acute effect) anemia, pancreas damage (Chronic effect)	0.3 mg/kg-day

The relevant oral reference dose (RfD) was obtained from the US EPA's Integrated Risk Information System (IRIS), available on their website, www.epa.gov/iris/.

3.4.2.2 Slope Factor of Carcinogen

EPA took a probabilistic approach to estimating carcinogenic risks. Cancer risk is assumed to be proportional to cumulative exposure and, at low exposure levels, may be very small or even zero. EPA assumed that carcinogens did not have “safe” thresholds for exposure; that is, any exposure to a carcinogen might pose some cancer risk. Carcinogenic risk is usually expressed as a slope factor (SF) value with units of risk per mg/kg-day exposure (Table 3.2). Risk might also be estimated for specific media. The cancer slope factor is derived from dose-response data obtained in an epidemiological study or a chronic animal bioassay (Siriwong, 2006).

Table 3.2 Critical effect and oral slope factor of arsenic

Heavy Metal	Critical Effect	Oral Slope Factor
As	Internal organ cancers (liver, kidney, lung, and bladder) and skin cancer	1.5 per (mg/kg-day)

The slope factor (SF) was obtained from the US EPA’s Integrated Risk Information System (IRIS), available on their website, www.epa.gov/iris/.

3.4.3 Step 3 Exposure Assessment

Exposure assessment is the process of measuring or estimating the magnitude, frequency, and duration of human exposure to an agent in the environment, or estimating future exposures for an agent that has not yet been released. An exposure assessment include some discussion of the size, nature, and types of human populations exposed to the agent, as well as discussion of the uncertainties in the above information. Exposure could be measured directly, but more commonly is estimated indirectly through consideration of measured concentrations in the environment, consideration of models of chemical transport and fate in the environment, and estimate of human intake over time (US EPA, 1992).

Average Daily Dose (ADD)

Calculations for the Intake Process via the Ingestion Route to determine whether a chemical is cancerous or not, the risk assessment considere the period of time over which exposure occured. Average exposures or doses over the period of exposure are sufficient for making an assessment. These averages are often in the form of average daily doses (ADDs). ADDs can be calculated by averaging the potential dose over the body weight and the average period of exposure (US EPA, 1992a), as show in the following equation (1):

$$ADDs = \frac{CxIRxEFxED}{BWxAT} \qquad (1)$$

ADDs = Exposure duration (mg/kg-day)
C = Concentration (e.g. μg/L, mg/L)
IR = Intake rate (e.g. mg/day)
EF = Exposure frequency (day/year)
ED = Exposure duration (year)
BW = Body weight (kg)
AT = Average time (day)
: for non-carcinogenic effects, AT = ED in days
: for cancinogenic effect, AT = 70 years or 25,550 days

3.4.4 Step 4 Risk Characterization

A risk characterization is the risk assessor's judgment as to the nature and presence or absence of risks, along with information about how the risk is assessed, where assumptions and uncertainties still exist, and where policy choices will need to be made. Risk characterization takes place in both human health risk assessments and ecological risk assessments.

In practice, each component of the risk assessment (e.g. hazard assessment, dose-response assessment, exposure assessment) have an individual risk characterization written to carry forward the key findings, assumptions, limitations,

and uncertainties. The set of these individual risk characterizations provide the information basis to write an integrative risk characterization analysis.

3.4.4.1 Non-Carcinogen Risk Estimation (Hazard Quotient)

The comparison of exposure to the RfD indicates the degree to which exposure is greater or less than the RfD. This relationship was shown in equation (4).

The RfD is defined as the daily oral dose of a chemical that is unlikely to cause adverse effects given a lifetime of exposure. An evaluation of non-carcinogenic toxicity of individual risks can be computed by using the hazard quotient (HQ) ratio. This value indicates the degree of exposure, greater or less than the RfD. When the ratio is equal to or greater than 1 when the exposure exceede the RfD, the exposure population may be at risk (US EPA, 1999a).

$$\text{Hazard Quotient(HQ)} = \frac{\text{Exposure}}{\text{RfD}} \qquad (4)$$

Where; Exposure = Chemical exposure level or ADDs (mg/kg-day)
RfD = Reference dose (mg/kg-day)

If; $HQ \geq 1$ Adverse non-carcinogenic effects of concern
$HQ < 1$ Acceptable level (no concern)

For the mixture chemicals risk assessment, the hazard quotients are combined to form the Hazard Index (HI) (5), which assumes that the effects of the different compounds and effects are additives. The HI method is recommended for groups of toxicologically similar chemicals that have dose response data. When the hazard index exceede unity (HI > 1), the exposure population may be at risk, whereas HI less than or equal to 1 should be taken as the acceptable reference or standard (US EPA, 1989a).

$$\text{Hazard Index (HI)} = \sum (\text{HQ}) \qquad (5)$$

If; HQ $\geq$ 1 Adverse non-carcinogenic effects of concern

HQ < 1 Acceptable level (no concern)

3.4.4.2 Carcinogen Risk Estimation (Cancer Risk)

Using cancer slope factor (SF) and exposure data in mg/kg-day, cancer risks are calculated using following equation (2):

$$\text{Cancer Risk} = \text{Exposure} \times \text{SF} \qquad (2)$$

Where; Exposure = Chemical exposure level or ADDs (mg/kg-day)

SF = Slope Factor (per mg/kg-day)

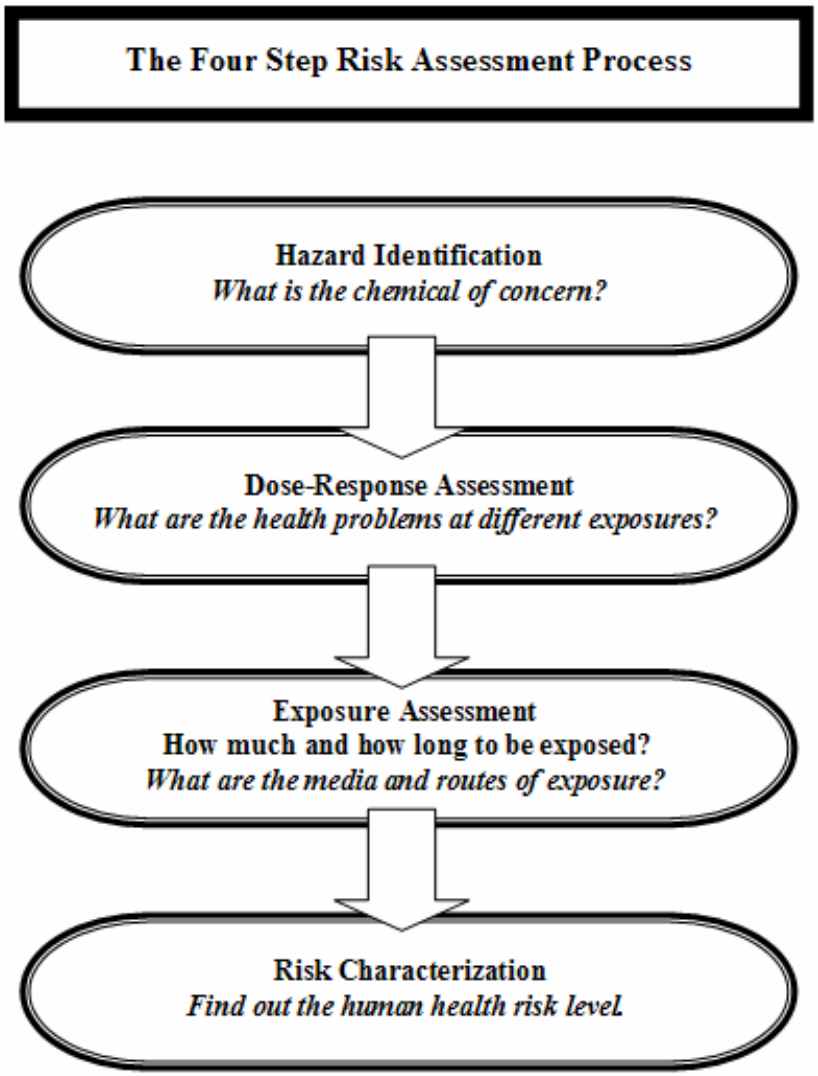

Figure 3.2 Four steps of risk assessment (adopted from EPA, 1992)

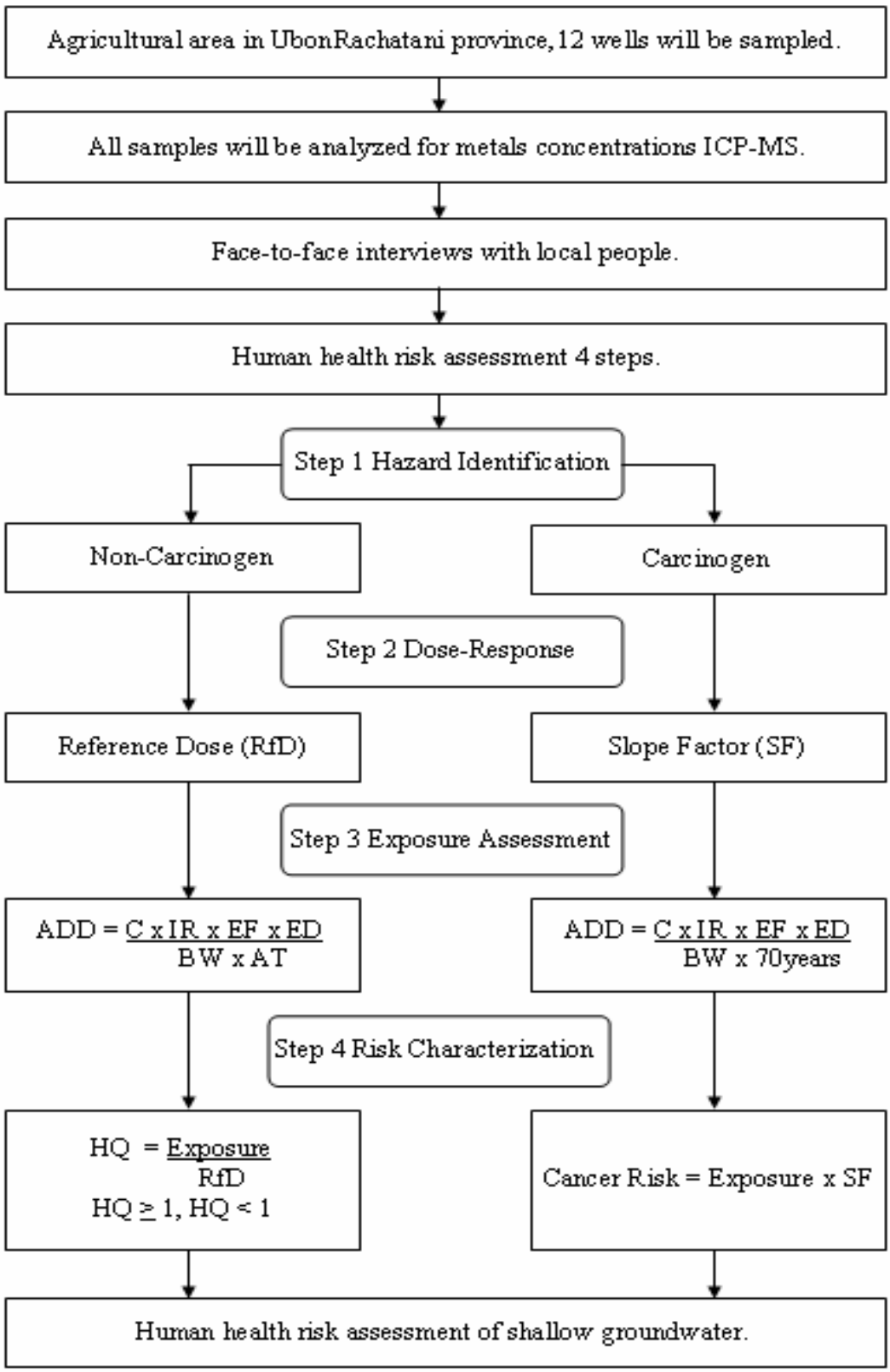

Figure 3.3 Methodology

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Face-to-face Interview

For the purpose of human health risk assessment calculation, face-to-face interviews with a hundred local people who lived and consumed shallow groundwater at Muang district, UbonRatchathani province have been used to collect personal information and evaluate rate of their groundwater consumption.

A hundred of local people (*n*=100) who generally consume shallow groundwater, 55 were female participants and 45 were male participants. The average age of participants (mean ± S.D.) was 42 $\pm$ 16 years (in range of 15 - 90 years) and the average weight (mean ± S.D.) was 60 $\pm$ 12 kg (in range of 30-94 kg.). Most participants graduated in elementary school or below (*n*=61, 61%) and some of them graduated in secondary school (*n*=35, 35%), only a few of them graduated in diploma (*n*=2, 2%) and bachelor's degree (*n*=2, 2%). In addition, most of them were agriculturalist (*n*=79, 79%).

The interview showed the average of groundwater consumption of a hundred participants was 3.45 $\pm$ 2.0 L/day. The results of interview questionnaires were shown in table 4.1

Table 4.1 Characteristic of local people who consume shallow groundwater at Muang district, UbonRatchathani province, Thailand

Characterization	***Number (n = 100)***	***Percentage (%)***
Sex		
Female	55	55%
Male	45	45%
Mean age (ranges 15 - 90 years)	42 ± 16	
Mean weight (ranges 30 - 94 kg)	60 ± 12	
Education		
≥ Elementary school	61	61%
Secondary school	35	35%
Diploma	2	2%
Bachelor's degree	2	2%
Occupation		
Government official	2	2%
Officer	1	1%
Merchant	5	5%
Agriculturist	79	79%
Student	4	4%
Employee	2	2%
Unemployed	7	7%
Other	0	-
Average groundwater consumption (L/day) (ranges from1 to 10 L/day)	3.45 ± 2.0	

4.2 Properties of Shallow Groundwater and Wells

4.2.1 pH

The pH values of shallow groundwater during wet season ranged from 3.69 to 9.33. The pH values of shallow groundwater during dry season ranged from 3.90 to

9.33 and average pH of shallow groundwater during dry season was 4.65 ± 0.57. The average pH values of whole year ranged from 3.97 to 7.77. pH values of shallow groundwater in twelve shallow groundwater wells were shown in table 4.2 and figure 4.1 – 4.4.

The comparison of pH at study area between wet season and dry season, T-test showed that the difference between pH during wet season and dry season was not statistical significance (p>0.05).

The standard pH value of drinking water in Thailand was 6.5-9.2 (Pollution Control Department, 2008).The comparisons of pH at study area with drinking water standard, there were found that almost all of studied well stations were lower than drinking water standard except for well station number 11. Similarly, the average pH of all year round was also lower than drinking water standard.

In addition, Srithongdee (2009) studied about distribution of pesticide and nitrate concentrations in ten shallow groundwater wells in this area and reported similarly about pH values of shallow groundwater ranged from 3.68 to 4.88, which is not proper for drinking. By the way, pesticide concentrations were generally less than detection limit, consequently, they were not found in shallow groundwater. Furthermore, the nitrate concentrations were positively correlated with pH as a result of using fertilizers in long period, suggesting that they affected to the acidity of soil and shallow groundwater. Moreover, Jeyaruba et al. (2002) studied about the effect of agriculture on quality of groundwater. They reported that the groundwater in agricultural area was acidity because the effect of fertilizers using in agricultural area.

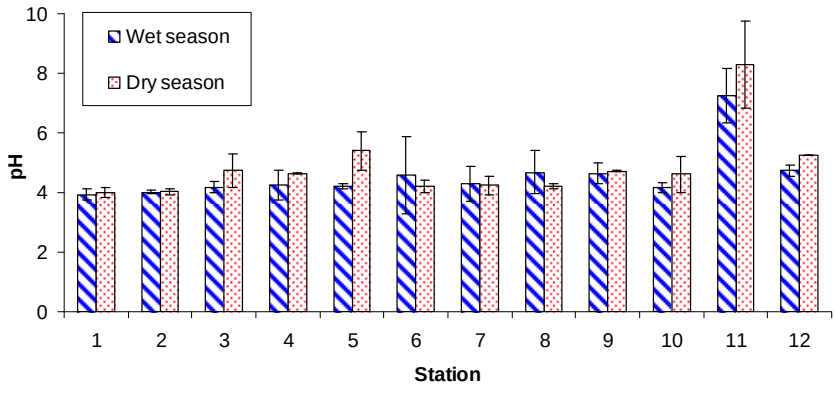

Figure 4.1 pH of shallow groundwater at Muang district, UbonRatchathani province, Thailand

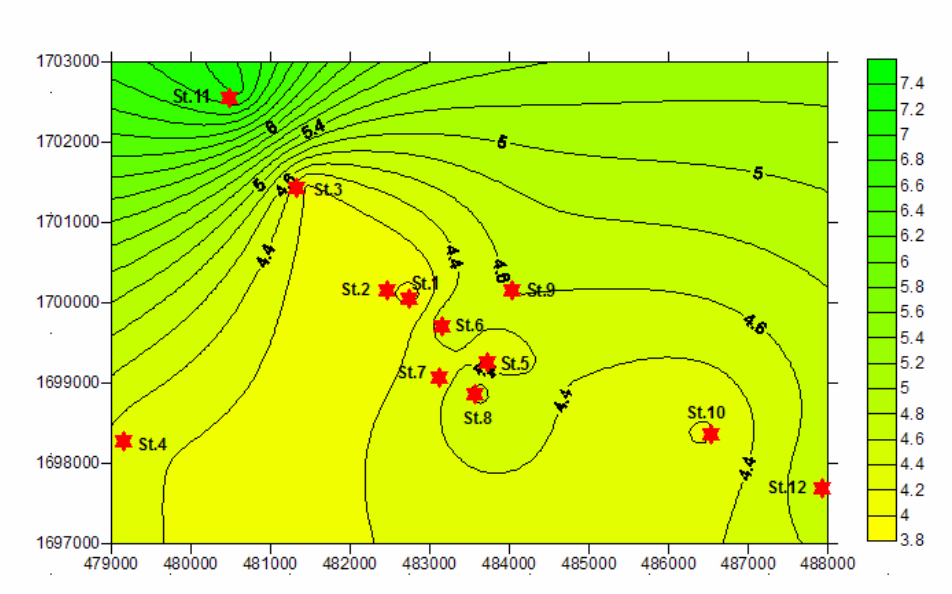

Figure 4.2 Contour map of pH values at study area during wet season

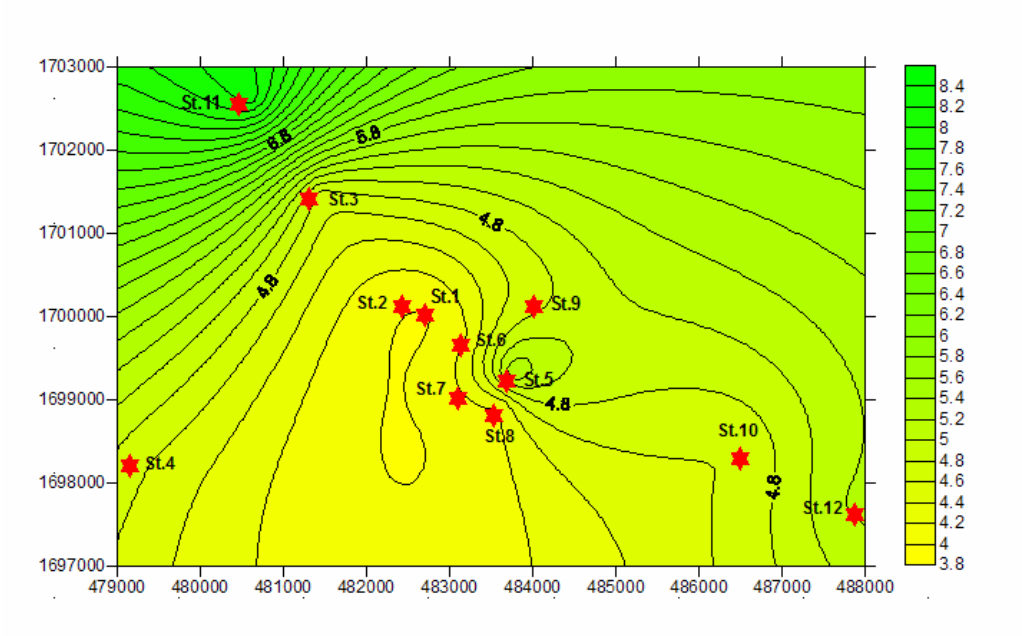

Figure 4.3 Contour map of pH values at study area during dry season

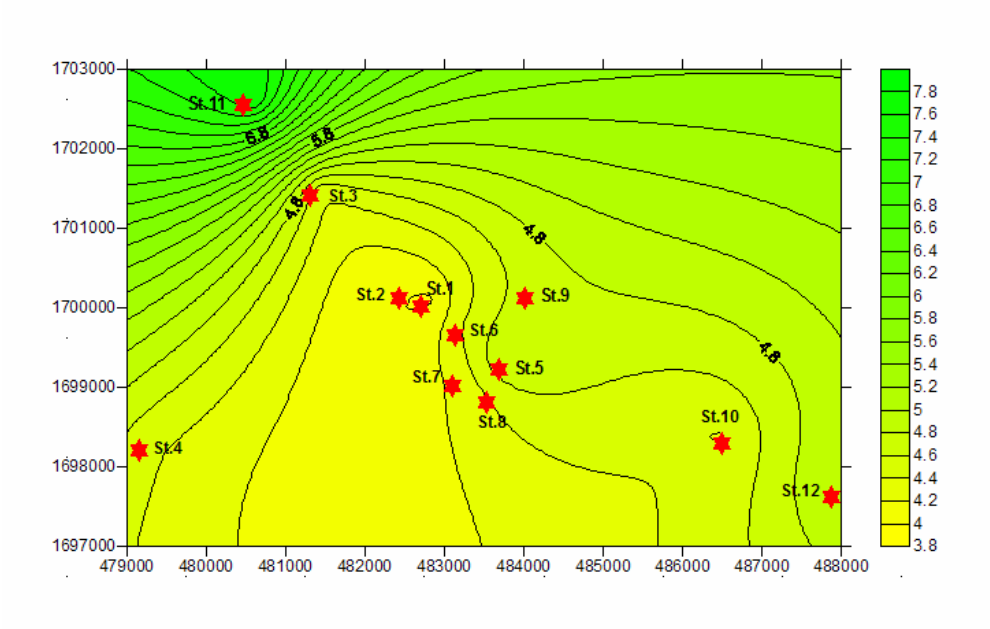

Figure 4.4 Contour map of pH values at study area all year round

From figures 4.2 - 4.4, they showed that pH value of shallow groundwater at well station number 11 was higher than others. There were different from other wells because shallow groundwater around wells station number 11 might be diluted by water from upstream pond that was nearly located and supplied recharge water to such area. By the way, there were slightly alkaline might cause by geologic formation.

4.2.2 Groundwater Level

The shallow groundwater level during wet season ranged from 111.15 to 133.00 m. (mean sea level, MSL) and average groundwater level was 124.18 $\pm$ 5.23 m. (MSL). The groundwater level during dry season ranged from 112.32 to 133.20 m and average groundwater level was 124.95 $\pm$ 5.17 m. (MSL). Groundwater levels during wet season and dry season in twelve shallow groundwater wells were shown in table 4.2 and figure 4.5 – figure 4.7.

The comparison of shallow groundwater level at study area between wet season and dry season, T-test showed that the difference between shallow groundwater level during wet season and dry season was not statistical significance (p>0.05).

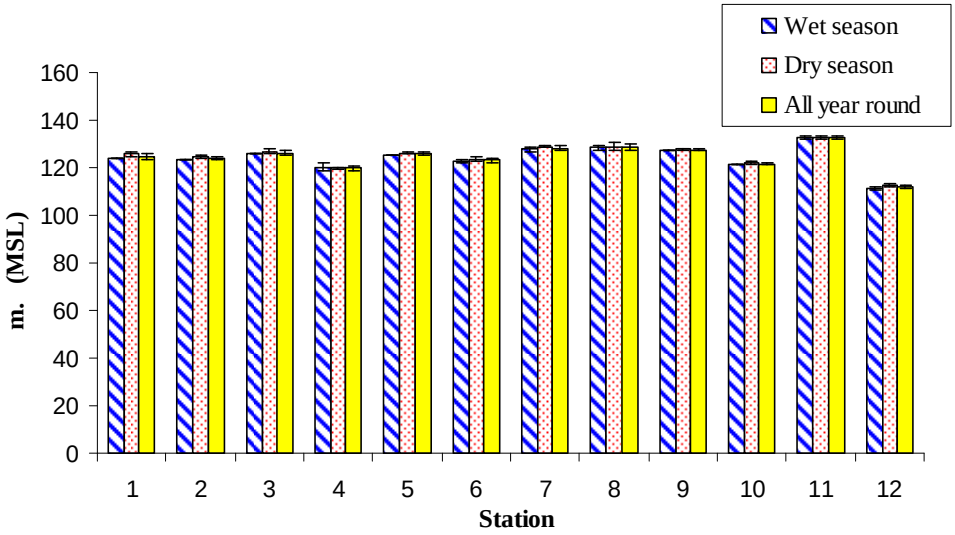

Figure 4.5 Shallow groundwater level (m. MSL) at study area

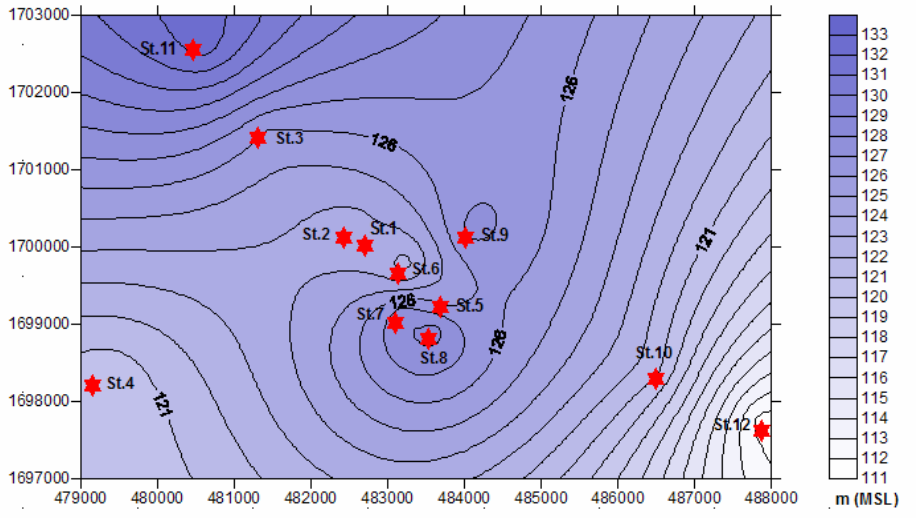

Figure 4.6 Shallow groundwater level (m, MSL) contour map during wet season

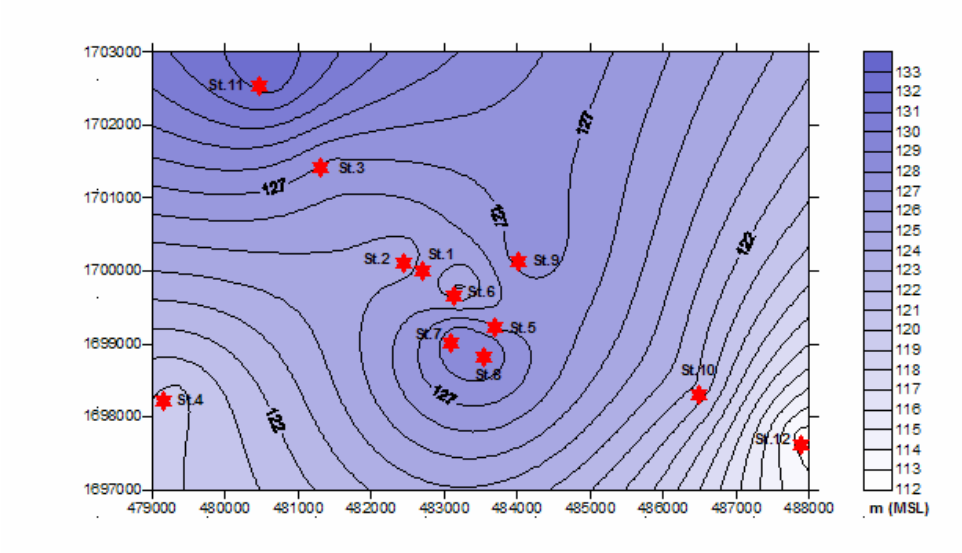

Figure 4.7 Shallow groundwater level (m, MSL) contour map during dry season

Groundwater level at Muang district, UbonRatchathani province was not significantly difference between wet season and dry season because there were affected from climate change. Thai Meteorological Department (TMD) reported about tropical storm during October-November, 2010, which was the reason why the groundwater level in dry season was slightly higher than those in wet season.

4.2.3 Conductivity

The conductivity of shallow groundwater during wet season ranged from 57.50 to 1215.00 µS/cm and average conductivity was 225.42 $\pm$ 284.13 µS/cm. The conductivity during dry season ranged from 50.90 to 1425.00 µS/cm and average conductivity was 239.44 $\pm$ 317.36 µS/cm. The all year round conductivity was 232.43 $\pm$ 9.92 µS/cm. Conductivity during wet season and dry season at twelve shallow groundwater wells were showed in table 4.2 and figure 4.8 – 4.11.

The comparison of conductivity of shallow groundwater at study area between wet season and dry season, T-test showed that the difference between conductivity during wet season and dry season was not statistical significance (p>0.05).

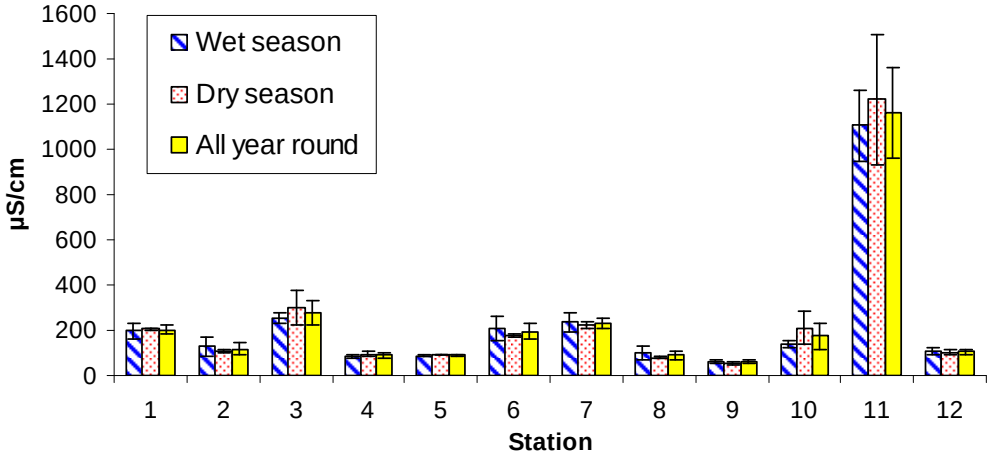

Figure 4.8 Conductivity of shallow groundwater at Muang district, UbonRatchathani province, Thailand

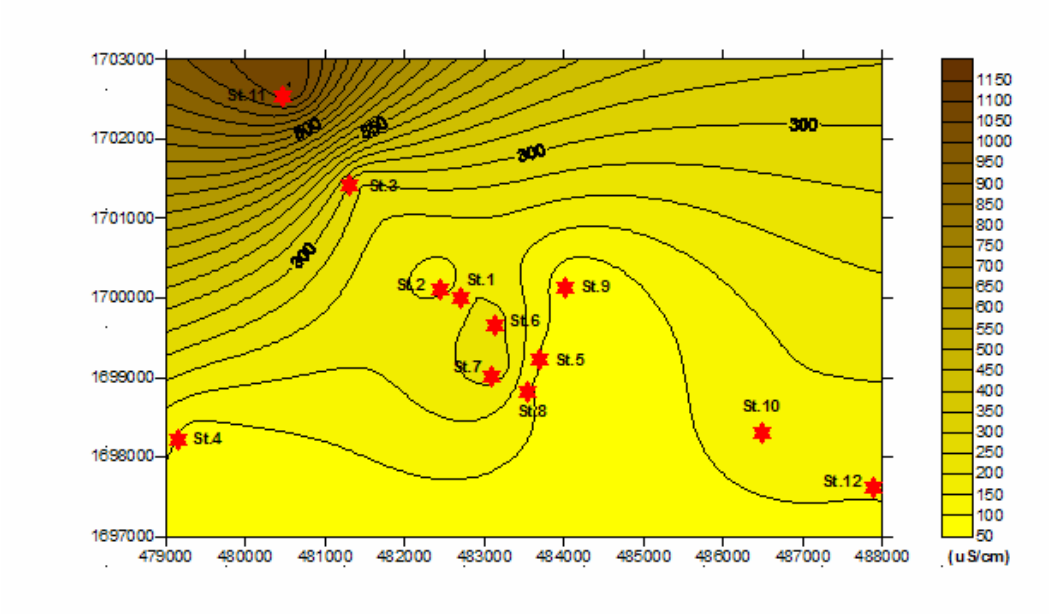

Figure 4.9 Conductivity contour map at study area during wet season

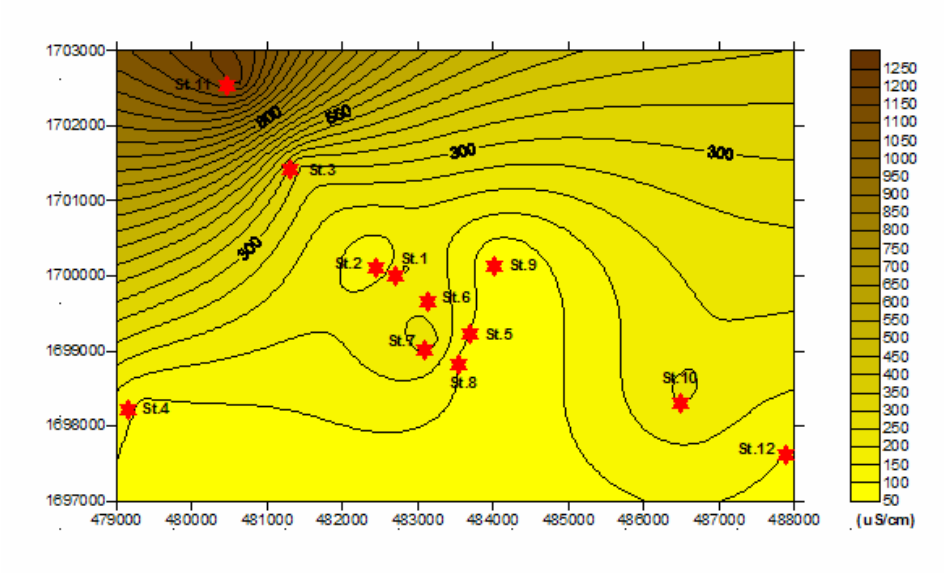

Figure 4.10 Conductivity contour map at study area during dry season

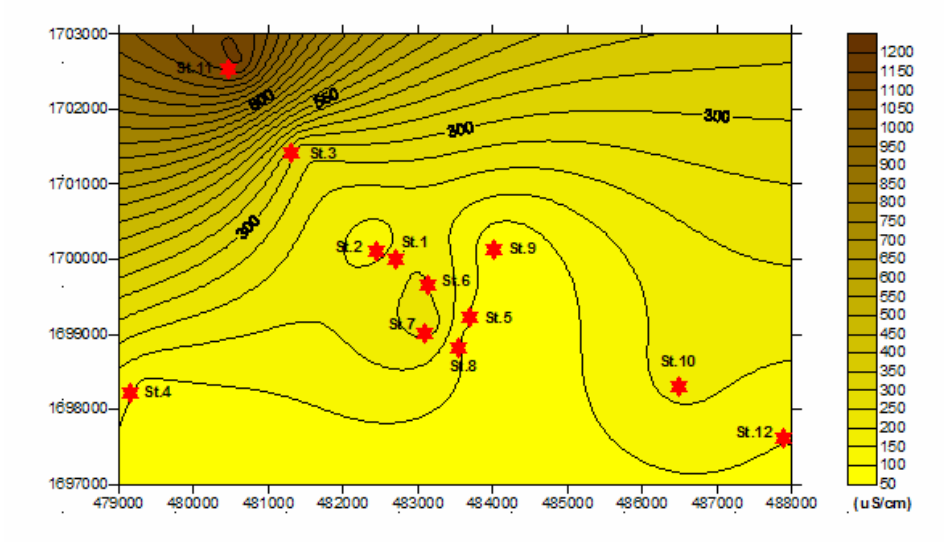

Figure 4.11 Conductivity contour map at study area average all year round

4.2.4 Well Depth

The well depths of shallow groundwater wells during wet season ranged from 0.75 to 4.90 m. and average well depth was 3.24 $\pm$ 0.73 m. The well depths during dry season ranged from 1.50 to 4.80 m. and average well depth was 2.46 $\pm$ 0.66 m. All year round well depth was 2.85 $\pm$ 0.79 m. The well depths during wet season and dry season at twelve shallow groundwater wells were showed in table 4.2 and figure 4.12.

The comparison of well depths of shallow groundwater wells at study area between wet season and dry season, T-test showed that the difference between well depths during wet season and dry season was statistical significance (p<0.05).

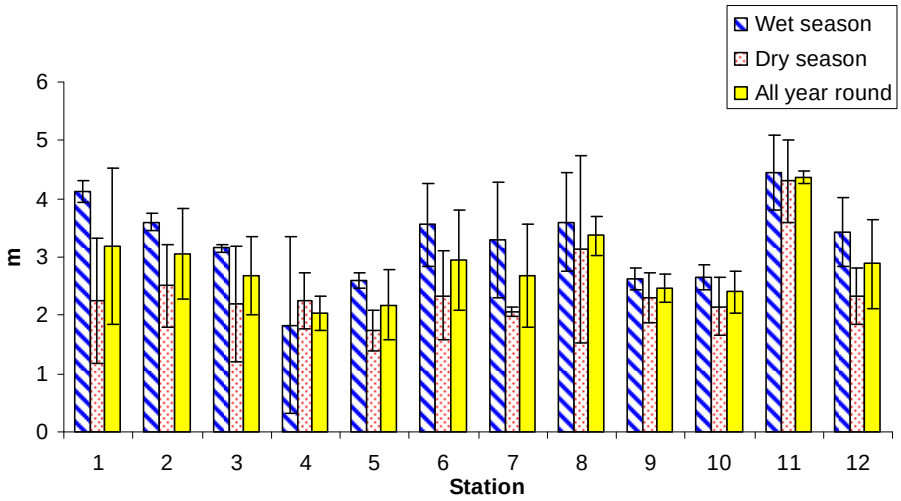

Figure 4.12 Well depths of shallow groundwater at Muang district, UbonRatchathani province, Thailand

Table 4.2 Properties of Shallow Groundwater and Wells

Properties of Shallow Groundwater and Wells at Muang District, Ubon Rachatani Province, Thailand														
Station		1	2	3	4	5	6	7	8	9	10	11	12	Ave.+ SD
Elevation		128.00	127.00	129.00	122.00	128.00	126.00	131.00	132.00	130.00	124.00	137.00	115.00	127.42 ± 5.50
Wet Season	**pH**	3.80-4.05	3.97-4.06	4.05-4.30	3.90-4.61	4.13-4.26	3.69-5.51	3.89-4.71	4.15-5.20	4.39-4.89	4.05-4.29	6.59-7.90	4.60-4.87	-
	Groundwater Level (m MSL)	123.88 ± 0.18	123.40 ± 0.14	125.85 ± 0.07	120.18 ± 1.52	125.40 ± 0.14	122.45 ± 0.71	127.70 ± 0.99	128.40 ± 0.85	127.38 ± 0.18	121.35 ± 0.21	132.55 ± 0.64	111.58 ± 0.60	124.18 ± 5.23
	Conductivity (µS/cm)	196.20 ± 31.40	127.45 ± 41.37	254.00 ± 25.46	85.00 ± 9.90	85.05 ± 3.46	209.50 ± 53.32	235.90 ± 41.15	97.30 ± 30.97	62.75 ± 7.42	141.10 ± 15.98	1104.50 ± 156.27	106.25 ± 16.33	225.42 + 284.13
	Well Depth (m)	4.13 ± 0.18	3.60 ± 0.14	3.15 ± 0.07	1.83 ± 1.52	2.60 ± 0.14	3.55 ± 0.71	3.30 ± 0.99	3.60 ± 0.85	2.63 ± 0.18	2.65 ± 0.21	4.45 ± 0.64	3.43 ± 0.60	3.24 ± 0.73
Dry Season	**pH**	3.90-4.12	3.95-4.10	4.33-5.14	4.62-4.65	4.95-5.85	4.04-4.34	4.01-4.46	4.16-4.26	4.70-4.74	4.19-5.03	7.25-9.33	5.23-5.25	-
	Groundwater Level (m MSL)	125.75 ± 1.06	124.50 ± 0.71	126.80 ± 0.99	119.75 ± 0.49	126.25 ± 0.35	123.66 ± 0.76	128.94 ± 0.08	128.87 ± 1.60	127.70 ± 0.42	121.85 ± 0.49	132.70 ± 0.71	112.66 ± 0.48	124.95 ± 5.17
	Conductivity (µS/cm)	205.50 ± 4.95	110.8 ± 7.35	299.00 ± 74.95	95.75 ± 8.27	92.50 ± 2.97	179.55 ± 8.41	223.50 ± 12.02	80.70 ± 4.24	54.95 ± 5.73	209.25 ± 73.19	1220.00 ± 289.91	101.80 ± 10.04	239.44 ± 317.36
	Well Depth (m)	2.25 ± 1.06	2.51 ± 0.71	2.20 ± 0.99	2.25 ± 0.49	1.75 ± 0.35	2.34 ± 0.76	2.06 ± 0.08	3.13 ± 1.60	2.30 ± 0.42	2.15 ± 0.49	4.30 ± 0.71	2.34 ± 0.48	2.46 ± 0.66
All Year Round	**Groundwater Level (m MSL)**	3.19 ± 1.33	3.06 ± 0.77	2.68 ± 0.67	2.04 ± 0.30	2.18 ± 0.60	2.95 ± 0.86	2.68 ± 0.88	3.37 ± 0.33	2.47 ± 0.23	2.4 ± 0.35	4.38 ± 0.11	2.89 ± 0.77	2.85 ± 0.79
	Conductivity (µS/cm)	200.85 ± 19.12	119.13 ± 26.09	276.50 ± 52.57	90.38 ± 9.70	88.78 ± 5.04	194.53 ± 35.64	229.70 ± 25.77	89.00 ± 20.44	58.85 ± 7.04	175.18 ± 58.47	1162.25 ± 201.5	104.03 ± 11.36	232.43 ± 9.92
	Well Depth (m)	3.19 ± 1.33	3.06 ± 0.77	2.68 ± 0.67	2.04 ± 0.30	2.18 ± 0.60	2.95 ± 0.86	2.68 ± 0.88	3.37 ± 0.33	2.47 ± 0.23	2.4 ± 0.35	4.38 ± 0.11	2.89 ± 0.77	2.85 ± 0.79

4.2.5 The concentrations of heavy metals

4.2.5.1 Arsenic (As)

The concentrations of arsenic contamination in shallow groundwater during wet season ranged from 0.32-8.68 µg/L and average was 1.52 ± 2.37 µg/L. The concentrations of arsenic contamination in shallow groundwater during dry season ranged from 0.17-5.87 µg/L and average was 0.60 ± 1.14 µg/L. The average concentrations of arsenic of whole year ranged from 0.25 ± 0.11 µg/L to 6.44 ± 3.17 µg/L and average was 1.06 ± 1.74 µg/L. The highest arsenic concentration was observed in well station number 11. The concentrations of arsenic contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.13 – 4.16.

All standard concentrations of arsenic in drinking water was 0.01 mg/L (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of arsenic contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of arsenic at study area between wet season and dry season, T-test showed that the difference between pH during wet season and dry season was not statistical significance (p>0.05).

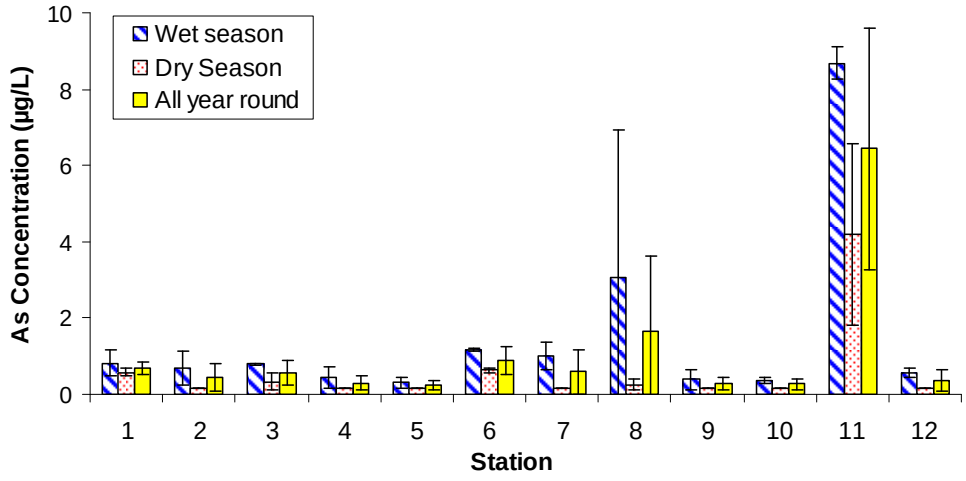

Figure 4.13 The concentration (µg/L) of arsenic (As) in shallow groundwater

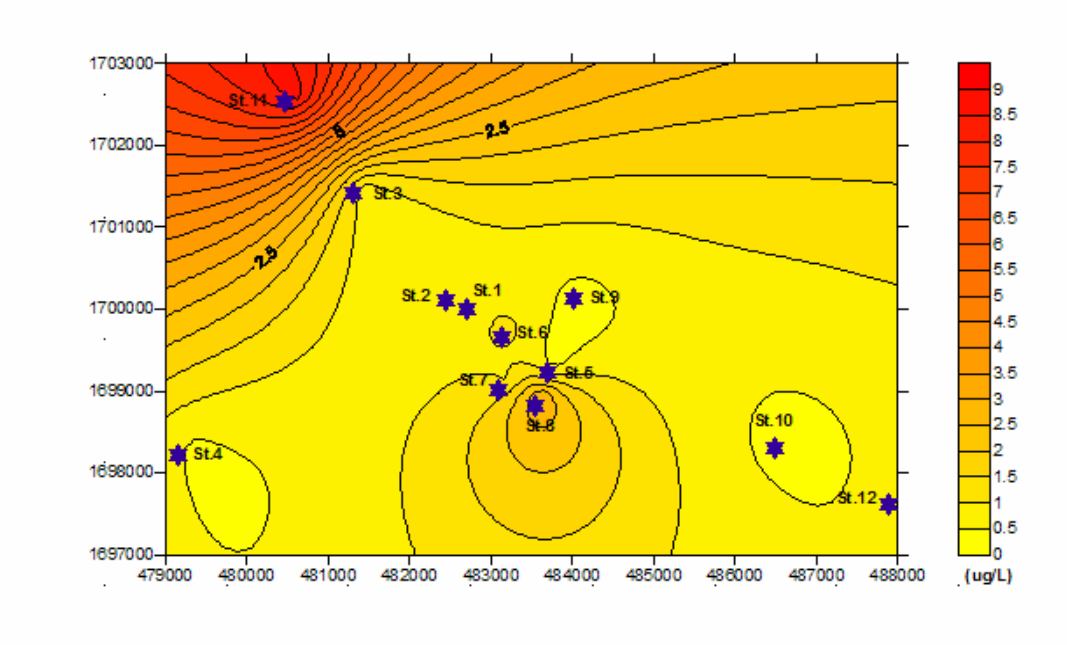

Figure 4.14 Concentration (µg/L) contour map of arsenic (As) during wet season

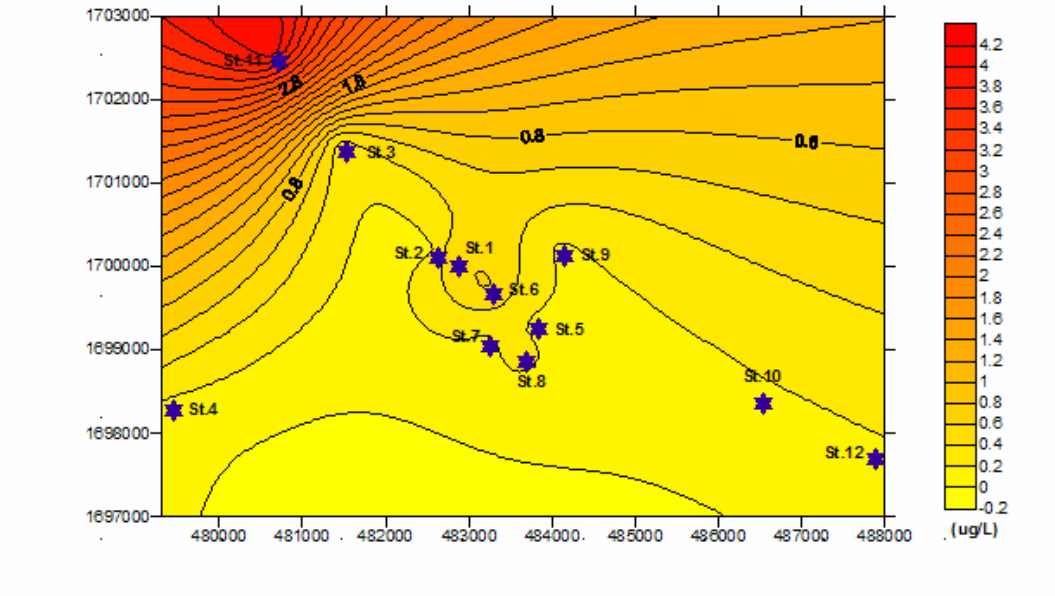

Figure 4.15 Concentration (µg/L) contour map of arsenic (As) during dry season

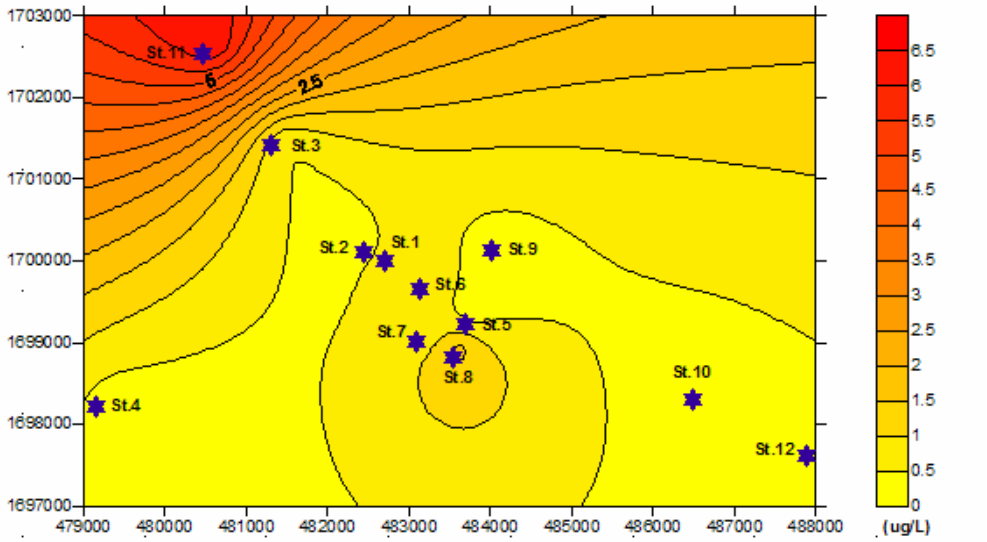

Figure 4.16 Concentration (µg/L) contour map of arsenic (As) average all year round

The concentration of arsenic at well station number 11 was higher than other wells suggesting that there might be affected from pH value of shallow groundwater which was alkaline. From the study of Takeno (2005) reported that arsenic would be in $H_2AsO_3^-$ and easily dissolve in water at high pH value. Therefore, the high pH values might affect to concentration of arsenic. In addition, Claesson and Fagerberg (2003) reported that arsenic existed in nature in four oxidation states, -3, 0, +3, and +5 but the forms which in groundwater were arsenite, As(III) (as $H_2AsO_3^-$ and H_3AsO_3) and arsenate, As(V) (as $H_2AsO_4^-$ and $HAsO_4^{2-}$). Moreover, their study showed pH of groundwater of Santiago del Estero in Argentina ranged from 6.4 to 9.3 and arsenic concentrations would be increased when pH values increased.

4.2.5.2 Cadmium (Cd)

The concentrations of cadmium contamination in shallow groundwater during wet season ranged from 0.13 to 0.25 µg/L and average of cadmium was 0.16 $\pm$ 0.06 µg/L. The concentrations of cadmium contamination in shallow groundwater during dry season ranged from 0.13-0.17 µg/L and average was 0.14 $\pm$ 0.01 µg/L. The average concentrations of cadmium of whole year ranged from 0.13 $\pm$ 0 µg/L to 0.23 $\pm$

0.12 µg/L and average was 0.15 ± 0.03 µg/L. The highest concentration of cadmium was observed in well station number 7. The concentrations of cadmium contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.17 - 4.20.

The standard concentrations of cadmium in drinking water was 0.003, 0.003, and 0.005 mg/L from Pollution Control Department, WHO, and EU respectively (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of cadmium contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of cadmium at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

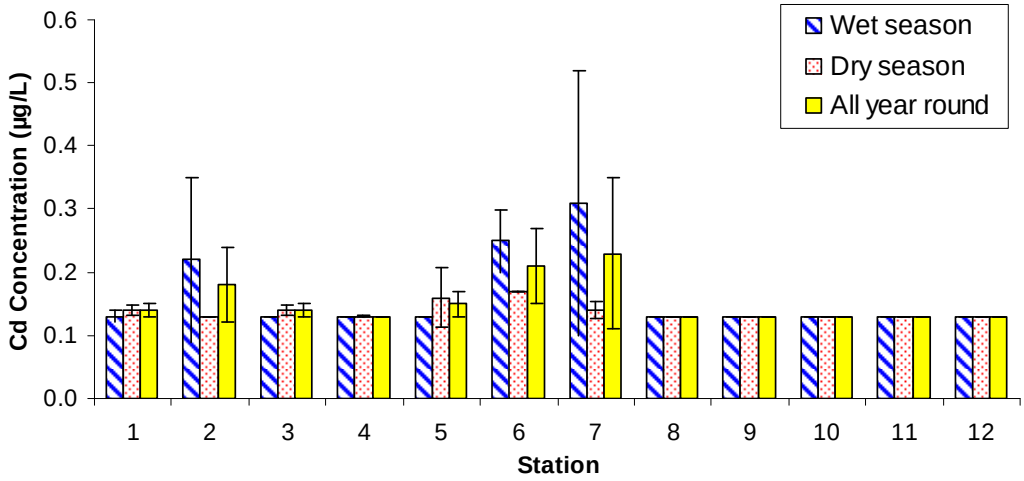

Figure 4.17 The concentration (µg/L) of cadmium (Cd) in shallow groundwater

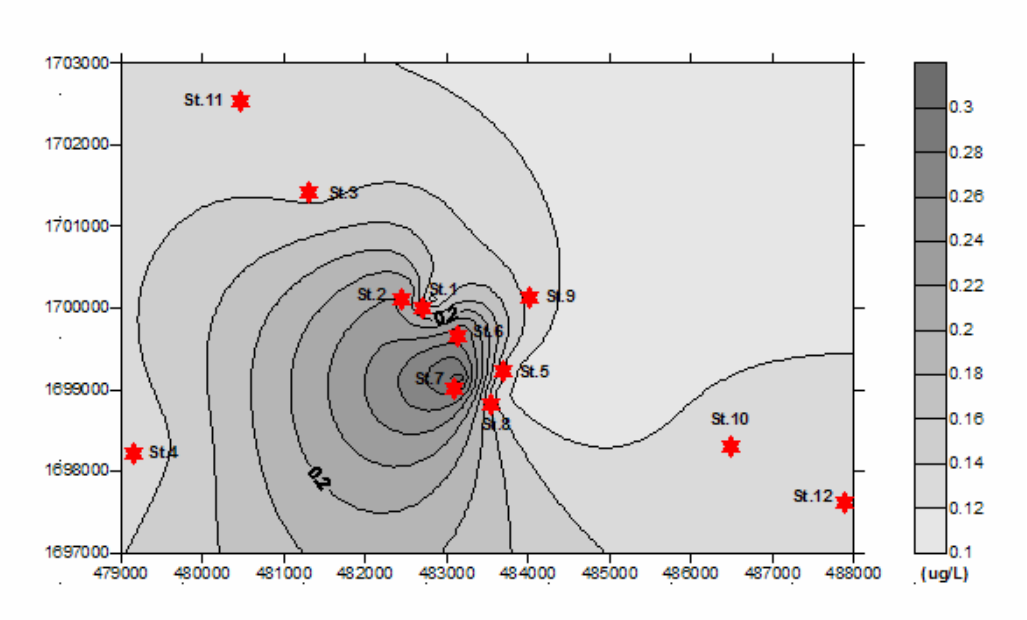

Figure 4.18 Concentration (µg/L) contour map of cadmium (Cd) during wet season

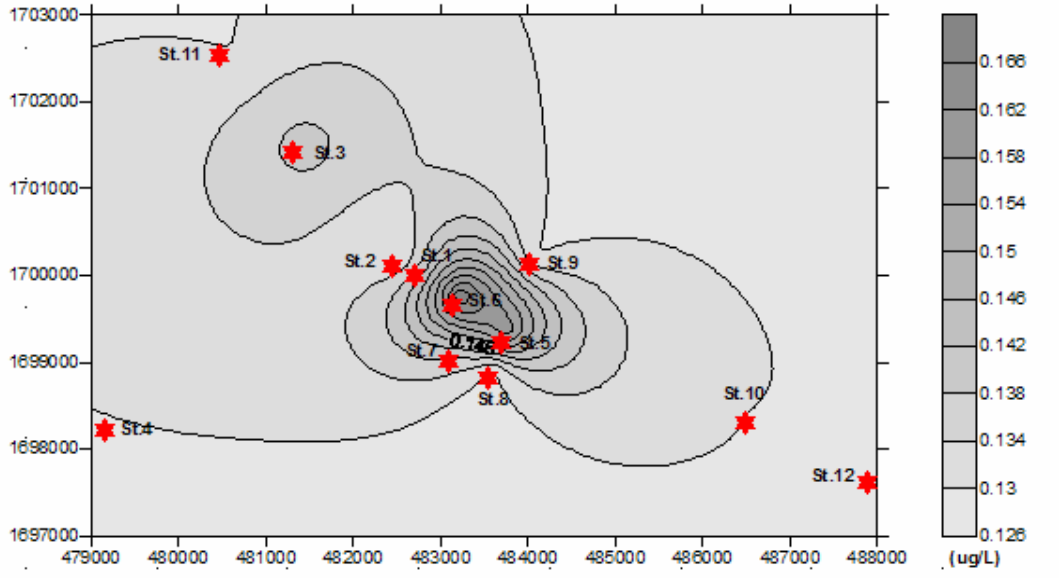

Figure 4.19 Concentration (µg/L) contour map of cadmium (Cd) during dry season

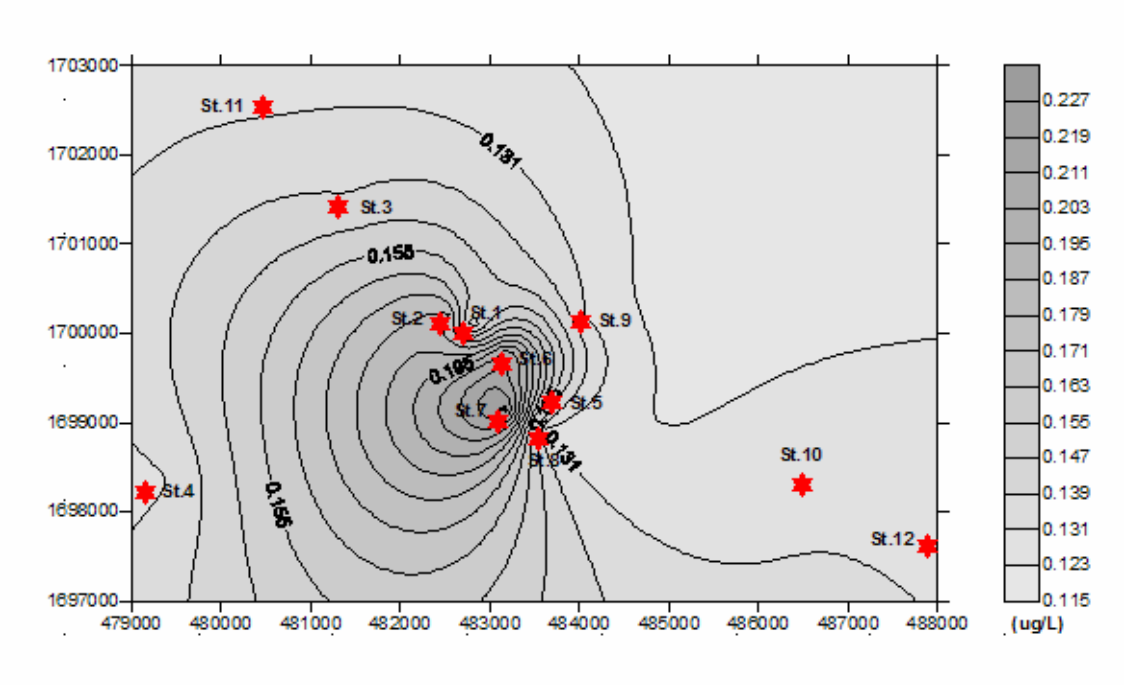

Figure 4.20 Concentration (µg/L) contour map of cadmium (Cd) average all year round

4.2.5.3 Chromium (Cr)

The concentrations of chromium contamination in shallow groundwater during wet season ranged from 0.14 to 3.84 µg/L and average of chromium was 0.71 $\pm$ 1.04 µg/L. All concentrations of chromium contamination in shallow groundwater during dry season were lower than detection limit of ICP-MS analysis during that time (<0.44 µg/L) so estimated average was 0.44 $\pm$ 0.00 µg/L. The average concentrations of chromium of whole year ranged from 0.29 $\pm$ 0.21 µg/L to 2.14 $\pm$ 2.4 µg/L and average was 0.58 $\pm$ 0.52 µg/L. The highest concentration of chromium was observed in well station number 3. The concentrations of chromium contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.21 – 4.22.

All standard concentrations of chromium in drinking water were 0.05 mg/L (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of chromium contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of chromium at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

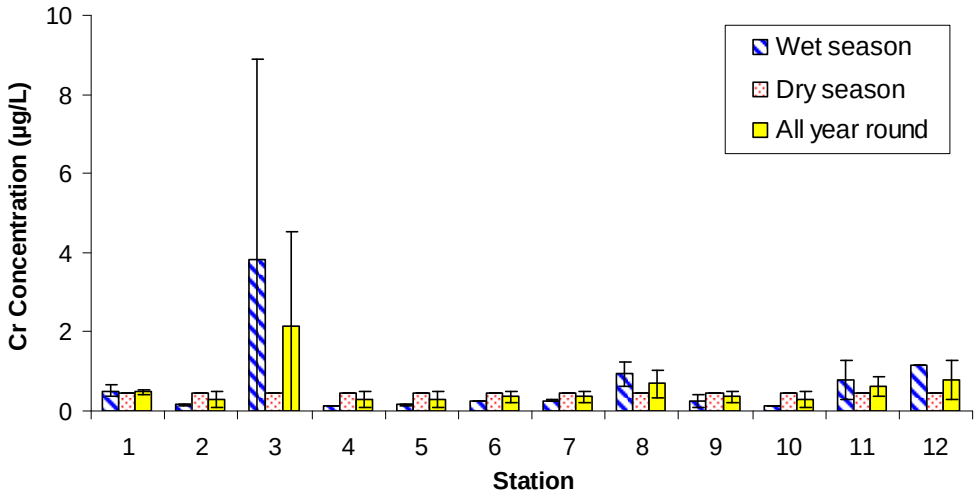

Figure 4.21 The concentration (µg/L) of chromium (Cr) in shallow groundwater

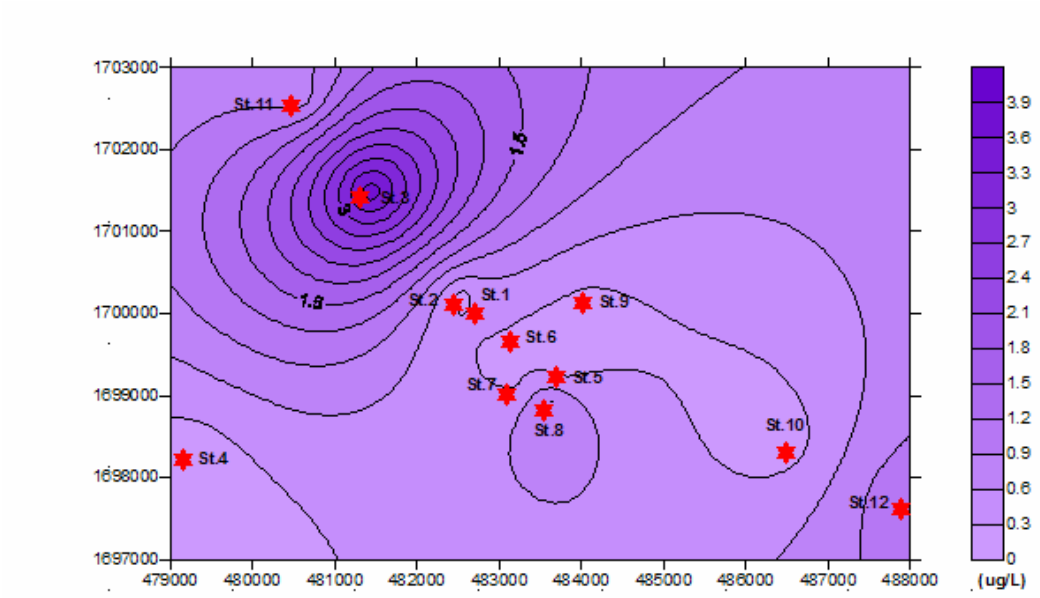

Figure 4.22 Concentration (µg/L) contour map of chromium (Cr) during wet season

The concentrations of chromium (Cr) contaminated in shallow groundwater during dry season and average all year round could not plot to be concentrations contour map because all of the concentration of chromium during dry season were lower than detection limited.

4.2.5.4 Copper (Cu)

The concentrations of copper contamination in shallow groundwater during wet season ranged from 4.27 to 751.0 µg/L and average of copper was 92.49 ± 164.27 µg/L. The concentrations of copper contamination in shallow groundwater during dry season ranged from 0.58 to 234.0 µg/L and average of copper was 28.03 ± 39.47 µg/L. The average concentrations of copper of whole year ranged from 10.03 ± 1.23 µg/L to 323.23 ± 384.35 µg/L and average was 60.26 ± 90.98 µg/L. The highest concentration of cupper was observed in well station number 7. The concentrations of copper contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.23 – 4.26

The standard concentrations of copper in drinking water was 1.0, 2, 2 mg/L from Pollution Control Department, WHO, and EU respectively (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of copper contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of copper at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

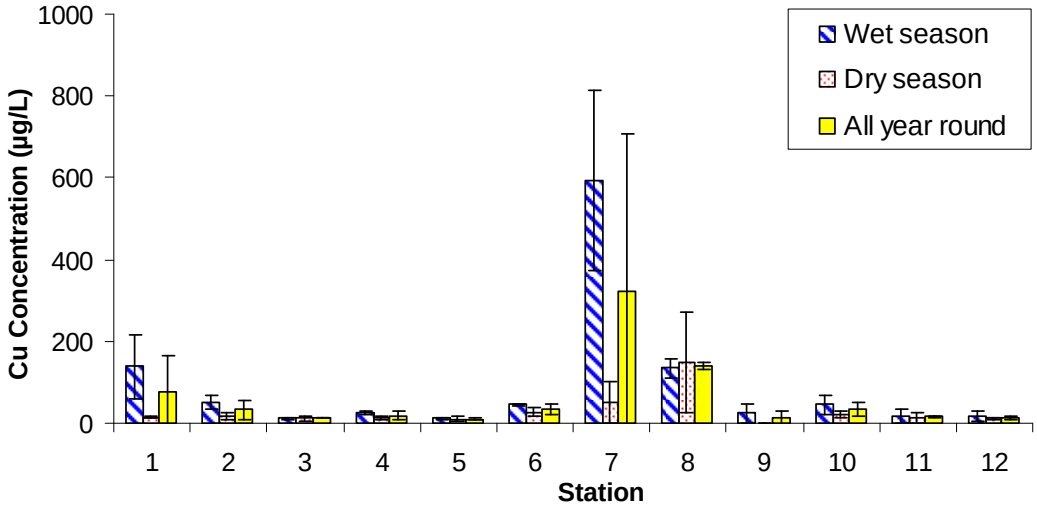

Figure 4.23 The concentration (µg/L) of copper (Cu) in shallow groundwater

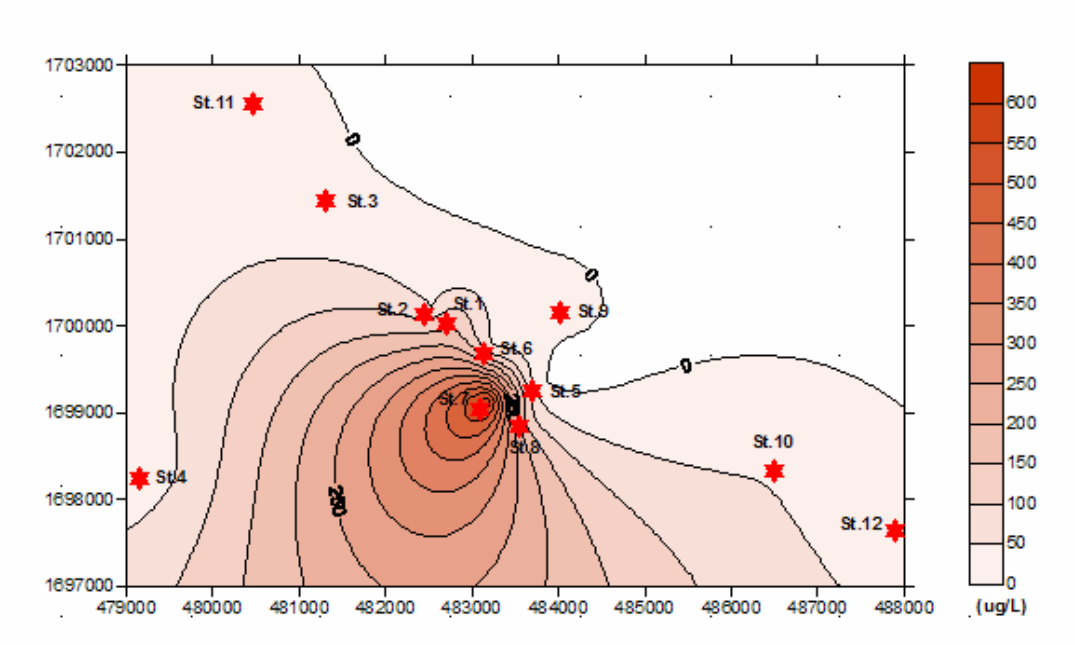

Figure 4.24 Concentration (µg/L) contour map of copper (Cu) during wet season

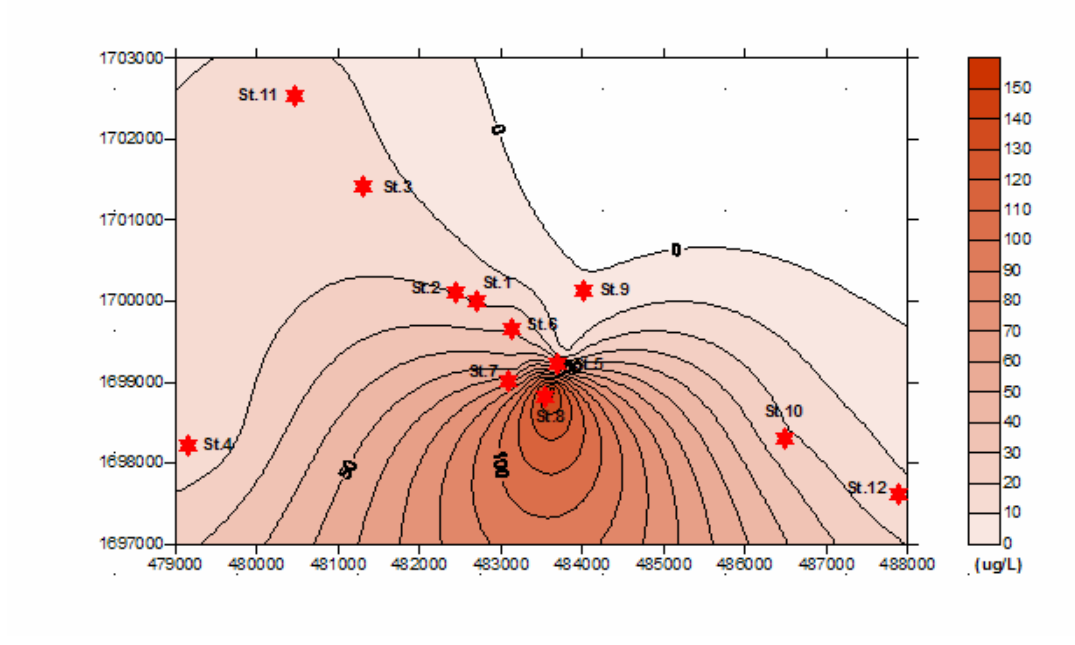

Figure 4.25 Concentration (µg/L) contour map of copper (Cu) during dry season

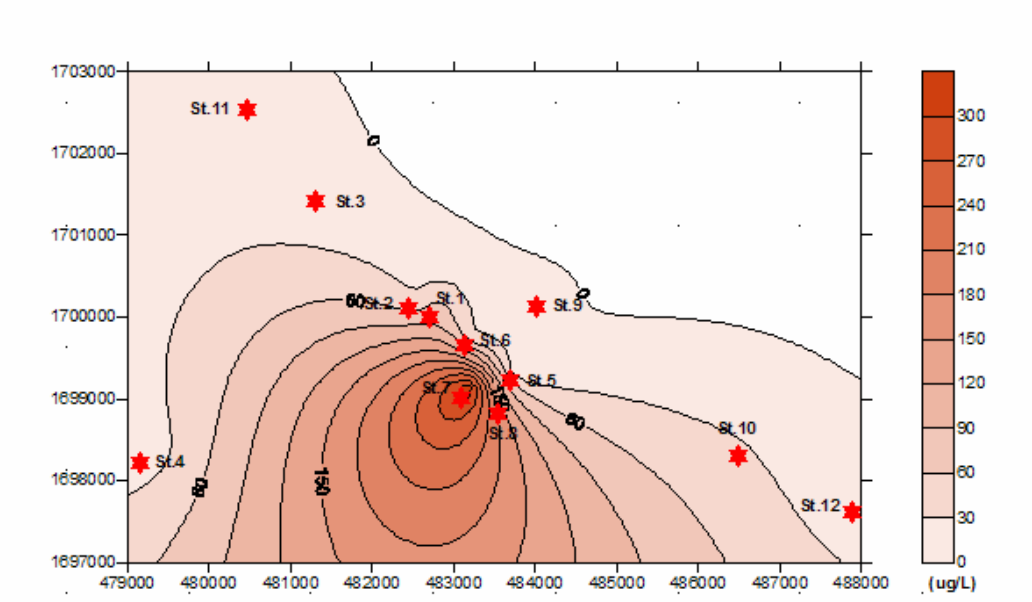

Figure 4.26 Concentration (µg/L) contour map of copper (Cu) average all year round

4.2.5.5 Lead (Pb)

The concentrations of lead contamination in shallow groundwater during wet season ranged from 0.82 to 92.55 µg/L and average was 18.64 ± 25.38 µg/L. The concentrations of lead contamination in shallow groundwater during dry season ranged from 0.65 to 48.10 µg/L and average was 14.67 ± 4.38 µg/L.

The average concentrations of lead of whole year ranged from 0.95 ± 0.42 µg/L to 66.85 ± 36.35 µg/L and average was 16.66 ± 18.52 µg/L. The highest concentration of lead was observed in well station number 7. The concentrations of lead contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.27 – 4.30

All standard concentrations of lead in drinking water were 0.01 mg/L from Pollution Control Department, WHO, and EU respectively (Pollution Control Department, 2000; WHO, 1993; EU, 1998). The average concentrations of lead during wet season, dry season, and whole year were higher than drinking water standard.

The comparison of concentrations of lead at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

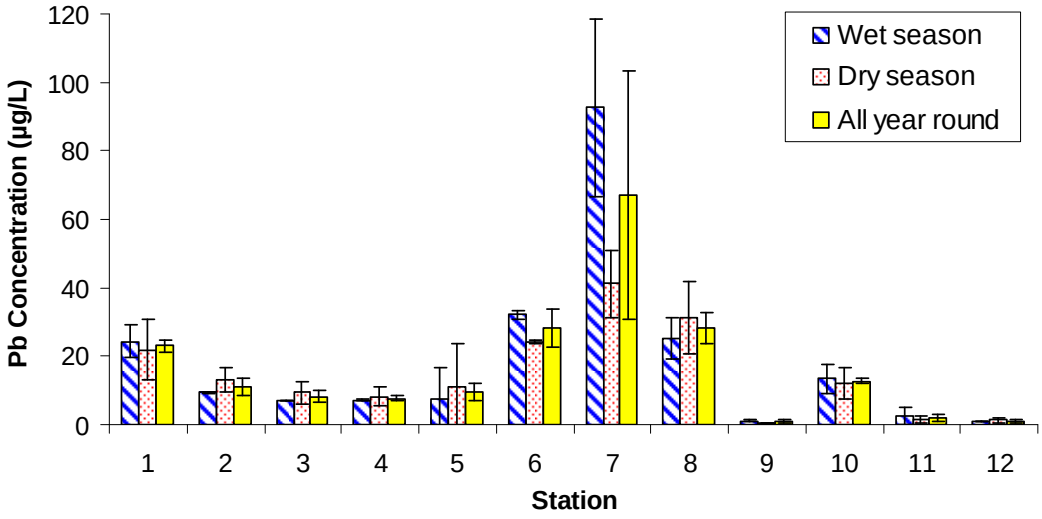

Figure 4.27 The concentration (µg/L) of lead (Pb) in shallow groundwater

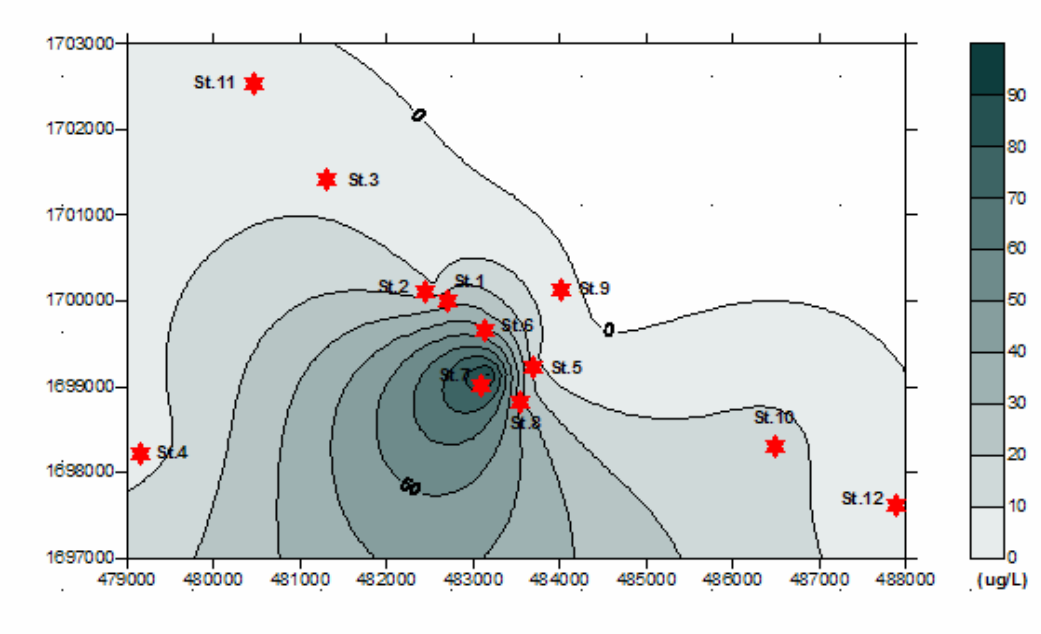

Figure 4.28 Concentration (µg/L) contour map of lead (Pb) during wet season

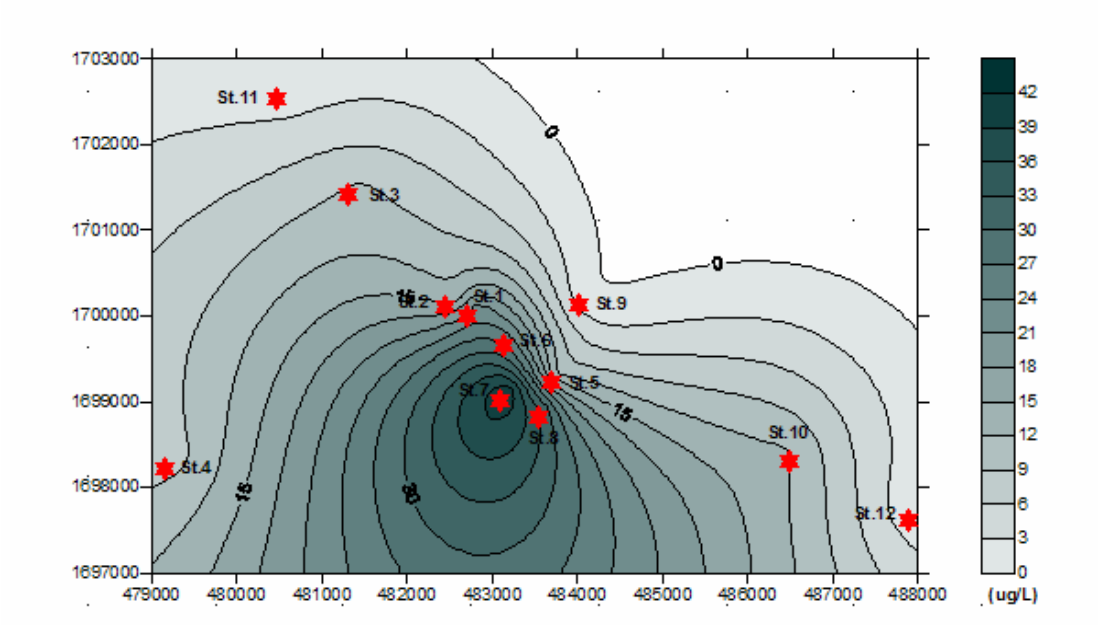

Figure 4.29 Concentration (µg/L) contour map of lead (Pb) during dry season

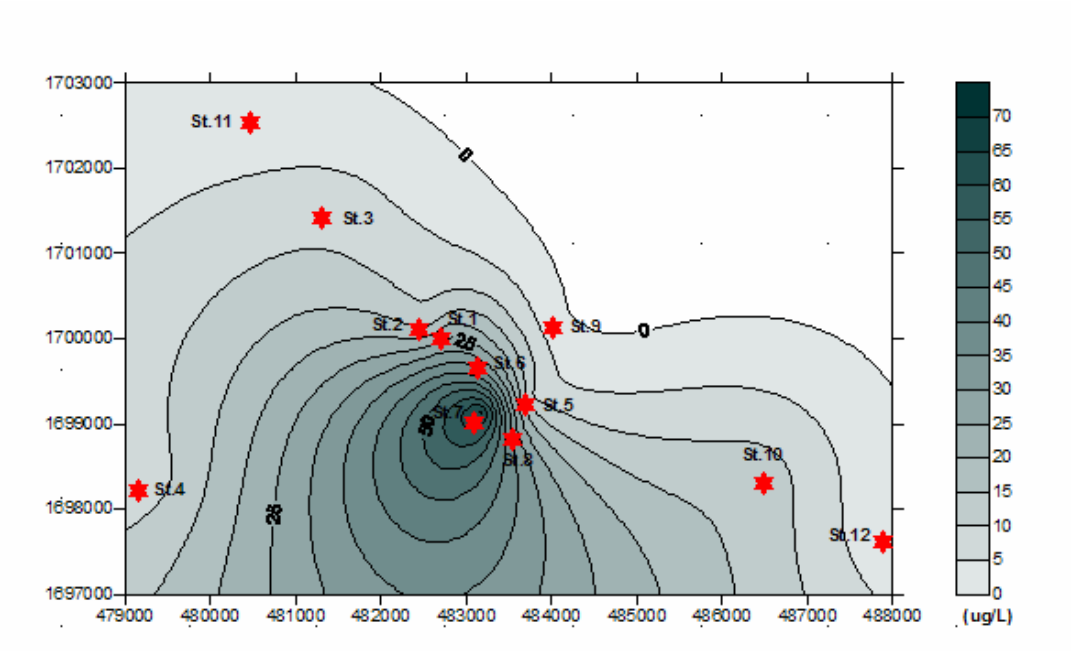

Figure 4.30 Concentration (µg/L) contour map of lead (Pb) average all year round

4.2.5.6 Mercury (Hg)

All concentrations of mercury contamination in shallow groundwater during wet season were lower than detection limit (<0.05 µg/L) therefore the assumed average was 0.05 $\pm$ 0 µg/L. The concentrations of mercury contamination in shallow groundwater during dry season ranged from 0.07 $\pm$ 0 µg/L to 0.96 $\pm$ 0.64 µg/L and

average was 0.14 ± 0.26 µg/L. The average concentrations of mercury of whole year ranged from 0.06 ± 0.01 µg/L to 0.51 ± 0.64 µg/L and average of mercury was 0.10±0.13 µg/L. The highest concentration of mercury was observed in well station number 1. The concentrations of mercury contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.31.

All the standard concentrations of mercury in drinking water were 0.001 mg/L from Pollution Control Department, WHO, and EU respectively (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of mercury contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of mercury at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

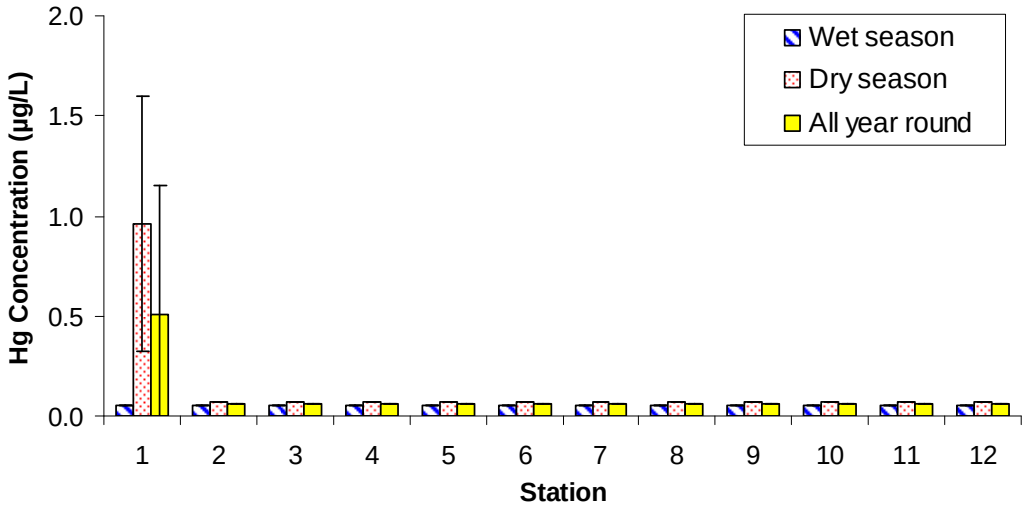

Figure 4.31 The concentration (µg/L) of mercury (Hg) in shallow groundwater

4.2.5.7 Nickel (Ni)

The concentrations of nickel contamination in shallow groundwater during wet season ranged from 0.91-18.90 µg/L and average of nickel was 6.87 ± 4.99 µg/L. The concentrations of nickel contamination in shallow groundwater during dry season ranged from 0.38 to 14.90 µg/L and average was 5.40 ± 3.95 µg/L. The average concentrations of nickel of whole year ranged from 0.65 ± 0.37 µg/L to 15.63 ± 4.63

µg/L and average of nickel was 6.13 ± 4.38 µg/L. The highest concentration of nickel was observed in well station number 6. The concentrations of nickel contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.32 – 4.35.

All standard concentrations of nickel in drinking water were 0.02 mg/L (Pollution Control Department, 2000; WHO, 1993; EU, 1998). All concentrations of nickel contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of nickel at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

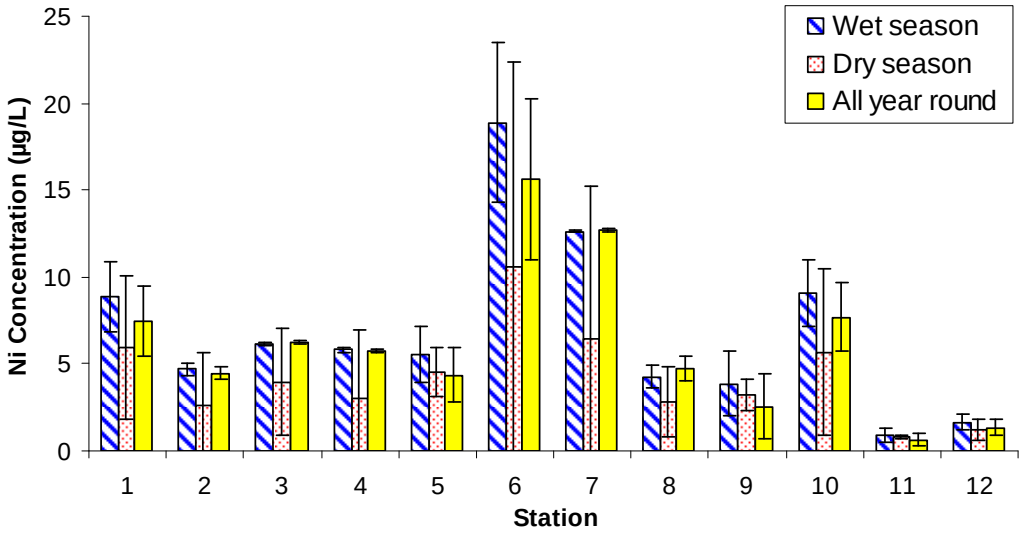

Figure 4.32 The concentration (µg/L) of nickel (Ni) in shallow groundwater

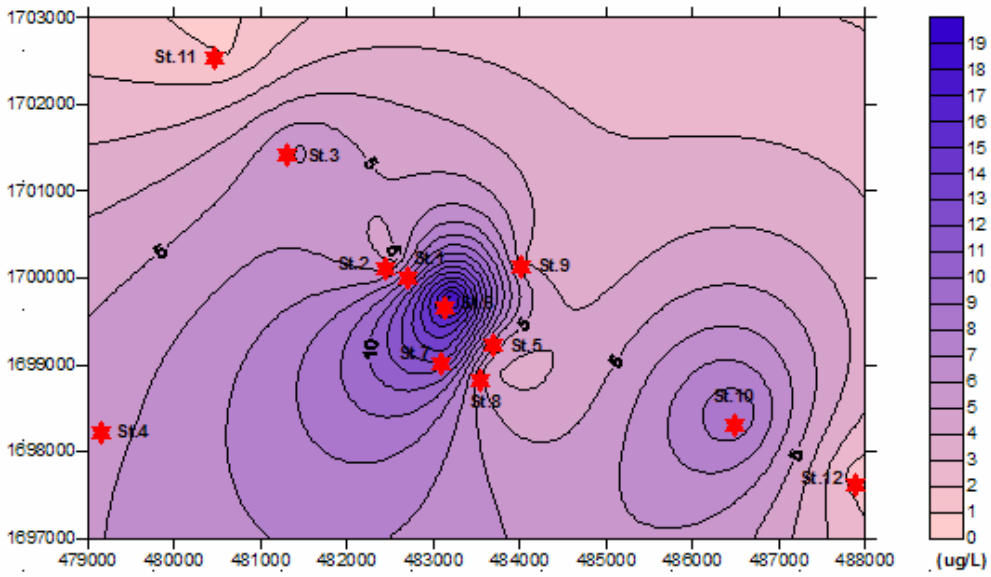

Figure 4.33 Concentration (µg/L) contour map of nickel (Ni) during wet season

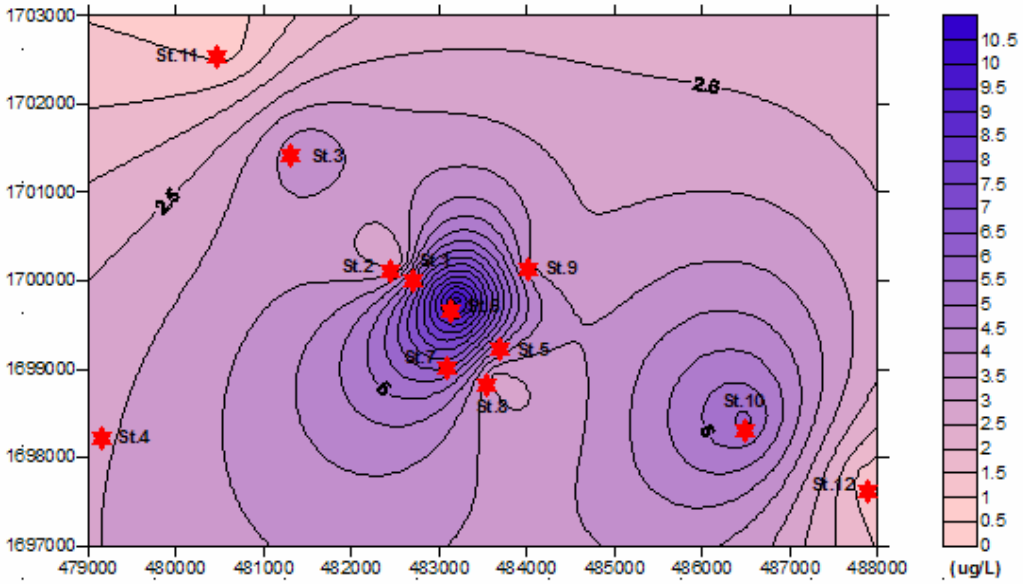

Figure 4.34 Concentration (µg/L) contour map of nickel (Ni) during dry season

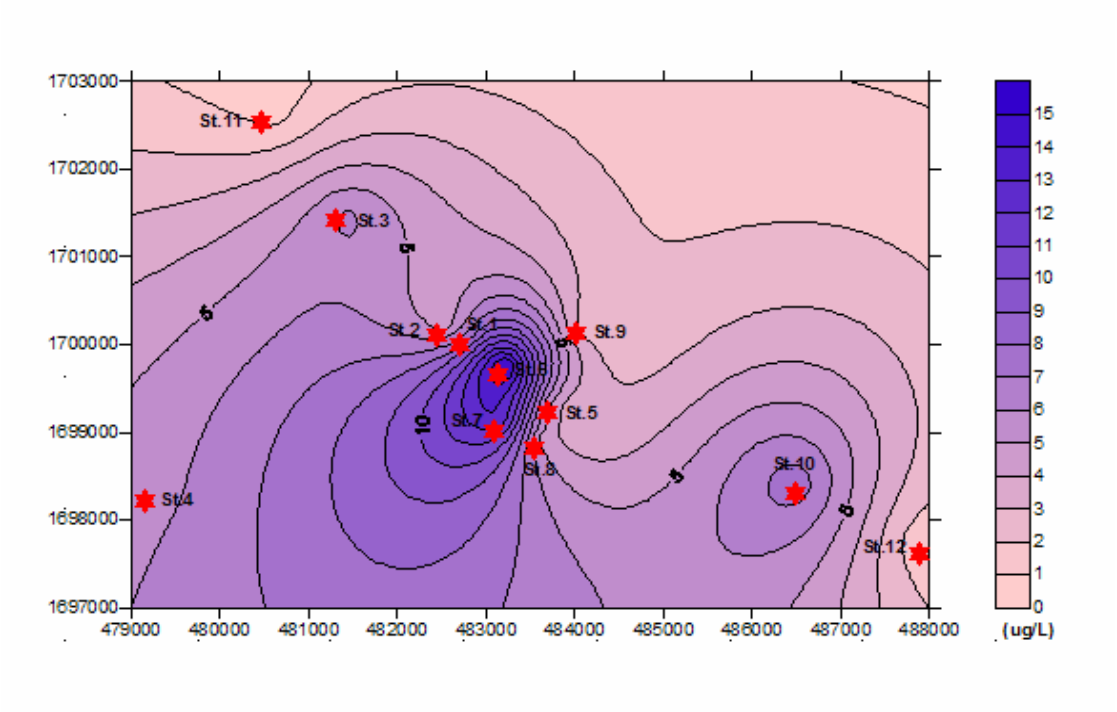

Figure 4.35 Concentration (µg/L) contour map of nickel (Ni) average all year round

4.2.5.8 Zinc (Zn)

The concentrations of zinc contamination in shallow groundwater during wet season ranged from 10.05 to 509.50 µg/L and average of zinc was 79.53 ± 139.27 µg/L. The concentrations of zinc contamination in shallow groundwater during dry season ranged from 1.70 to 424.0 µg/L and average of zinc was 47.32 ± 62.89 µg/L. The average concentrations of zinc of whole year ranged from 6.94 ± 5.73 µg/L to 302.43 ± 292.85 µg/L and average of zinc was 63.43 ± 87.75 µg/L. The highest concentration of zinc was observed in well station number 7. The concentrations of zinc contaminated in twelve shallow groundwater wells were shown in table 4.5 and figure 4.36 – 4.39.

The standard concentrations of zinc in drinking water were 5 and 3 mg/L from Pollution Control Department and WHO respectively (Pollution Control Department, 2000; WHO, 1993). All concentrations of zinc contamination in shallow groundwater at study area were lower than drinking water standard.

The comparison of concentrations of zinc at study area between wet season and dry season, T-test showed that the difference between wet season and dry season was not statistical significance (p>0.05).

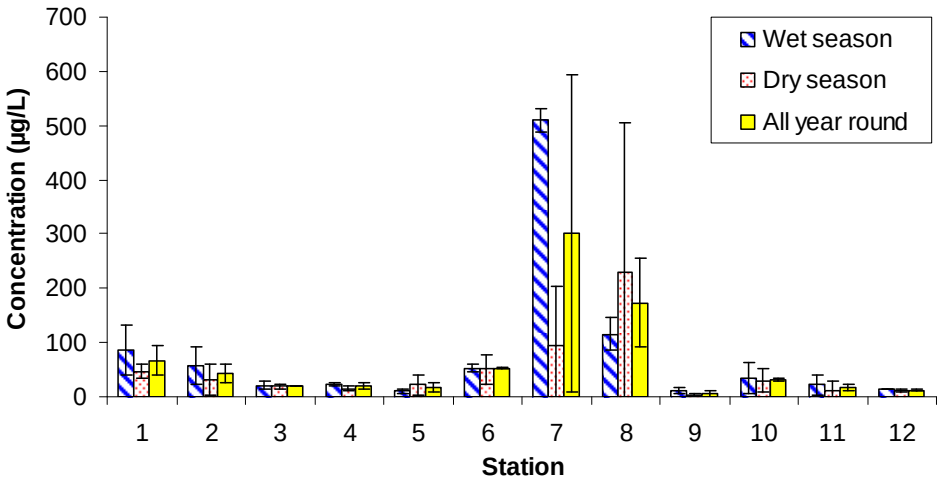

Figure 4.36 The concentration (µg/L) of zinc (Zn) in shallow groundwater

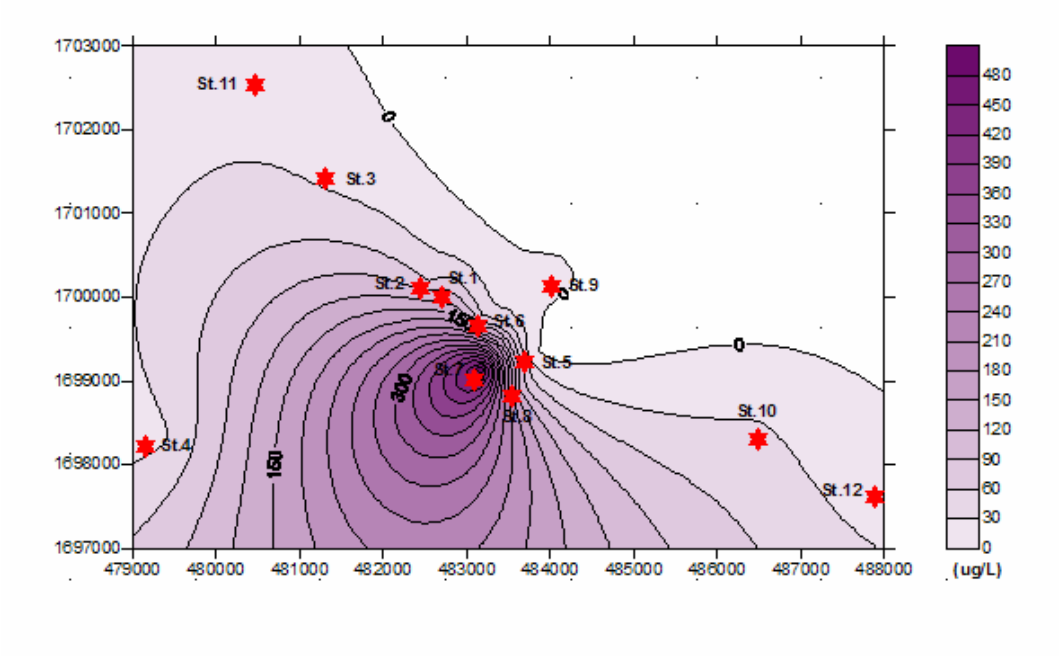

Figure 4.37 Concentration (µg/L) contour map of zinc (Zn) during wet season

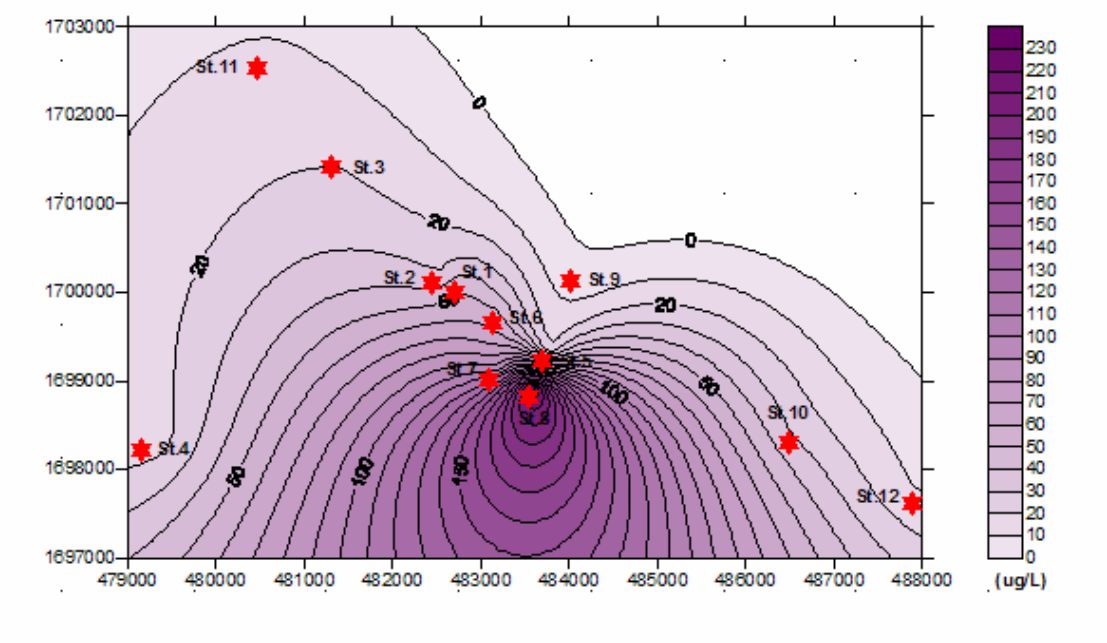

Figure 4.38 Concentration (µg/L) contour map of zinc (Zn) during dry season

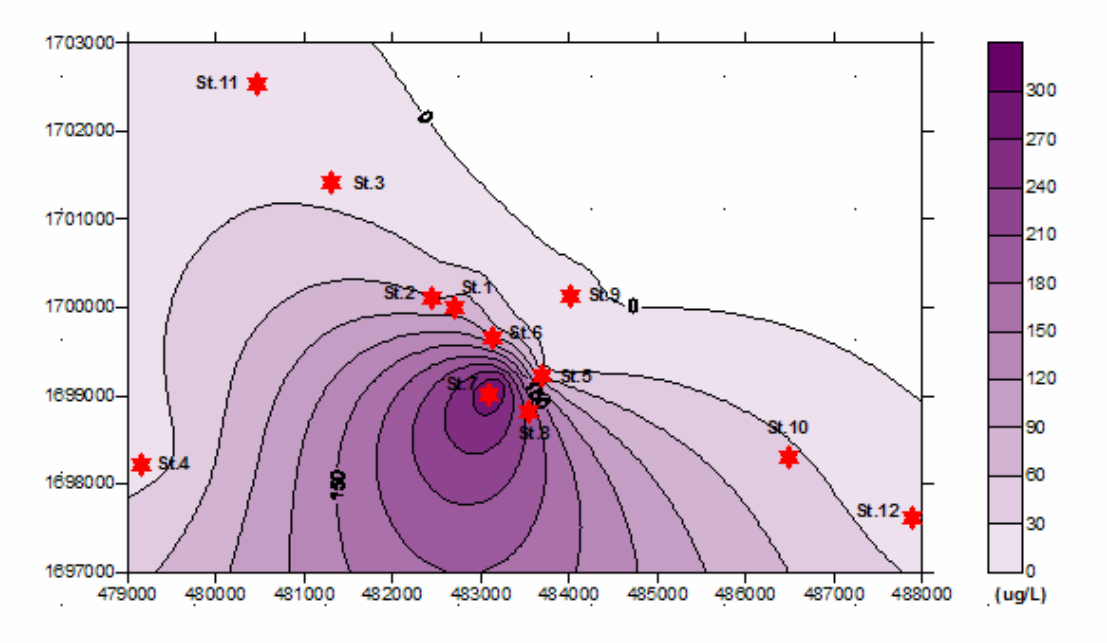

Figure 4.39 Concentration (µg/L) contour map of zinc (Zn) average all year round

As a result of concentration contour maps, the concentrations of each heavy metal had similar pattern that high concentration were in the middle. In addition, the study of Suesat (2010) about Hydraulic gradient at the same well stations and the same study area at Muang district, Ubonratchathani Province, this study reported that

distribution of heavy metal in groundwater was conformed the hydraulic gradient of groundwater at study area. This study supported that characteristic distribution of heavy metals related to the flow of groundwater hydraulic gradient (hydraulic gradient = △Height / △Distance) which in the middle of study area was lower than surrounding therefore the flow of groundwater was lower than surrounding. As a result, this study showed the heavy metals concentrations were higher than surrounding which had higher hydraulic gradient and groundwater flow.

Moreover, the concentrations of heavy metals contaminated in shallow groundwater at study area had similar order when compared with the concentrations of heavy metals in fertilizers that local people generally used in their farm at study area for long period. The orders of concentration as following:

; concentrations in fertilizers: Zn > Cr > Ni > Cu > As > Pb > Cd > Hg

; concentrations in shallow groundwater: Zn > Cu > Pb > Ni > As > Cr > Cd > Hg

There were some correlations among heavy metals, pH, and conductivity. During wet season, the correlations of pH and As was significant positive correlation (0.942), also the correlations of conductivity and As (0.906). The correlations between Cd and Cu, Pb, Ni, Zn were significant positive correlation (range from 0.674 to 0.815). The correlations between Cu and Cd, Pb, Zn were significant positive correlation (range from 0.723 to 0.996). The correlations between Pb and Cd ,Cu ,Ni,Zn were significant positive correlation (range from 0.623 to 0.964). The correlations between Ni and Cd, Pb were significant positive correlation (range from 0.623 to 0.674). The correlations between Zn and Cd, Cu, Pb were significant positive correlation (range from 0.760 to 0.996).

During dry season, the correlations of pH and As was significant positive correlation (0.889), also the correlations of conductivity and As (0.976). The correlations between Cd and Ni were significant positive correlation (0.760). The correlations between Cu and Pb, Zn were significant positive correlation (range from 0.649 to 0.989). The correlations between Pb and Cu, Ni, Zn were significant positive correlation (range from 0.583 to 0.735). The correlations between Ni and Cd, Pb were significant positive correlation (range from 0.583 to 0.760). The correlations between Zn and Cu, Pb were significant positive correlation (range from 0.735 to 0.989). The correlations showed in table 4.3 and 4.4

Table 4.3 The correlations of heavy metals during wet season

Correlations

		pH	Conductivity	As_Conc	Cd_Conc	Cr_Conc	Cu_Conc	Pb_Conc	Hg_Conc	Ni_Conc	Zn_Conc
pH	Pearson Correlation	1	.906**	.942**	-.164	.019	-.162	-.205	.[a]	-.381	-.140
	Sig. (2-tailed)		.000	.000	.610	.954	.614	.523	.	.222	.664
	N	12	12	12	12	12	12	12	12	12	12
Conductivity	Pearson Correlation	.906**	1	.930**	-.046	.128	-.040	-.068	.[a]	-.234	-.021
	Sig. (2-tailed)	.000		.000	.888	.693	.901	.833	.	.465	.948
	N	12	12	12	12	12	12	12	12	12	12
As_Conc	Pearson Correlation	.942**	.930**	1	-.132	.061	-.067	-.103	.[a]	-.343	-.048
	Sig. (2-tailed)	.000	.000		.682	.851	.836	.751	.	.275	.883
	N	12	12	12	12	12	12	12	12	12	12
Cd_Conc	Pearson Correlation	-.164	-.046	-.132	1	-.263	.723**	.815**	.[a]	.674*	.760**
	Sig. (2-tailed)	.610	.888	.682		.408	.008	.001	.	.016	.004
	N	12	12	12	12	12	12	12	12	12	12
Cr_Conc	Pearson Correlation	.019	.128	.061	-.263	1	-.175	-.191	.[a]	-.198	-.156
	Sig. (2-tailed)	.954	.693	.851	.408		.586	.552	.	.537	.629
	N	12	12	12	12	12	12	12	12	12	12
Cu_Conc	Pearson Correlation	-.162	-.040	-.067	.723**	-.175	1	.960**	.[a]	.399	.996**
	Sig. (2-tailed)	.614	.901	.836	.008	.586		.000	.	.198	.000
	N	12	12	12	12	12	12	12	12	12	12
Pb_Conc	Pearson Correlation	-.205	-.068	-.103	.815**	-.191	.960**	1	.[a]	.623*	.964**
	Sig. (2-tailed)	.523	.833	.751	.001	.552	.000		.	.030	.000
	N	12	12	12	12	12	12	12	12	12	12
Hg_Conc	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.
	N	12	12	12	12	12	12	12	12	12	12
Ni_Conc	Pearson Correlation	-.381	-.234	-.343	.674*	-.198	.399	.623*	.[a]	1	.408
	Sig. (2-tailed)	.222	.465	.275	.016	.537	.198	.030	.		.188
	N	12	12	12	12	12	12	12	12	12	12
Zn_Conc	Pearson Correlation	-.140	-.021	-.048	.760**	-.156	.996**	.964**	.[a]	.408	1
	Sig. (2-tailed)	.664	.948	.883	.004	.629	.000	.000	.	.188	
	N	12	12	12	12	12	12	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4.4 The correlations of heavy metals during dry season

Correlations

		pH	Conductivity	As_Conc	Cd_Conc	Cr_Conc	Cu_Conc	Pb_Conc	Hg_Conc	Ni_Conc	Zn_Conc
pH	Pearson Correlation	1	.877**	.889**	-.154	.[a]	-.246	-.529	-.229	-.508	-.325
	Sig. (2-tailed)		.000	.000	.632	.	.440	.077	.474	.092	.303
	N	12	12	12	12	12	12	12	12	12	12
Conductivity	Pearson Correlation	.877**	1	.976**	-.144	.[a]	-.143	-.249	-.034	-.290	-.188
	Sig. (2-tailed)	.000		.000	.656	.	.658	.435	.917	.360	.558
	N	12	12	12	12	12	12	12	12	12	12
As_Conc	Pearson Correlation	.889**	.976**	1	-.111	.[a]	-.112	-.284	-.005	-.306	-.158
	Sig. (2-tailed)	.000	.000		.730	.	.729	.372	.988	.333	.623
	N	12	12	12	12	12	12	12	12	12	12
Cd_Conc	Pearson Correlation	-.154	-.144	-.111	1	.[a]	-.116	.303	.039	.760**	-.045
	Sig. (2-tailed)	.632	.656	.730		.	.720	.339	.904	.004	.890
	N	12	12	12	12	12	12	12	12	12	12
Cr_Conc	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.
	N	12	12	12	12	12	12	12	12	12	12
Cu_Conc	Pearson Correlation	-.246	-.143	-.112	-.116	.[a]	1	.649*	-.109	.009	.989**
	Sig. (2-tailed)	.440	.658	.729	.720	.		.022	.737	.978	.000
	N	12	12	12	12	12	12	12	12	12	12
Pb_Conc	Pearson Correlation	-.529	-.249	-.284	.303	.[a]	.649*	1	.180	.583*	.735**
	Sig. (2-tailed)	.077	.435	.372	.339	.	.022		.575	.047	.007
	N	12	12	12	12	12	12	12	12	12	12
Hg_Conc	Pearson Correlation	-.229	-.034	-.005	.039	.[a]	-.109	.180	1	.200	.000
	Sig. (2-tailed)	.474	.917	.988	.904	.	.737	.575		.533	1.000
	N	12	12	12	12	12	12	12	12	12	12
Ni_Conc	Pearson Correlation	-.508	-.290	-.306	.760**	.[a]	.009	.583*	.200	1	.104
	Sig. (2-tailed)	.092	.360	.333	.004	.	.978	.047	.533		.747
	N	12	12	12	12	12	12	12	12	12	12
Zn_Conc	Pearson Correlation	-.325	-.188	-.158	-.045	.[a]	.989**	.735**	.000	.104	1
	Sig. (2-tailed)	.303	.558	.623	.890	.	.000	.007	1.000	.747	
	N	12	12	12	12	12	12	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4.5 Concentrations of Heavy Metals Contaminated in Shallow Groundwater

Concentrations of Heavy Metals (µg/L) Contaminated in Shallow Groundwater at Muang District, Ubon Rachatani Province, Thailand.														
Time	**Metals**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**	**Station 9**	**Station 10**	**Station 11**	**Station 12**	**Ave.+ SD**
Wet Season	As	0.81 ± 0.34	0.68 ± 0.44	0.80 ± 0.02	0.44 ± 0.28	0.32 ± 0.02	1.15 ± 0.04	1.00 ± 0.36	3.06 ± 3.87	0.39 ± 0.25	0.36 ± 0.07	8.68 ± 0.42	0.56 ± 0.11	1.52 ± 2.37
	Cd	0.13 ± 0.01	0.22 ± 0.13	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.25 ± 0.05	0.31 ± 0.21	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.16 ± 0.06
	Cr	0.51 ± 0.15	0.15 ± 0.01	3.84 ± 5.05	0.14 ± 0.00	0.15 ± 0.01	0.25 ± 0.00	0.26 ± 0.03	0.93 ± 0.30	0.25 ± 0.15	0.14 ± 0.00	0.78 ± 0.51	1.14 ± 0.00	0.71 ± 1.04
	Cu	137.85 ± 76.58	50.30 ± 16.12	11.10 ± 1.41	25.55 ± 3.89	10.90 ± 2.13	44.75 ± 3.75	595.00 ± 220.62	134.00 ± 22.63	23.40 ± 24.33	44.50 ± 24.32	16.19 ± 16.85	16.30 ± 11.74	92.49 ± 164.27
	Pb	24.30 ± 4.81	9.46 ± 0.28	7.02 ± 0.18	7.20 ± 0.32	7.81 ± 9.04	32.10 ± 1.13	92.55 ± 26.09	25.00 ± 6.08	1.24 ± 0.18	13.50 ± 4.38	2.64 ± 2.60	0.82 ± 0.03	18.64 ± 25.38
	Hg	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
	Ni	8.89 ± 2.99	4.73 ± 0.44	6.15 ± 1.79	5.80 ± 0.18	5.51 ± 3.54	18.90 ± 2.26	12.65 ± 0.35	4.27 ± 1.43	3.88 ± 2.60	9.07 ± 2.31	0.91 ± 0.72	1.64 ± 0.76	6.87 ± 4.99
	Zn	85.85 ± 46.88	56.25 ± 34.72	20.80 ± 7.21	22.80 ± 2.69	10.05 ± 4.88	52.85 ± 6.15	509.50 ± 21.92	115.50 ± 30.41	10.99 ± 5.68	33.70 ± 28.85	22.10 ± 18.82	14.00 ± 0.71	79.53 ± 139.27
Dry Season	As	0.58 ± 0.09	0.17 ± 0.00	0.33 ± 0.22	0.17 ± 0.00	0.17 ± 0.00	0.63 ± 0.07	0.17 ± 0.00	0.26 ± 0.13	0.17 ± 0.00	0.17 ± 0.00	4.19 ± 2.38	0.17 ± 0.00	0.60 ± 1.14
	Cd	0.14 ± 0.01	0.13 ± 0.00	0.14 ± 0.01	0.13 ± 0.00	0.16 ± 0.05	0.17 ± 0.00	0.14 ± 0.01	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.14 ± 0.01
	Cr	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00	0.44 ± 0.00
	Cu	14.40 ± 1.84	17.05 ± 7.71	12.17 ± 5.98	11.89 ± 3.41	9.16 ± 6.42	26.90 ± 10.75	51.45 ± 49.30	146.95 ± 123.11	0.99 ± 0.59	20.35 ± 8.27	13.69 ± 13.60	11.33 ± 2.64	28.03 ± 39.47
	Pb	21.90 ± 8.63	13.05 ± 3.61	9.49 ± 3.27	8.27 ± 2.59	11.30 ± 12.59	24.15 ± 0.64	41.15 ± 9.83	31.25 ± 10.54	0.53 ± 0.17	12.13 ± 4.49	1.48 ± 1.17	1.28 ± 1.89	14.67 ± 4.38
	Hg	0.96 ± 0.64	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.14 ± 0.26
	Ni	6.03 ± 1.71	4.23 ± 0.83	6.29 ± 0.37	5.64 ± 1.38	3.25 ± 0.68	12.35 ± 0.07	12.75 ± 3.04	5.22 ± 0.02	1.26 ± 1.08	6.35 ± 2.59	0.38 ± 0.00	1.03 ± 0.02	5.40 ± 3.95
	Zn	47.30 ± 14.14	30.70 ± 28.14	19.45 ± 4.17	14.90 ± 4.81	22.02 ± 19.06	50.85 ± 26.52	95.35 ± 108.40	230.75 ± 273.30	2.89 ± 1.68	30.05 ± 20.58	12.80 ± 15.70	10.78 ± 2.44	47.32 ± 62.89
All Year Round	As	0.69 ± 0.16	0.43 ± 0.36	0.56 ± 0.33	0.30 ± 0.19	0.25 ± 0.11	0.89 ± 0.36	0.59 ± 0.59	1.66 ± 1.98	0.28 ± 0.16	0.27 ± 0.13	6.44 ± 3.17	0.36 ± 0.28	1.06 ± 1.74
	Cd	0.14 ± 0.01	0.18 ± 0.06	0.14 ± 0.01	0.13 ± 0.00	0.15 ± 0.02	0.21 ± 0.06	0.23 ± 0.12	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.13 ± 0.00	0.15 ± 0.03
	Cr	0.48 ± 0.05	0.30 ± 0.21	2.14 ± 2.40	0.29 ± 0.21	0.30 ± 0.21	0.35 ± 0.13	0.35 ± 0.13	0.69 ± 0.35	0.35 ± 0.13	0.29 ± 0.21	0.61 ± 0.24	0.79 ± 0.49	0.58 ± 0.52
	Cu	76.13 ± 87.29	33.68 ± 23.51	11.64 ± 0.76	18.72 ± 9.66	10.03 ± 1.23	35.83 ± 12.62	323.23 ± 384.35	140.48 ± 9.16	12.20 ± 15.85	32.43 ± 17.08	14.94 ± 1.77	13.82 ± 3.51	60.26 ± 90.98
	Pb	23.10 ± 1.70	11.26 ± 2.54	8.26 ± 1.75	7.74 ± 1.76	9.56 ± 2.47	28.13 ± 5.62	66.85 ± 36.35	28.13 ± 4.42	0.95 ± 0.42	12.82 ± 0.97	2.06 ± 0.82	1.05 ± 0.33	16.66 ± 18.52
	Hg	0.51 ± 0.64	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.10 ± 0.13
	Ni	7.46 ± 2.02	4.48 ±0.35	6.22 ± 0.10	5.72 ± 0.11	4.38 ± 1.60	15.63 ± 4.63	12.70 ± 0.07	4.75 ± 0.67	2.57 ± 1.85	7.71 ± 1.92	0.65 ± 0.37	1.34 ± 0.43	6.13 ± 4.38
	Zn	66.58 ± 27.26	43.48 ± 18.07	20.13 ± 0.95	18.85 ± 5.59	16.04 ± 8.46	51.85 ± 1.41	302.43 ± 292.85	173.13 ± 81.49	6.94 ± 5.73	31.88 ± 2.58	17.45 ± 6.58	12.39 ± 2.28	63.43 ± 87.75

4.3 The Human Health Risk Assessment during Wet and Dry Season

4.3.1 Arsenic (As)

The human health risk assessment of arsenic contaminated in shallow groundwater could be divided into two types; non-carcinogenic risk and carcinogenic risk. According to non-carcinogenic risk, during wet season the hazard quotient ranged from 0.93 to 687.50. All hazard quotient were higher than one ($HQ \geq 1$) and adverse non-carcinogenic effects of concern excepted only well station number 5, which was lower than one ($HQ < 1$) and an acceptable level. In addition, the cancer risk of all wells was acceptable level (cancer risk $\leq 10^{-6}$) except only well station number 11, which was carcinogenic effect (cancer risk $> 10^{-6}$).

During dry season for non-carcinogenic risk, the hazard quotient ranged from 0.26 to 160.20. The hazard quotient at station number 1,6,11 were higher than one ($HQ \geq 1$) and adverse non-carcinogenic effects of concern, while other stations were lower than one ($HQ < 1$) and acceptable level. In addition, the cancer risk of all well stations was acceptable level (cancer risk $\leq 10^{-6}$).

For all year round, the hazard quotient ranged from 0.57 to 378.45. All hazard quotient were higher than one ($HQ \geq 1$) and adverse non-carcinogenic effects of concern excepted only station number 4, 5, 9, 10 were lower than one ($HQ < 1$) and an acceptable level. In addition, the cancer risk of all well stations was acceptable level (cancer risk $\leq 10^{-6}$) except only well station number 11, which was carcinogenic effect (cancer risk $> 10^{-6}$). The highest HQ was observed in well station number 11. The human health risk characterization of arsenic contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.6 - 4.7 and figure 4.40 – 4.45.

Table 4.6 Cancer Risk of arsenic during wet and dry season by location

Cancer Risk of Arsenic Contaminated in Shallow Groundwater at Muang District, Ubon Rachatani Province, Thailand												
Time	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**	**Station 9**	**Station 10**	**Station 11**	**Station 12**
Wet Season	$0.034x10^{-6}$	$0.024x10^{-6}$	$0.033x10^{-6}$	$0.01x10^{-6}$	$0.0053x10^{-6}$	$0.068x10^{-6}$	$0.052x10^{-6}$	$0.49x10^{-6}$	$0.0079x10^{-6}$	$0.0067x10^{-6}$	$3.9x10^{-6}$	$0.016x10^{-6}$
Dry Season	$0.01.7x10^{-8}$	$0.001.5x10^{-9}$	$0.005.6x10^{-9}$	$0.001.5x10^{-9}$	$0.001.5x10^{-9}$	$0.02.1x10^{-8}$	$0.001.5x10^{-9}$	$0.003.5x10^{-9}$	$0.001.5x10^{-9}$	$0.001.5x10^{-9}$	$0.9.1x10^{-7}$	$0.001.5x10^{-9}$
All Year Round	$0.025x10^{-6}$	$0.0096x10^{-6}$	$0.016x10^{-6}$	$0.0047x10^{-6}$	$0.0032x10^{-6}$	$0.041x10^{-6}$	$0.018x10^{-6}$	$0.14x10^{-6}$	$0.0041x10^{-6}$	$0.0038x10^{-6}$	$2.6x10^{-6}$	$0.0067x10^{-6}$

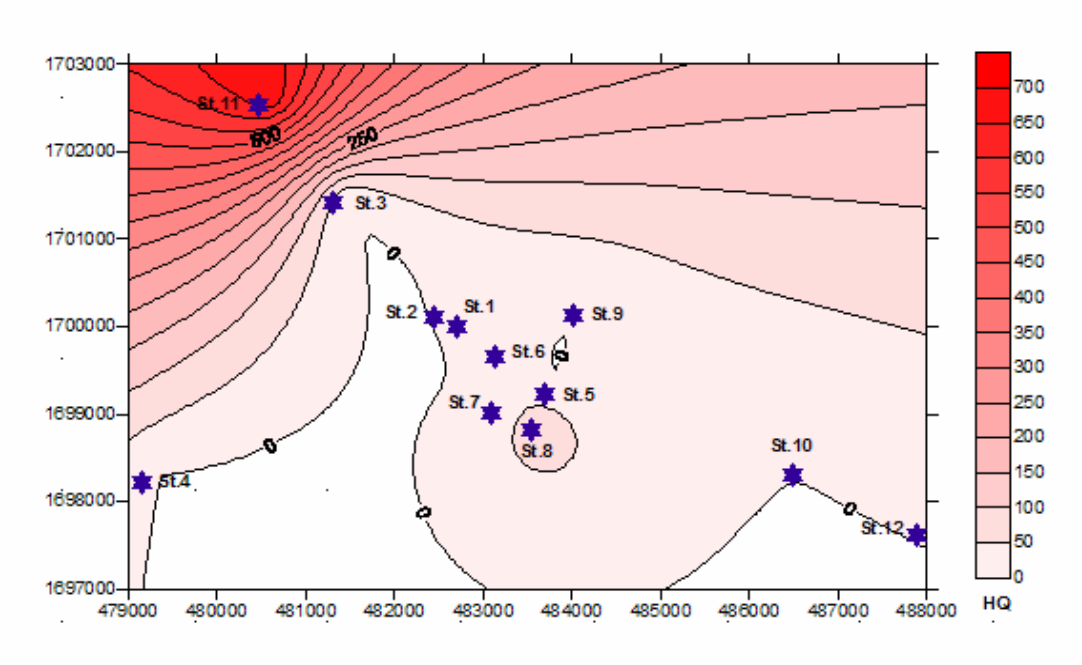

Figure 4.40 Non-carcinogenic risk map of arsenic (As) at study area during wet season

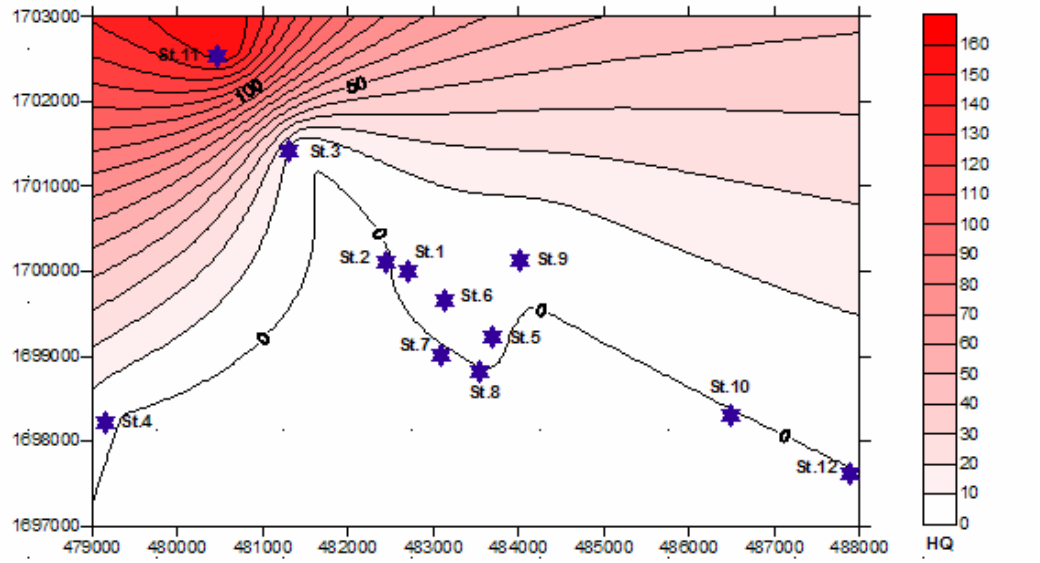

Figure 4.41 Non-carcinogenic risk map of arsenic (As) at study area during dry season

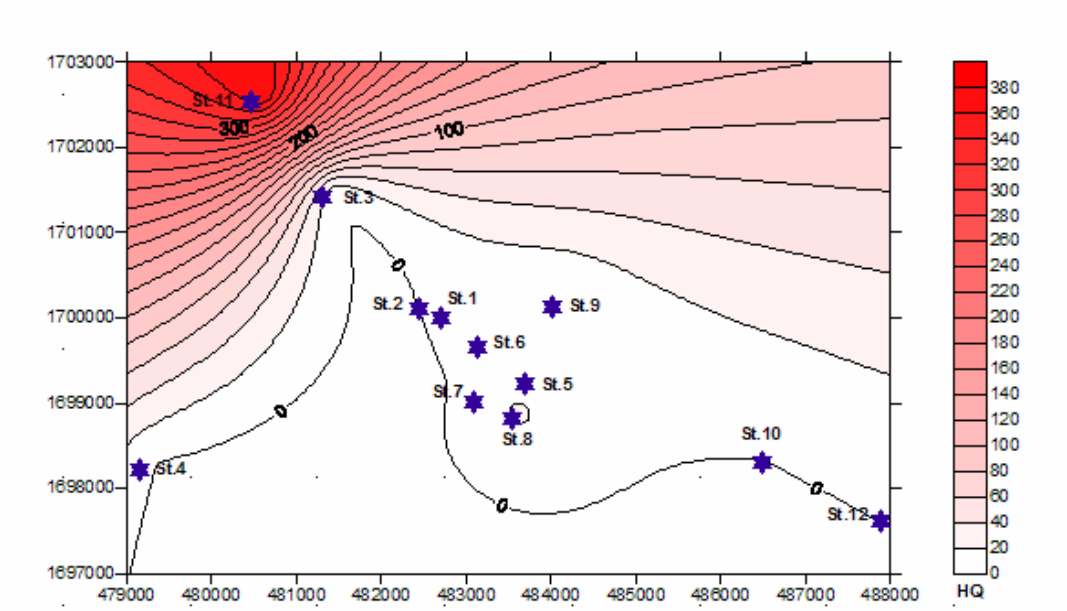

Figure 4.42 Non-carcinogenic risk map of arsenic (As) at study area average all year round

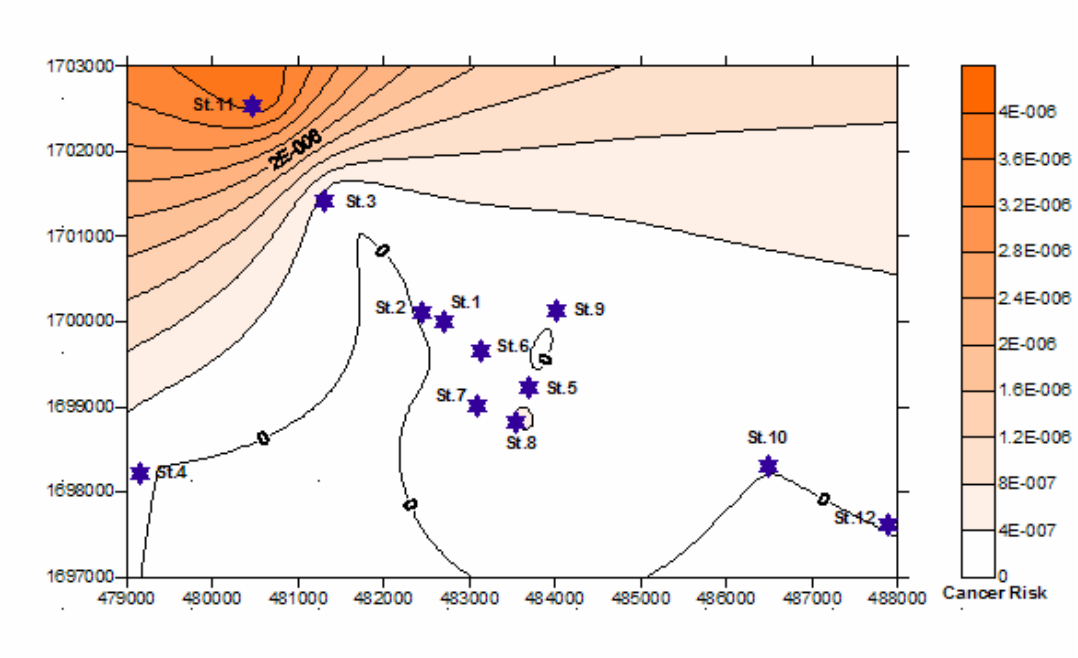

Figure 4.43 Carcinogenic risk map of arsenic (As) at study area during wet season

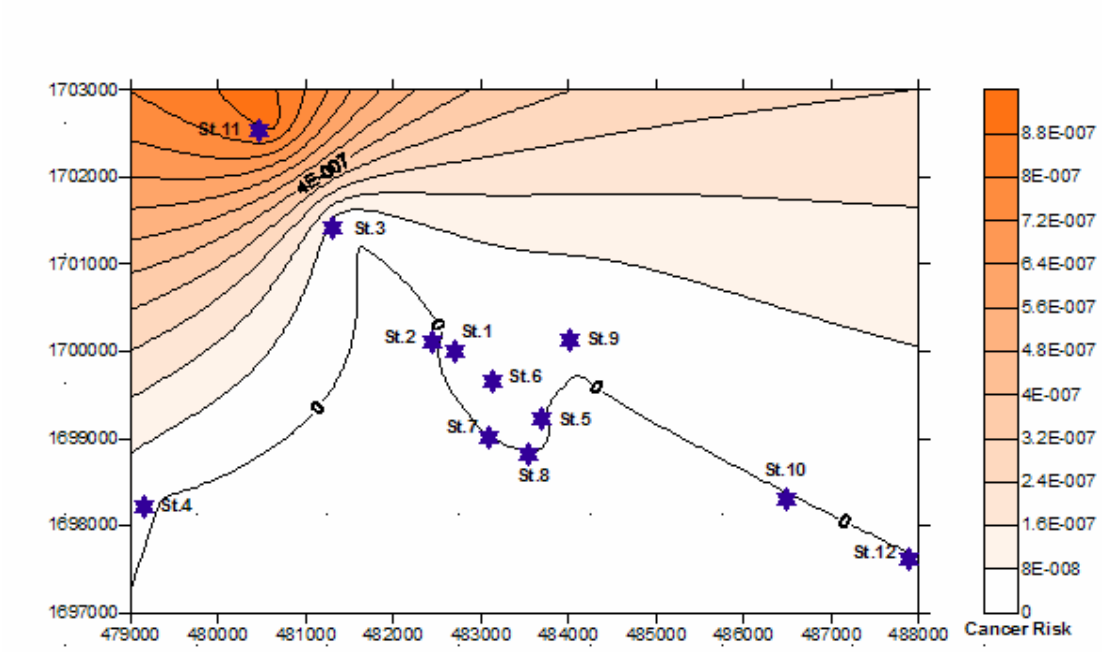

Figure 4.44 Carcinogenic risk map of arsenic (As) at study area during dry season

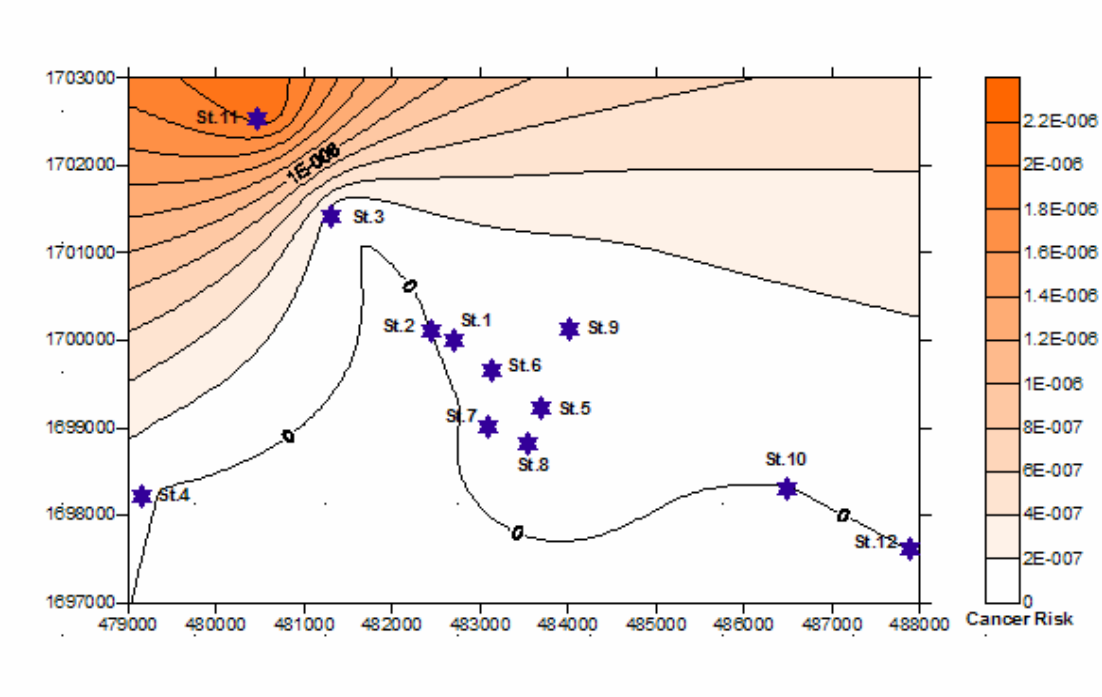

Figure 4.45 Carcinogenic risk map of arsenic (As) at study area average all year round

The human health risk assessment of arsenic were higher than acceptable level although the concentration of arsenic contaminated in shallow groundwater were

lower than groundwater drinking standard, because local people who lived in study area generally worked in their agricultural farm, so they needed to drink a lot of water during day. In addition, Thailand was tropical country and generally hot weather therefore local people always drink water all the day. As a result, human health risk assessment was not only depended on As concentration but also amount of intake rate. Hence the human health risk assessment of arsenic in this study area could higher than acceptable level although the concentration of arsenic contaminated in shallow groundwater were lower than Thailand drinking water standard.

4.3.2 Cadmium (Cd)

The human health risk assessment of cadmium contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there had not report for cancer risk from cadmium by oral route of exposure, only carcinogenic risk from inhalation exposure.

According to non-carcinogenic risk, during wet season the hazard quotient ranged from 0.001 to 0.004. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, all hazard quotient were 0.001 so lower than one (HQ<1) and acceptable level.

For all year round, the hazard quotient ranged from 0.001 to 0.002. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 7. The human health risk characterization of cadmium contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.46 – 4.58.

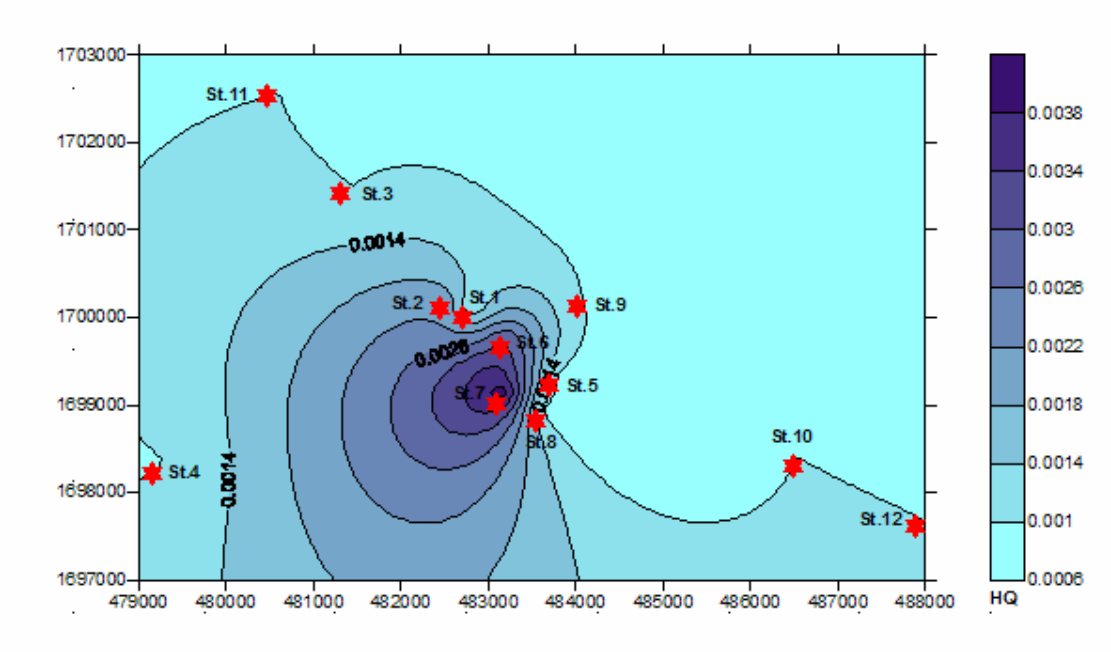

Figure 4.46 Non-carcinogenic risk map of cadmium (Cd) at study area during wet season

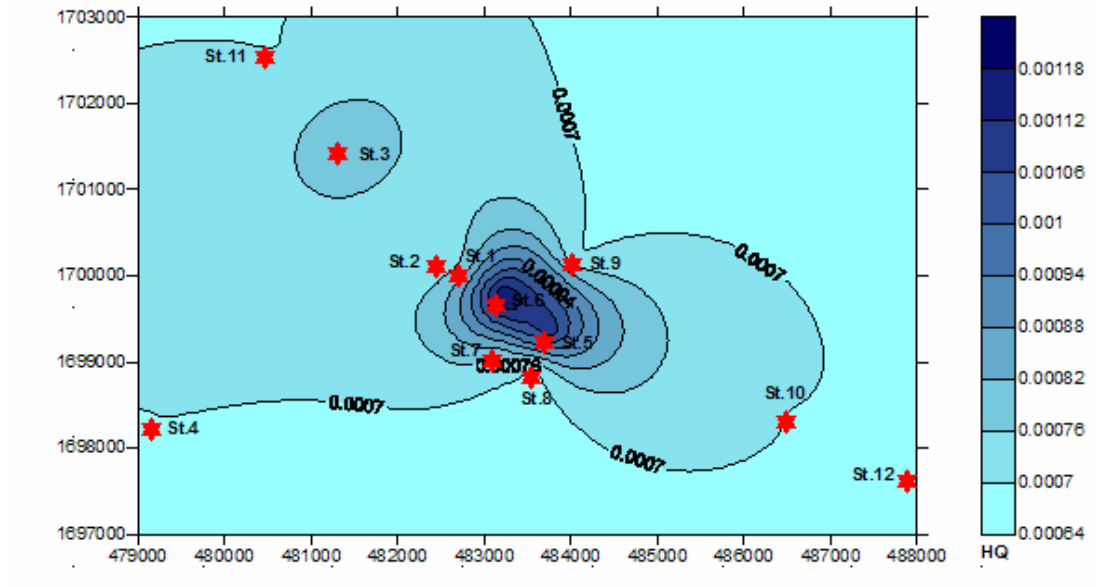

Figure 4.47 Non-carcinogenic risk map of cadmium (Cd) at study area during dry season

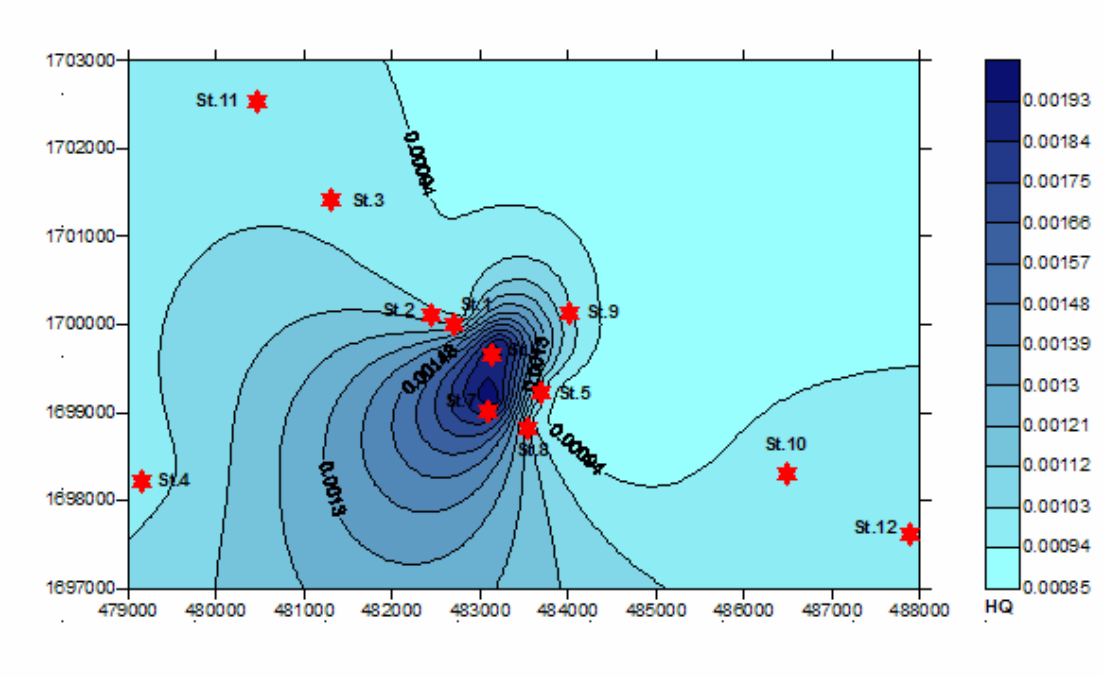

Figure 4.48 Non-carcinogenic risk map of cadmium (Cd) at study area average all year round

4.3.3 Chromium (Cr)

The human health risk assessment of chromium contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there had not report for cancer risk from chromium by oral route of exposure, only carcinogenic risk from inhalation exposure.

According to non-carcinogenic risk, during wet season the hazard quotient ranged from $1.6x10^{-4}$ to $1x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, all hazard quotient were $1.4x10^{-3}$so lower than one (HQ<1) and acceptable level.

For all year round, the hazard quotient ranged from 0.001-0.032. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 3. The human health risk characterization of chromium contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.49.

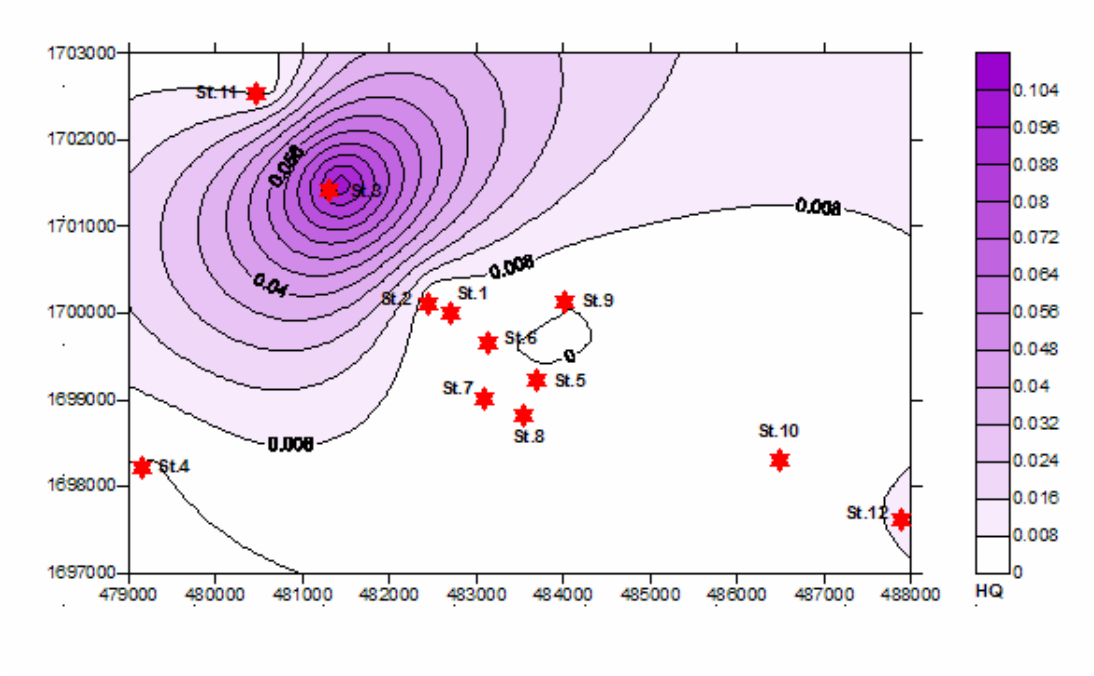

Figure 4.49 Non-carcinogenic risk map of chromium (Cr) at study area during wet season

The hazard quotient (HQ) of chromium (Cr) during dry season and average all year round could not plot to be non-carcinogenic contour risk map because all of the hazard quotients of chromium during dry season were equal.

4.3.4 Copper (Cu)

The human health risk assessment of copper contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there had not report for cancer risk from copper. Also there had not report for copper was carcinogen or not carcinogen, therefore no slope factor value.

According to non-carcinogenic risk, during wet season the hazard quotient ranged from $6x10^{-5}$ to $1.8x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, the hazard quotient ranged from $1x10^{-6}$ to $1.1x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level.

For all year round, the hazard quotient ranged from $5.3x10^{-5}$ to $5.5x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 7. The human health risk characterization of copper contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.50 –4.52.

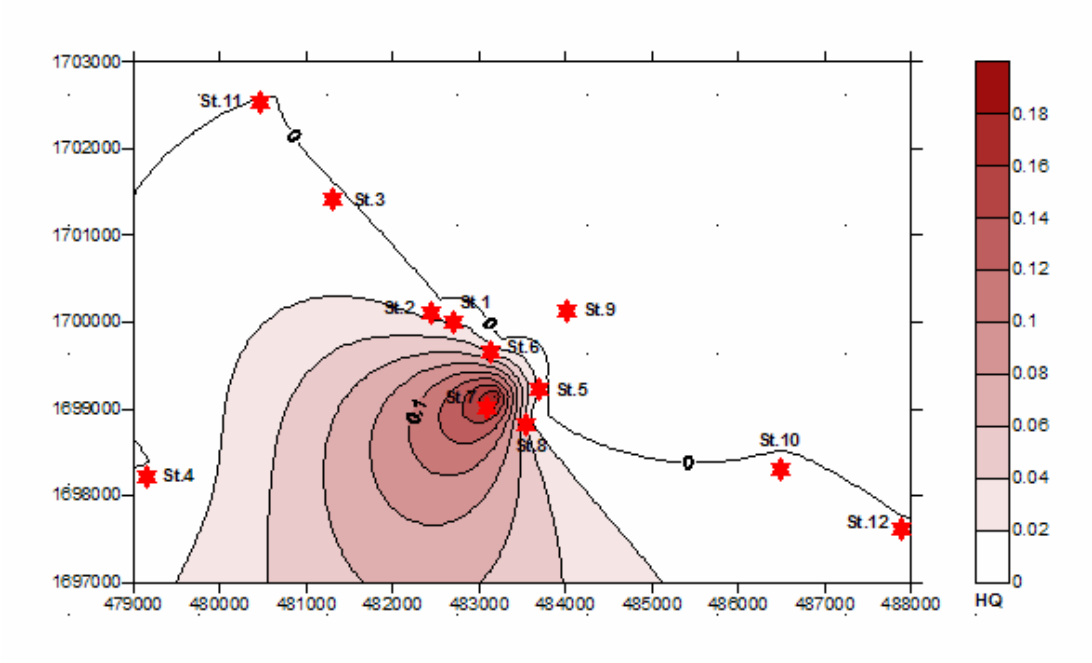

Figure 4.50 Non-carcinogenic risk map of copper (Cu) at study area during wet season

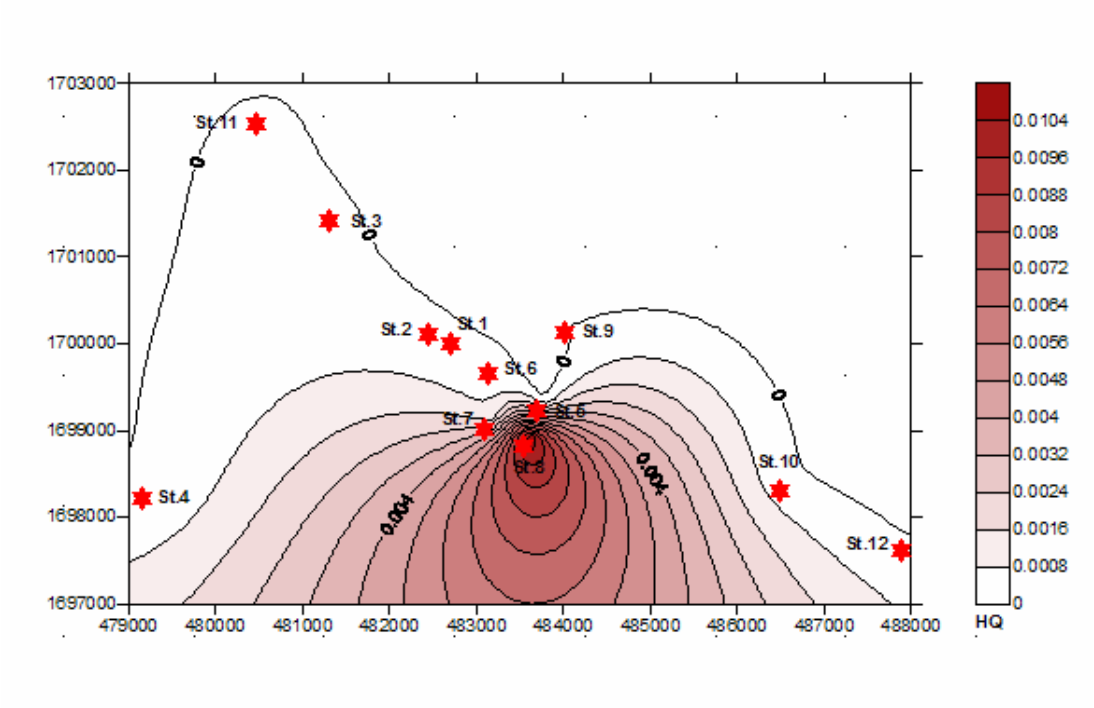

Figure 4.51 Non-carcinogenic risk map of copper (Cu) at study area during dry season

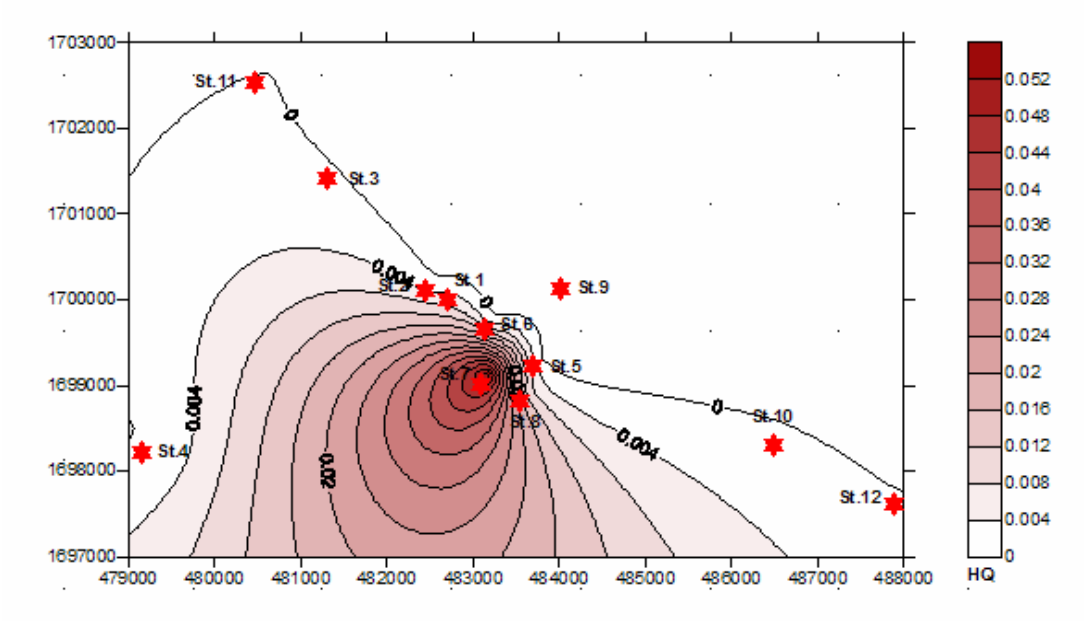

Figure 4.52 Non-carcinogenic risk map of copper (Cu) at study area average all year round

4.3.5 Lead (Pb))

The human health risk assessment of lead contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there had not report for cancer risk from lead. Also there had not report for lead was carcinogen or not carcinogen, therefore no slope factor value. during wet season the hazard quotient ranged from $4x10^{-6}$ to $5.1x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, the hazard quotient ranged from $3x10^{-6}$ to $1x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level.

According to non-carcinogenic risk,

For all year round, the hazard quotient ranged from $5.4x10^{-6}$ to $2.7x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 7. The human health risk characterization of lead contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.53 – 4.55.

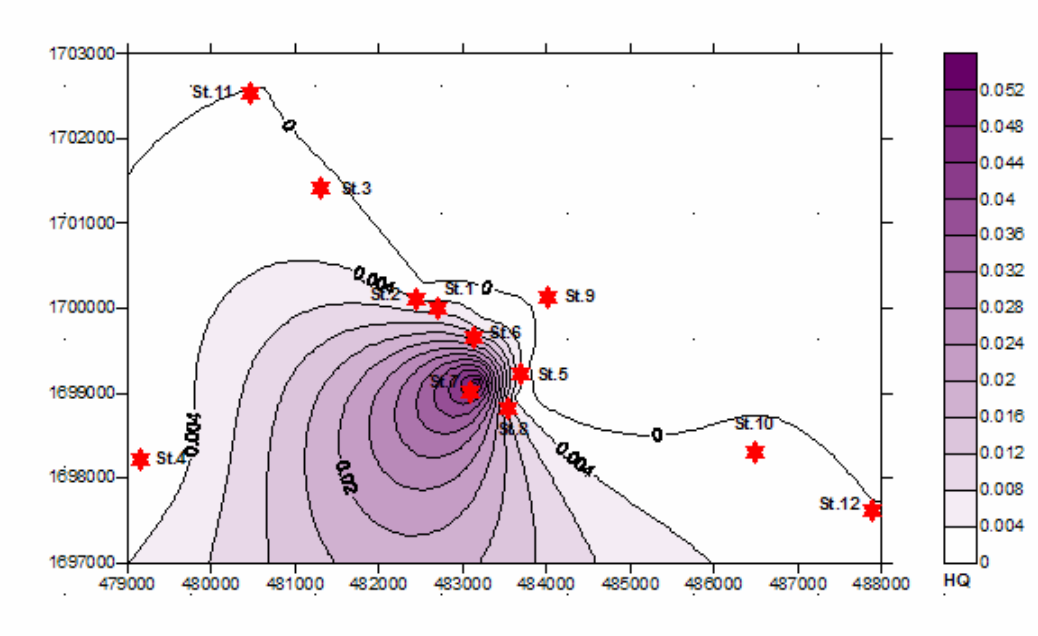

Figure 4.53 Non-carcinogenic risk map of lead (Pb) at study area during wet season

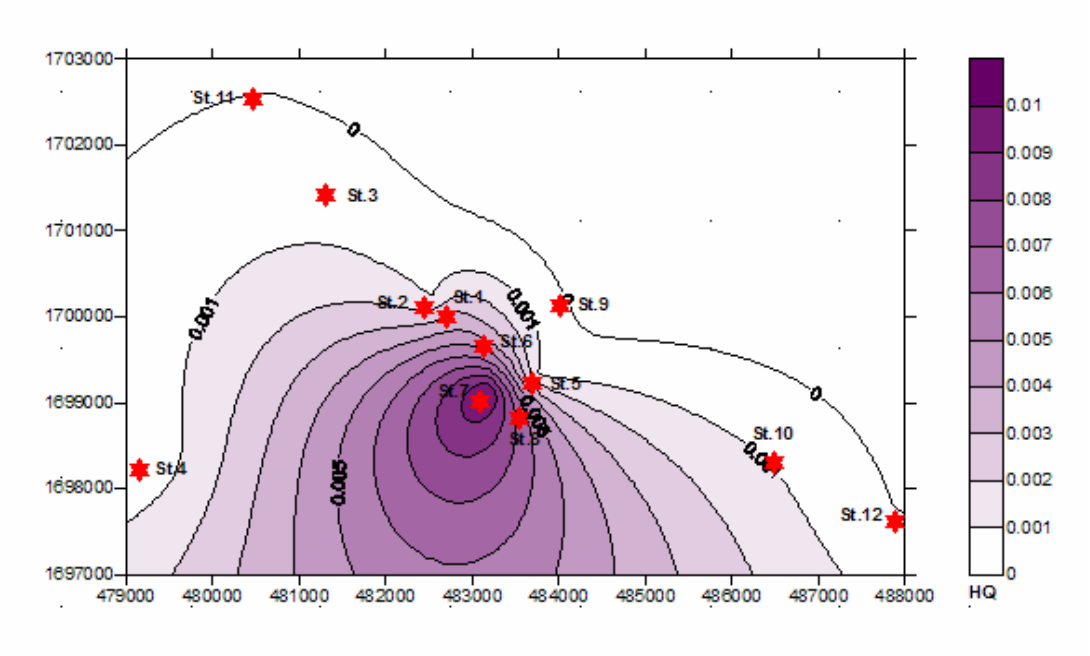

Figure 4.54 Non-carcinogenic risk map of lead (Pb) at study area during dry season

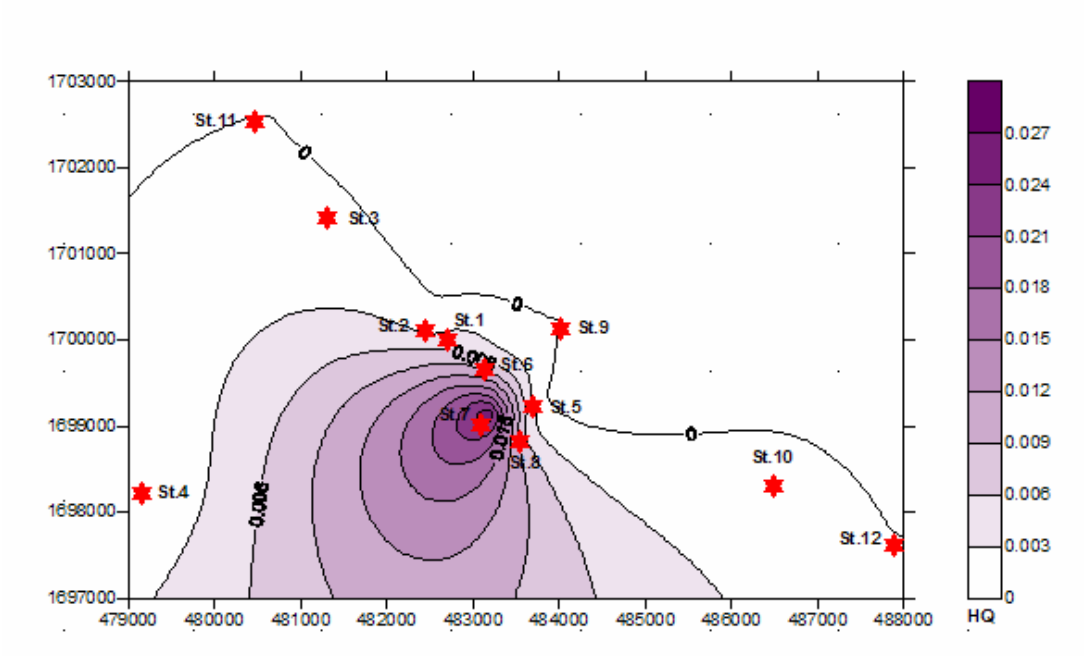

Figure 4.55 Non-carcinogenic risk map of lead (Pb) at study area average all year round

4.3.6 Mercury (Hg)

The human health risk assessment of mercury contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there had not report for cancer risk from mercury. Also there had not report for mercury was carcinogen or not, therefore no slope factor value.

According to non-carcinogenic risk, during wet season the hazard quotient was $2x10^{-4}$. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, the hazard quotient ranged from $3x10^{-4}$ to $6.5x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level.

For all year round, the hazard quotient ranged from $3x10^{-4}$ to $1.8x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 1. The human health risk characterization of mercury contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7.

4.3.7 Nickel (Ni)

The human health risk assessment of nickel contaminated in shallow groundwater was only non-carcinogenic risk, because nickel was non-carcinogen only. During wet season for non-carcinogenic risk, the hazard quotient ranged from $1x10^{-3}$ to $3.8x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level. During dry season for non-carcinogenic risk, the hazard quotient ranged from $1.5x10^{-4}$ to $1.7x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level.

For all year round, the hazard quotient ranged from $4.4x10^{-4}$ to $2.6x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The highest HQ was observed in well station number 6. The human health risk characterization of nickel contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.56 – 4.58.

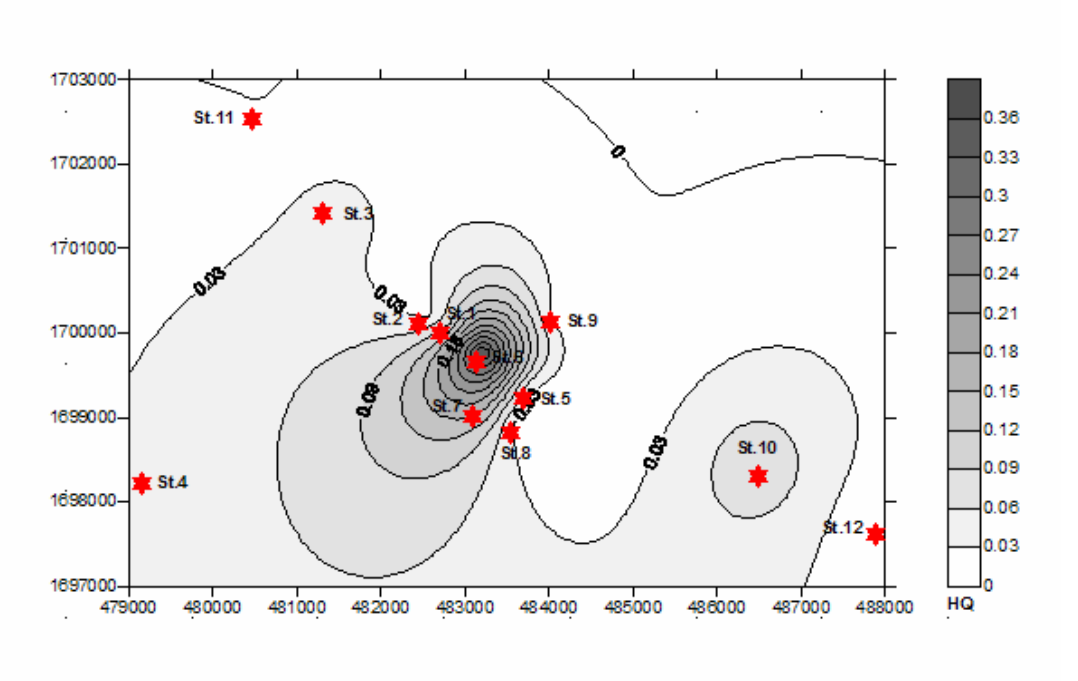

Figure 4.56 Non-carcinogenic risk map of nickel (Ni) at study area during wet season

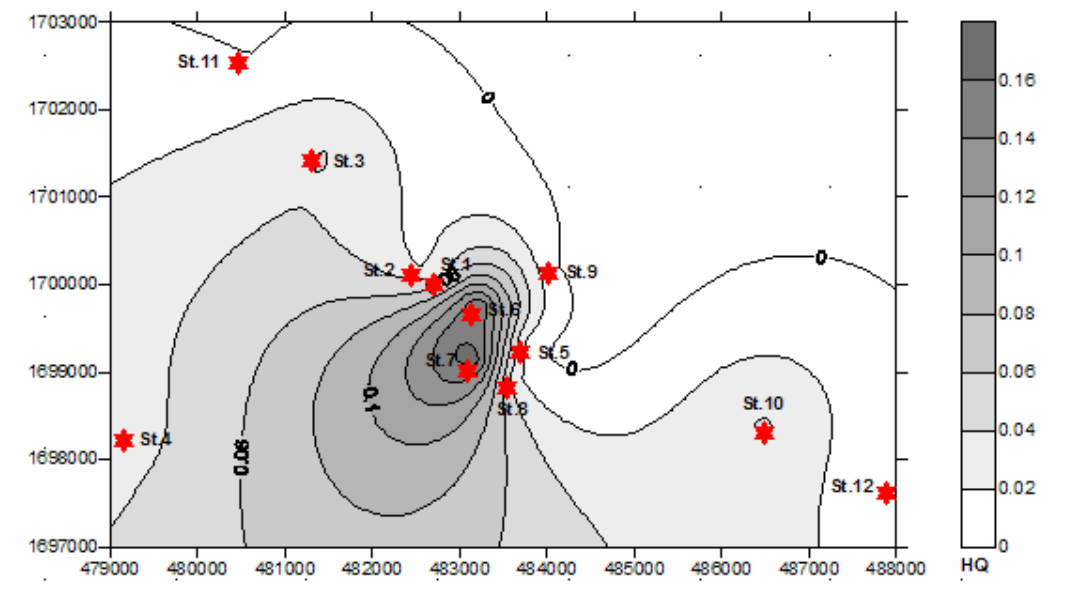

Figure 4.57 Non-carcinogenic risk map of nickel (Ni) at study area during dry season

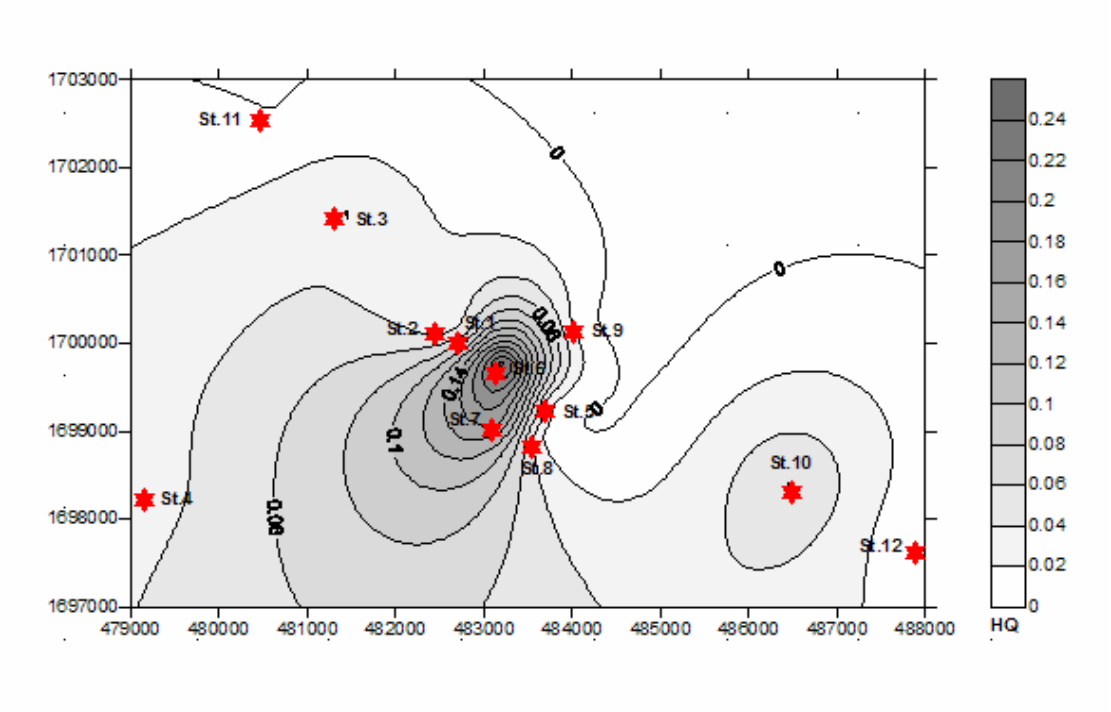

Figure 4.58 Non-carcinogenic risk map of nickel (Ni) at study area average all year round

4.3.8 Zinc (Zn)

The human health risk assessment of zinc contaminated in shallow groundwater was only non-carcinogenic risk. In addition, there were not reported for cancer risk of zinc. Also there had not report that zinc was carcinogen or not carcinogen, therefore no slope factor value.

According to non-carcinogenic risk, during wet season the hazard quotient ranged from $8x10^{-3}$ to 18.2. All hazard quotient were lower than one (HQ<1) and acceptable level except for station 7 that hazard quotient were higher than one (HQ>1) and non-carcinogenic risk.

During dry season for non-carcinogenic risk, the hazard quotient ranged from $8x10^{-3}$ to 3.73. All hazard quotient were lower than one (HQ<1) and acceptable level except station 8 that hazard quotient were higher than one (HQ>1) and non-carcinogenic effect.

For all year round, the hazard quotient ranged from 0.003-6.399. All hazard quotient were lower than one (HQ<1) and acceptable level except station number 7

and 8 that hazard quotient were higher than one (HQ>1) and non-carcinogenic risk. The highest HQ was observed in well station number 7. The human health risk characterization of zinc contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.7 and figure 4.59 – 4.61.

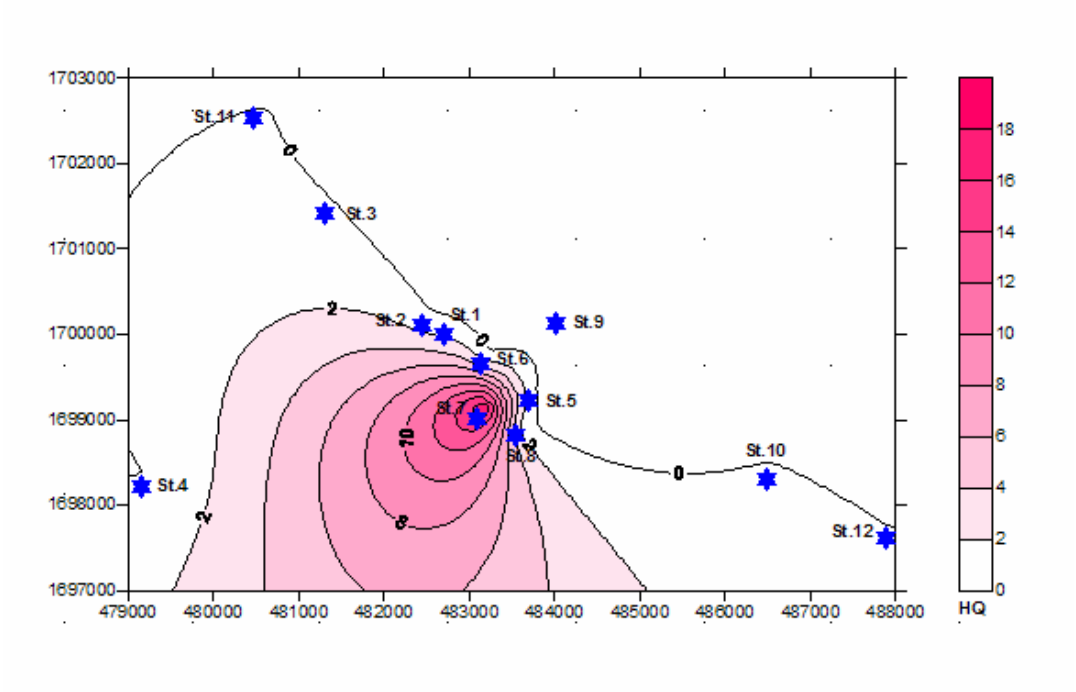

Figure 4.59 Non-carcinogenic risk map of zinc (Zn) at study area during wet season

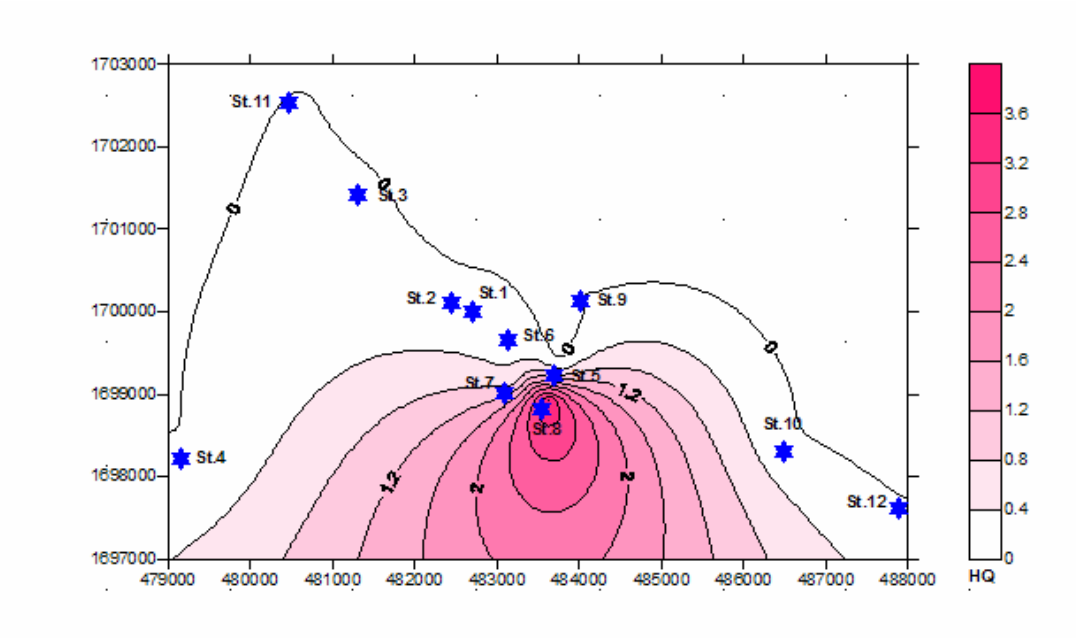

Figure 4.60 Non-carcinogenic risk map of zinc (Zn) at study area during dry season

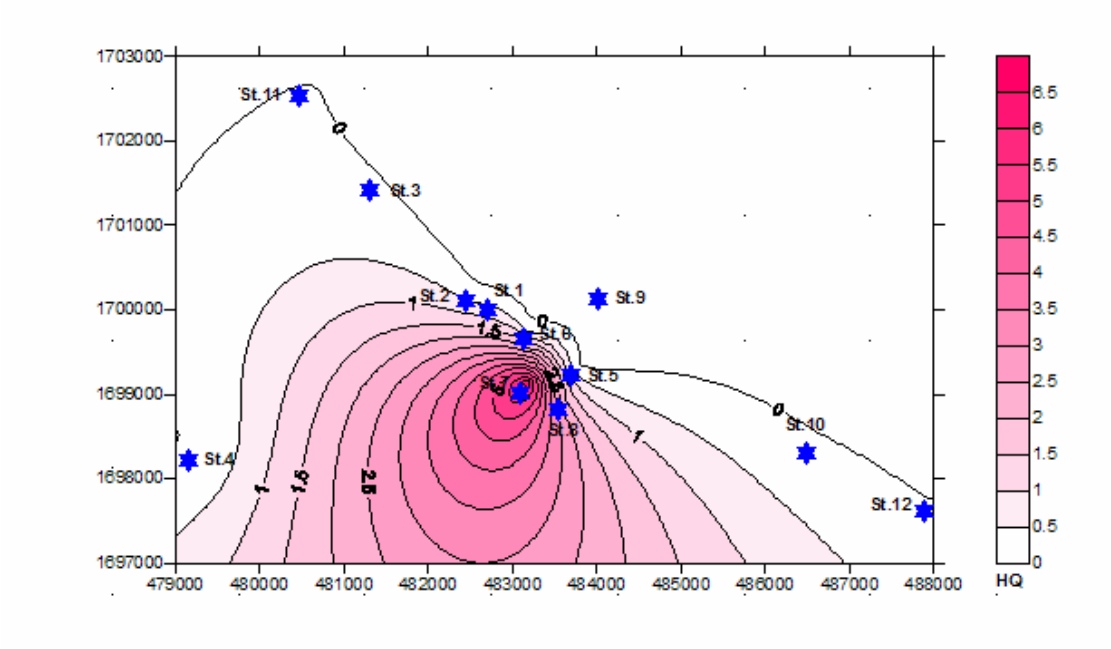

Figure 4.61 Non-carcinogenic risk map of zinc (Zn) at study area average all year round

Table 4.7 Non-Carcinogenic Risk (Hazard Quotient) of heavy metals during wet and dry season by location

Non-Carcinogenic Risk (HQ) of Heavy Metals Contaminated in Shallow Groundwater at Muang District, Ubon Rachatani Province, Thailand													
Time	**Metals**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**	**Station 9**	**Station 10**	**Station 11**	**Station 12**
Wet Season	As	5.99	4.22	5.84	1.77	0.93	12.07	9.13	85.44	1.39	1.18	687.5	2.86
	Cd	0.001	0.002	0.001	0.001	0.001	0.003	0.004	0.001	0.001	0.001	0.001	0.001
	Cr	1.8E-3	1.6E-4	1.0E-1	1.4E-4	1.6E-4	4.4E-4	4.7E-4	6.1E-3	4.4E-4	1.4E-4	4.3E-3	9.1E-3
	Cu	1.0E-2	1.3E-3	6.0E-5	3.4E-4	6.0E-5	1.1E-3	1.9E-1	9.4E-3	2.9E-4	1.0E-3	1.4E-4	1.4E-4
	Pb	3.5E-3	5.4E-4	3.0E-4	3.1E-4	3.7E-4	6.2E-3	5.1E-2	3.7E-3	9.0E-6	1.1E-3	4.2E-5	4.0E-6
	Hg	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4	2.0E-4
	Ni	8.3E-2	2.3E-2	4.0E-2	3.5E-2	3.2E-2	3.8E-1	1.7E-1	1.9E-2	1.6E-2	8.6E-2	1.0E-3	3.0E-3
	Zn	0.52	0.22	0.03	0.04	0.01	0.20	18.16	0.93	0.01	0.08	0.03	0.01
Dry Season	As	3.07	0.26	0.99	0.26	0.26	3.62	0.26	0.62	0.26	0.26	160.20	0.26
	Cd	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Cr	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3	1.4E-3
	Cu	1.1E-4	1.5E-4	7.8E-5	7.4E-5	4.4E-5	3.8E-4	1.4E-3	1.1E-2	1.0E-6	2.2E-4	9.8E-5	6.7E-5
	Pb	2.9E-3	1.0E-3	5.4E-4	4.1E-4	7.7E-4	3.5E-3	1.0E-2	5.9E-3	3.0E-6	8.8E-4	1.3E-5	1.0E-5
	Hg	6.5E-2	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4
	Ni	3.8E-2	1.9E-2	4.2E-2	3.3E-2	1.1E-2	1.6E-1	1.7E-1	2.9E-2	1.7E-3	4.2E-2	1.5E-4	1.1E-3
	Zn	0.157	0.066	0.026	0.016	0.034	0.181	0.636	3.725	0.001	0.063	0.011	0.008
All Year Round	As	4.34	1.69	2.86	0.82	0.57	7.23	3.18	25.14	0.72	0.67	378.45	1.18
	Cd	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001
	Cr	0.002	0.001	0.032	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.003	0.004
	Cu	3.0E-3	6.0E-4	7.1E-5	1.8E-4	5.3E-5	6.7E-4	5.5E-2	1.0E-2	7.8E-5	5.5E-4	1.2E-4	1.0E-4
	Pb	3.2E-3	7.6E-4	4.1E-4	3.6E-4	5.5E-4	4.7E-3	2.7E-2	4.7E-3	5.4E-6	9.9E-4	2.5E-5	6.6E-6
	Hg	1.8E-2	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4
	Ni	5.8E-2	2.1E-2	4.1E-2	3.4E-2	2.0E-2	2.6E-1	1.7E-1	2.4E-2	6.9E-3	6.2E-2	4.4E-4	1.9E-3
	Zn	0.310	0.132	0.028	0.025	0.018	0.188	6.399	2.097	0.003	0.071	0.021	0.011

4.4 The Human Health Risk Assessment from Heavy Metals Contaminated in Drinking Shallow Groundwater for Adult and aging participants

All human health risks from heavy metal contaminated in drinking shallow groundwater of adult participants were higher than all human health risks of aging participants at study area. According to human health risk assessment, the groundwater consumption or groundwater drinking rate were calculated. The drinking rate of adult was higher than aging because adult worked harder than aging during day in their farm. Consequently, the human health risks of adult were higher than the aging do.

4.4.1 Arsenic (As)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from 0.59 to 393.80. All hazard quotient were higher than one ($HQ \geq 1$) and adverse non-carcinogenic effects of concern excepted only well station number 4, 5, 9, 10 were lower than one ($HQ < 1$) and acceptable level. In addition, the cancer risk in adult of all well stations was acceptable level (cancer risk $\leq 10^{-6}$) except only well station number 11 was carcinogenic effect (cancer risk $> 10^{-6}$).

Aging participants for non-carcinogenic risk, the hazard quotient ranged from 0.43 to 284.11. All hazard quotient were higher than one ($HQ \geq 1$) and adverse non-carcinogenic effects of concern excepted only well station number 4, 5, 9, 10, 12 were lower than one ($HQ < 1$) and acceptable level. In addition, the cancer risk in aging of all well stations was acceptable level (cancer risk $\leq 10^{-6}$) except only well station number 11 was carcinogenic effect (cancer risk $> 10^{-6}$). The carcinogenic risk in adult and aging of arsenic contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.8 and figure 4.62. The non-carcinogenic risk in adult and aging of arsenic were showed in table 4.9 and figure 4.63.

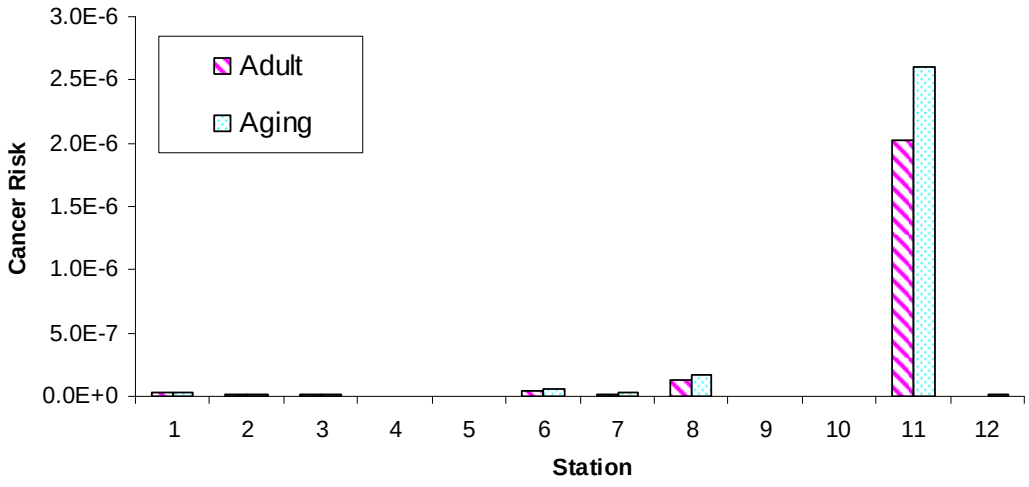

Figure 4.62 Carcinogenic risk of arsenic (As) in adult and aging

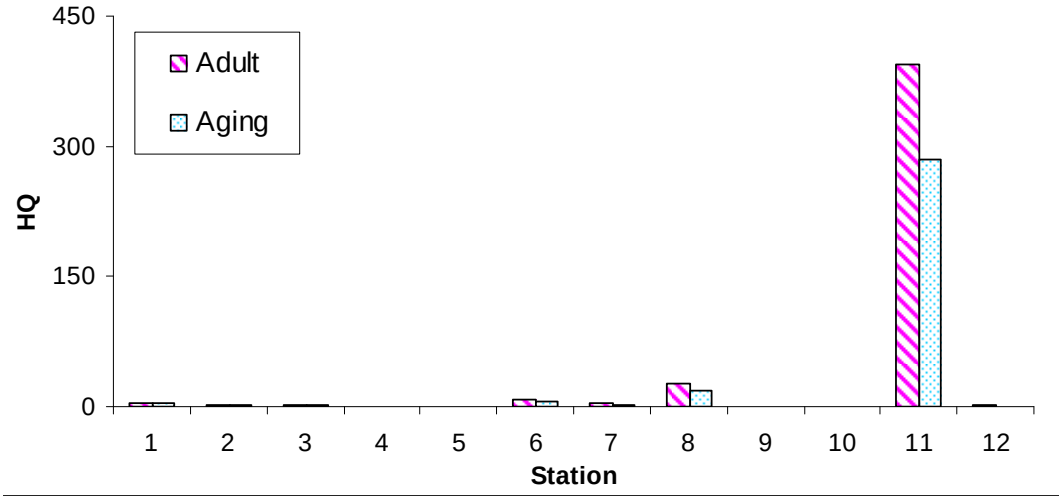

Figure 4.63 Non-carcinogenic risk of arsenic (As) in adult and aging

Table 4.8 Cancer Risk of arsenic for adult and aging by location

Cancer Risk of Arsenic Contaminated in Shallow Groundwater for Adult and Aging at Muang District, Ubon Rachatani Province, Thailand												
Group	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**	**Station 9**	**Station 10**	**Station 11**	**Station 12**
Adult	$0.023x10^{-6}$	$0.009x10^{-6}$	$0.015x10^{-6}$	$0.0044x10^{-6}$	$0.0031x10^{-6}$	$0.039x10^{-}$	$0.017x10^{-6}$	$0.13x10^{-6}$	$0.0038x10^{-6}$	$0.0036x10^{-6}$	$2x10^{-6}$	$0.0063x10^{-6}$
Aging	$0.03x10^{-6}$	$0.012x10^{-6}$	$0.02x10^{-6}$	$0.0057x10^{-6}$	$0.0039x10^{-6}$	$0.05x10^{-6}$	$0.022x10^{-6}$	$0.17x10^{-6}$	$0.0049x10^{-6}$	$0.0046x10^{-6}$	$2.6x10^{-6}$	$0.0082x10^{-6}$

4.4.2 Cadmium (Cd)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from $7.4x10^{-4}$ to $2.3x10^{-3}$. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from 0.001 to 0.002. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of cadmium contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.64.

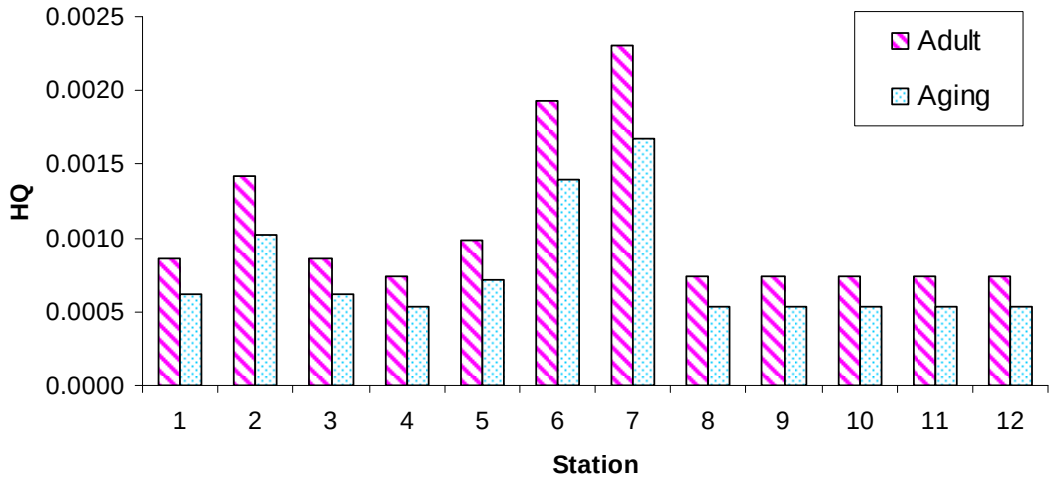

Figure 4.64 Non-carcinogenic risk of cadmium (Cd) in adult and aging

4.4.3 Chromium (Cr)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from 0.001-0.033. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from $4.4x10^{-4}$ to $2.4x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of chromium contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.65.

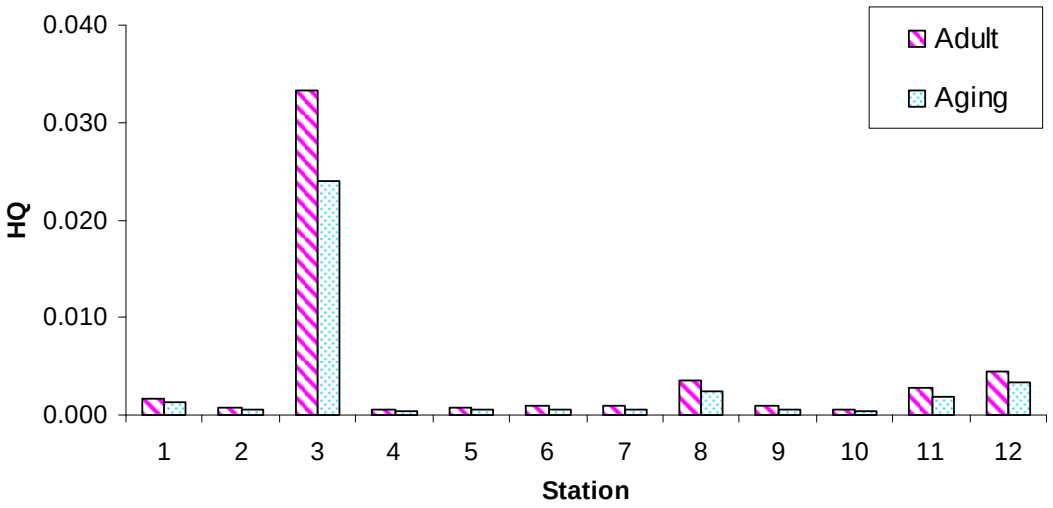

Figure 4.65 Non-carcinogenic risk of chromium (Cr) in adult and aging

4.4.4 Copper (Cu)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from $5.5x10^{-5}$ to $5.7x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from $4.0x10^{-5}$ to $4.1x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of copper contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.66.

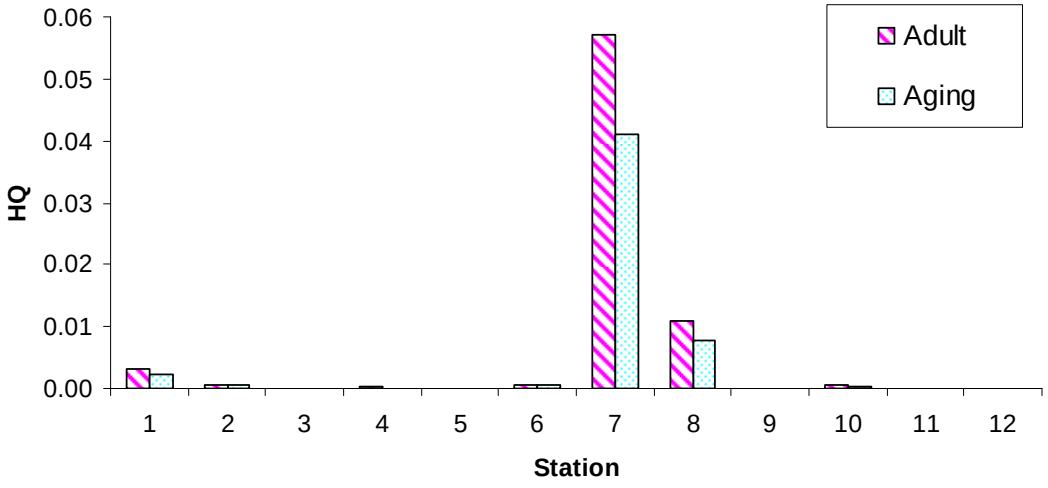

Figure 4.66 Non-carcinogenic risk of copper (Cu) in adult and aging

4.4.5 Lead (Pb)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from $5.6x10^{-6}$ to $2.8x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from $5.0x10^{-6}$ to $2.0x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of lead contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.67.

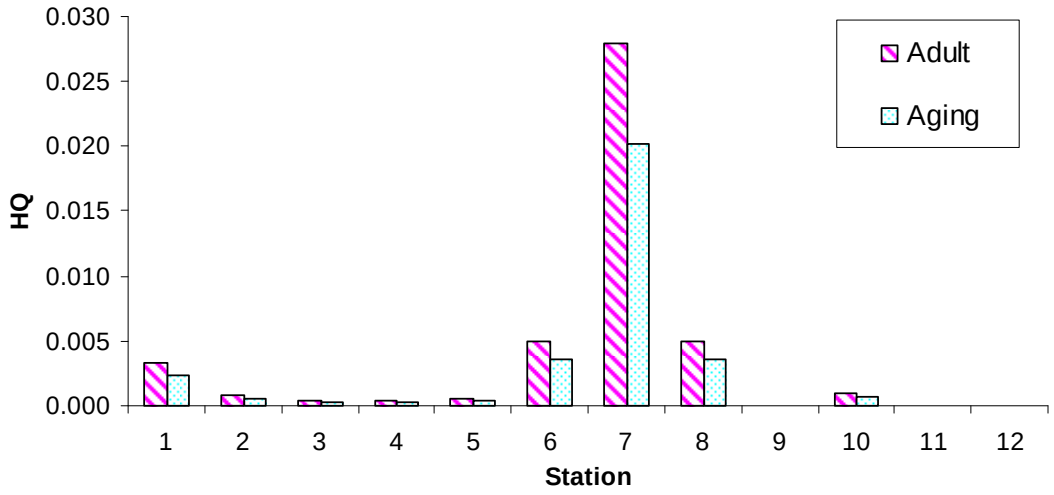

Figure 4.67 Non-carcinogenic risk of lead (Pb) in adult and aging

4.4.6 Mercury (Hg)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from $3x10^{-4}$ to $1.9x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from $1.9x10^{-4}$ to $1.4x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of mercury contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.68.

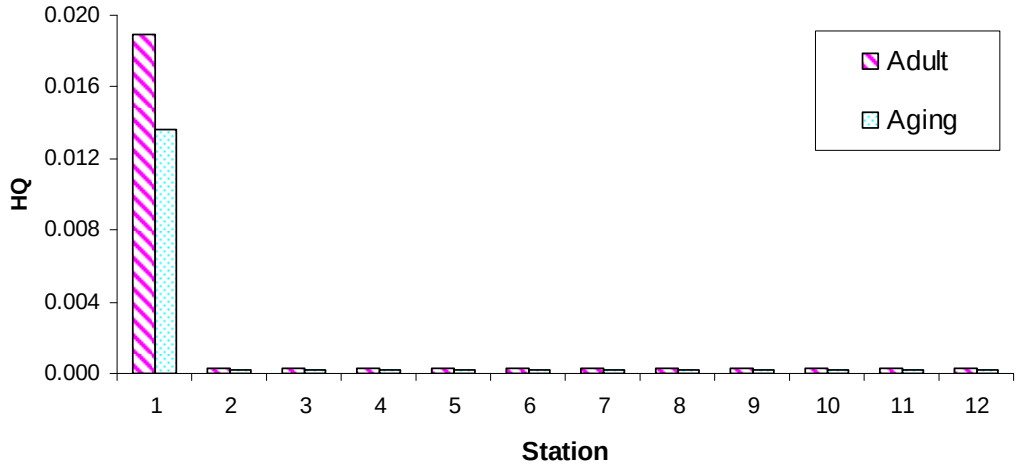

Figure 4.68 Non-carcinogenic risk of mercury (Hg) in adult and aging

4.4.7 Nickel (Ni)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from $4.6x10^{-4}$ to $2.7x10^{-2}$. All hazard quotient were lower than one (HQ<1) and acceptable level. Aging participants for non-carcinogenic risk, the hazard quotient ranged from $3.3x10^{-4}$ to $1.9x10^{-1}$. All hazard quotient were lower than one (HQ<1) and acceptable level. The non-carcinogenic risk in adult and aging of nickel contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.69.

The comparison of human health risk assessment of nickel at study area between adult and aging participants, T-test showed that the difference of non-carcinogenic risk between adult and aging participants was not statistical significance (p>0.05).

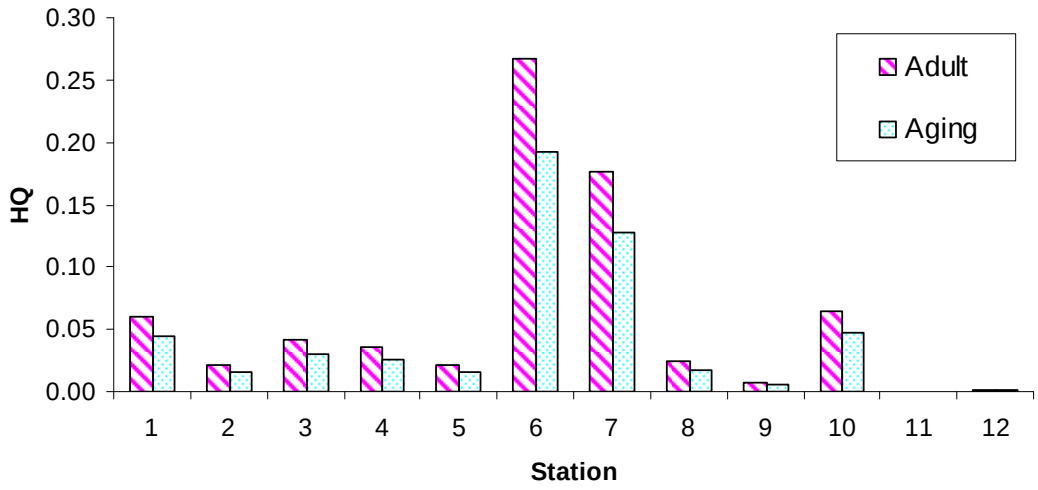

Figure 4.69 Non-carcinogenic risk of nickel (Ni) in adult and aging

4.4.8 Zinc (Zn)

Adult participants for non-carcinogenic risk, the hazard quotient ranged from 0.003-6.399. All hazard quotient were lower than one (HQ<1) and acceptable level except station number 7 and 8 that hazard quotient were higher than one (HQ>1) and non-carcinogenic risk.

Aging participants for non-carcinogenic risk, the hazard quotient ranged from 0.003 to 4.8. All hazard quotient were lower than one (HQ<1) and acceptable level except station number 7 and 8 that hazard quotient were higher than one (HQ>1) and non-carcinogenic risk. The non-carcinogenic risk in adult and aging of zinc contaminated in drinking shallow groundwater wells at Ubon Ratchathani province were showed in table 4.9 and figure 4.70.

The comparison of human health risk assessment of zinc at study area between adult and aging participants, T-test showed that the difference of non-carcinogenic risk between adult and aging participants was not statistical significance (p>0.05).

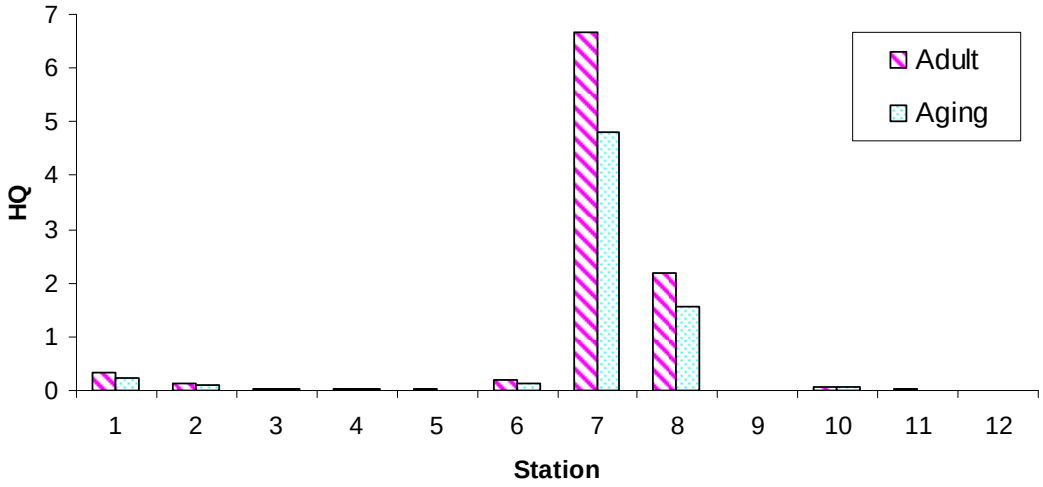

Figure 4.70 Non-carcinogenic risk of zinc (Zn) in adult and aging

All non-carcinogenic risks of all heavy metals in adult were higher than all non-carcinogenic risk in aging because of their different drinking or intake rates. Intake rate of adult were higher amount than that of aging. In addition, adult worked harder than aging for agriculture during day so adult needed to drink water much more than aging do.

Interestingly, cancer risk of aging, however, was higher than adult. Although intake rate of adult was higher than that of aging, but the exposure duration (ED) or ages of aging was higher than that of adult. The cancer risk assessment had to use exposure duration (ED) to be calculated which different from non-cancer risk assessment. As mentioned above, that why the cancer risk of aging was higher than adult.

Table 4.9 Non-Carcinogenic Risk (Hazard Quotient) of heavy metals for adult and aging by location

Non-Carcinogenic Risk (HQ) of Heavy Metals Contaminated in Shallow Groundwater at Muang District, Ubon Rachatani Province, Thailand													
Group	**Metals**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**	**Station 9**	**Station 10**	**Station 11**	**Station 12**
Adult	As	4.52	1.76	2.98	0.85	0.59	7.52	3.31	26.17	0.74	0.69	393.80	1.23
	Cd	8.6E-4	1.4E-3	8.6E-4	7.4E-4	9.8E-4	1.9E-3	2.3E-3	7.4E-4	7.4E-4	7.4E-4	7.4E-4	7.4E-4
	Cr	1.7E-3	6.6E-4	3.3E-2	6.1E-4	6.6E-4	8.9E-4	8.9E-4	3.5E-3	8.9E-4	6.1E-4	2.7E-3	4.5E-3
	Cu	3.2E-3	6.2E-4	7.0E-5	1.9E-4	5.0E-5	7.0E-4	5.7E-2	1.1E-2	8.0E-5	5.7E-4	1.2E-4	1.0E-4
	Pb	3.3E-3	7.9E-4	4.3E-4	3.7E-4	5.7E-4	4.9E-3	2.8E-2	4.9E-3	1.0E-5	1.0E-3	3.0E-5	1.0E-5
	Hg	1.9E-2	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4	2.6E-4
	Ni	6.1E-2	2.2E-2	4.2E-2	3.6E-2	2.1E-2	2.7E-1	1.8E-1	2.5E-2	7.2E-3	6.5E-2	4.6E-4	2.0E-3
	Zn	0.323	0.138	0.029	0.026	0.019	0.196	6.658	2.182	0.004	0.074	0.022	0.011
Aging	As	3.26	1.27	2.15	0.62	0.43	5.43	2.38	18.88	0.54	0.50	284.11	0.89
	Cd	6.2E-4	1.0E-3	6.2E-4	5.3E-4	7.1E-4	1.4E-3	1.7E-3	5.3E-4	5.3E-4	5.3E-4	5.3E-4	5.3E-4
	Cr	1.2E-3	4.7E-4	2.4E-2	4.4E-4	4.7E-4	6.4E-4	6.4E-4	2.5E-3	6.4E-4	4.4E-4	2.0E-3	3.3E-3
	Cu	2.3E-3	4.5E-4	5.0E-5	1.4E-4	4.0E-5	5.1E-4	4.1E-2	7.8E-3	6.0E-5	4.1E-4	9.0E-5	8.0E-5
	Pb	2.4E-3	5.7E-4	3.1E-4	2.7E-4	4.1E-4	3.6E-3	2.0E-2	3.6E-3	4.0E-6	7.4E-4	1.9E-5	5.0E-6
	Hg	1.4E-2	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4
	Ni	4.4E-2	1.6E-2	3.0E-2	2.6E-2	1.5E-2	1.9E-1	1.3E-1	1.8E-2	5.2E-3	4.7E-2	3.3E-4	1.4E-3
	Zn	0.233	0.099	0.021	0.019	0.014	0.141	4.804	1.574	0.003	0.053	0.016	0.008

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The results of properties of shallow groundwater at Muang district, UbonRatchathani province, Thailand showed that the average pH value was 4.72 $\pm$ 1.00. The average groundwater level was 124.95 $\pm$ 5.17 m. (MSL). The average all year round conductivity was 232.43 $\pm$ 9.92 µS/cm. The average wells depth was 2.85 $\pm$ 0.79 m.

The results of heavy metals concentrations for all year round showed that the average concentration of arsenic was 1.06 $\pm$ 1.74 µg/L. The average concentration of cadmium was 0.15 $\pm$ 0.03 µg/L. The average concentration of chromium was 0.58 $\pm$ 0.52 µg/L. The average concentration of copper was 60.26 $\pm$ 90.98 µg/L. The average concentration of lead was 16.66 $\pm$ 18.52 µg/L. The average concentration of mercury was 0.10$\pm$0.13 µg/L. The average concentration of nickel was 6.13 $\pm$ 4.38 µg/L. The average concentration of zinc was 63.43 $\pm$ 87.75 µg/L.

For human health risk assessment from drinking shallow groundwater in this area, the results showed that all heavy metals (As, Cd, Cr, Cu, Hg, Pb, Ni Zn) contamination were acceptable level for non-carcinogen which had the hazard quotient value lower than one (HQ<1) except arsenic and zinc that their hazard quotient were higher than one (HQ$\geq$1) and adverse non-carcinogenic effects of concern. Therefore, local people who drinking shallow groundwater at Ubon Ratchathani province might get diseases from arsenic and zinc toxicity.

For carcinogenic effect, the results showed that cancer risk from arsenic contamination was higher than the acceptable level (cancer risk$\geq 10^{-6}$) and carcinogenic effects of concern. Therefore, local people who drinking shallow groundwater at Ubon Ratchathani province might be cancer from arsenic toxicity.

5.2 Recommendation

This study shows that shallow groundwater at Muang district, Ubon Ratchathani province, Thailand had high heavy metals contamination to pose human health effect. Moreover, local people who generally drinking groundwater in this area could be get carcinogenic effect or cancer from heavy metals contamination. Moreover, there were not significant different concentration of heavy metals and health risk between wet and dry season. Therefore, local people who generally drinking groundwater in this area might get health effect for all time. This study can be beneficially used and applied for risk communication to local people who generally drinking shallow groundwater. Risk communication may continue to prevent the adverse human health effect on local people at Muang district, Ubon Ratchathani province, Thailand

REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR).2005.U.S. Department of Health and Human Services [Online]. Available from: URL: http://www.atsdr.cdc.gov/ [2010, October 1]

Claesson M. and Fagerberg J. Arsenic in groundwater of Santiago del Estero, Argentina. Minor Field Studies Scholarship Programme, MFS. Swedish International Development Cooperation Agency, Sida /Asdi, 2003

Dupler, D. Heavy metal poisoning. Gale Encyclopedia of Alternative Medicine 2001. Farmington Hills, MI: Gale Group.

Eck, P. and Wilson, L., Toxic Metals in Human Health and Disease, Eck Institute of Applied Nutrition and Bioenergetics, Ltd., Phoenix, AZ, 1989.

EU. EU's drinking water standards [Online]. 1998. Available from: http://www.lenntech.com/applications/drinking/standards/eu-s-drinking-water-standards.htm [2011, April]

Evens Emmanuel, Marie Gisèle Pierre, Yves Perrodin. Groundwater contamination by microbiological and chemical substances released from hospital wastewater: Health risk assessment for drinking water consumers. Environment International 35 (2009) 718–726

Ferner, D.J. Toxicity, heavy metals. eMed. J. 2001 May 25; 2(5): 1.

Glanze, W.D. Mosby Medical Encyclopedia, Revised Edition 1996. St. Louis, MO: C.V. Mosby.

Hye-Sook Lim, Jin-Soo Lee, Hyo-Taek Chon, Manfred Sager. Heavy metal contamination and health risk assessment in the vicinity of the abandoned Songcheon Au–Ag mine in Korea. School of Civil, Urban and Geosystem Engineering, College of Engineering, Seoul National University, Seoul 151-744. Journal of Geochemical Exploration 96 (2008) 223–230

International Occupational Safety and Health Information Centre. Metals. In Basics of Chemical Safety, Chapter 7, 1999 Sep. Geneva: International Labour Organization.

Jaipieam S., et al. Organophosphate Pesticide Residues in Drinking Water from Artesian Wells and Health Risk Assessment of Agricultural Communities, Thailand. Human and Ecological Risk Assessment: An International Journal 15, 6 (2009): 1304 - 16.

Jeyaruba and Thushyanthy.The effect of agriculture on quality of groundwater. Environment International, 2009. 110-114.

Lide, D. CRC Handbook of Chemistry and Physics, 73rd Edition 1992. Boca Raton, FL: CRC Press.

Limpakanwech C. Sorption and modeling transport of Chlorpyrifos through shallow groundwater aquifer in an agricultural area: a case study of Hua Rua area, Changwat Ubon Ratchathani. Bachelor's degree report, Geology, Faculty of Science, Chulalongkorn University, 2009.

Marcovecchio, J.E., S.E. Botte and R.H. Freije, 2007. Heavy Metals, Major Metals, Trace Elements. In: Handbook of Water Analysis. L.M. Nollet, (Ed.). 2nd Edn. London: CRC Press, pp: 275-311.

McMurry, J. and R.C. Fay, 2004. Hydrogen, Oxygen and Water. In: McMurry Fay Chemistry. K.P. Hamann, (Ed.). 4th Edn. New Jersey: Pearson Education, pp: 575-599.

Mendie, U., 2005. The Nature of Water. In: The Theory and Practice of Clean Water Production for Domestic and Industrial Use. Lagos: Lacto-Medals Publishers, pp: 1-21.

M.A. Momodu and C.A. Anyakora. Heavy Metal Contamination of Ground Water: The Surulere Case Study. Department of Pharmaceutical Chemistry, Faculty of Pharmacy, University of Lagos, Nigeria, 2009.

Naoto Takeno. Atlas of Eh-pH diagrams. Intercomparison of thermodynamic databases, National Institute of Advanced Industrial Science and Technology Research Center for Deep Geological Environments, Geological Survey of Japan Open File Report No.419, 2005.

Natural Healing Site. Heavy Metal Toxicity [Online]. 2010. Available from: http://www.tuberose.com [2010,August]

Nouri J., et al. Investigation of Heavy Metals in Groundwater. Department of environmental health engineering, center for environmental research, school of public health, Tehran University of Medical Sciences, Tehran, Iran, 2006.

Pollution Control Department, Ministry of Natural Resources and Environment. Ground. Groundwater Standards for Drinking Proposes. Manual inspection of contaminated groundwater from waste disposal facilities 35 (2000): 33

Rattan R.K., et al. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agriculture, Ecosystems and Environment 109 (2005): 310–322

Roberts, J.R. Metal toxicity in children. In Training Manual on Pediatric Environmental Health: Putting It into Practice 1999 Jun. Emeryville, CA: Children's Environmental Health Network.

Robson, G.M. and Ellerbusch, F. 2007. Introduction to risk assessment in public health. Robson, G.M. and Toscano, A.W., Risk Assessment for environmental Health, 31-53. United States of America: John Willey & Son,

Siriwong, W. Organophosphate Pesticide Residues in Aquatic Ecosystem and Health Risk Assessment of Local Agriculture Community. Doctoral dissertation, Program in Environmental Management (Interdisciplinary Programs), Graduate School. Chulalongkorn University, 2006.

Srithongdee T. Distribution of pesticide and nitrate concentrations in a shallow groundwater aquifer in an agricultural area: a case study of Hua Rua Area, Changwat Ubon Ratchatani. Bachelor's degree report, Geology, Faculty of Science, Chulalongkorn University, 2009.

Stanislav Rapant, Katarína Krčmová. Health risk assessment maps for arsenic groundwater content: application of national geochemical databases. Environ Geochem Health (2007) 29:131–141

Suesat S. Distribution and potential mobility of heavy metals in soil and shallow groundwater aquifer in an agricultural area: a case study of Hua Rua area, Changwat Ubon Ratchathani. Bachelor's degree report, Geology, Faculty of Science, Chulalongkorn University, 2010.

United States Environmental Protection Agency (US EPA). 2000b. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 2: Risk Assessment and Fish Consumption Limits – Third Edition. [online]. Available from: URL: http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/risk/upload/2009_04_23_fish_advice_volume2_v2cover.pdf. [October 1, 2010]

US EPA. Definitions and General Principles for Exposure Assessment: Guidelines for Exposure Assessment. Washington D.C: Office of Pesticide Programs, USA, 1992.

US EPA. Guidance for Performing Aggregate Exposure and Risk Assessment. Washington D.C: Office of Pesticide Programs, 1999a.

Vanloon, G.W. and S.J. Duffy, 2005. The Hydrosphere. In: Environmental Chemistry: A Global Perspective. 2nd Edn. New York: Oxford University Press, pp: 197-211.

Vodela, J.K., J.A. Renden, S.D. Lenz, W.H. Mchel Henney and B.W. Kemppainen, 1997. Drinking water contaminants. Poult. Sci., 76: 1474-1492.

WHO. WHO's drinking water standards [Online]. 1993**.** Available from: http://www.lenntech.com/applications/drinking/standards/who-s-drinking-water-standards.htm [2011, April]

WHO. Health Topic Aging [Online]. 2011. Available from: http://www.who.int/topics/ageing/en/ [2011, March]

WHO. Aluminum. In Guidelines for Drinking-Water Quality, Second Edition, Addendum to Volume 2, Health Criteria and Other Supporting Information 1998, pp. 3-13. Geneva: World Health Organization.

WHO, Water for Pharmaceutical Use. In: Quality Assurance of Pharmaceuticals: A Compendium of Guidelines and Related Materials. 2nd Updated Edn. World Health Organisation, Geneva, (2007) 2: 170-187.

Williamson D.R., Peck A.J. and Turner J.V., S.Arunin. Groundwater hydrology and salinity in a valley in Northeast Thailand. Groundwater Contamination (Proceedings of the Symposium held during the Third IAHS Scientific Assembly, Baltimore, MD, May 1989), IAHS Publ. no. 185, 1989.

Yang Q.W., et al. Cadmium in soil–rice system and health risk associated with the use of untreated mining wastewater for irrigation in Lechang, China. Agricultural water management 84 (2006): 147–152.

APPENDICES

Appendix A Face-to-Face Questionnaire

Interviewer name_____. Questionnaire no. _____ (____/____/____)

Center of Excellence for Environmental and Hazardous Waste Management
Chulalongkorn University

National Center of Exellence for Environmental and Hazardous Waste Management

---

Questionnaire for drinking shallow groundwater in agricultural area at Ubon Ratchathani Province, Thailand

Please answer the questions in the blanks provided and/or add a ✓ in the circle.

1. Name-Surname _____

2. Address: _____

3. Gender O Male O Female

4. What is your highest level of education?

O Elementary education O Secondary education
O Diploma O Bachelor's degree

5. Age_____ years

6. Body weight _____kg

7. What is your main occupation?

O Government official O Officer
O Business O Agriculturist
O Student O Employee
O Unemployed O Other _____

8. Do you drinking shallow groundwater?

O Yes, always.
O Yes, sometimes.
O No.

9. If you are always drinking shallow groundwater, how much you drink per day?

_____ liters per day

ชื่อผู้สัมภาษณ์_____ แบบสอบถามเลขที่ _____(____/____/____)

ศูนย์ความเป็นเลิศด้านการจัดการสิ่งแวดล้อมและของเสียอันตราย
จุฬาลงกรณ์มหาวิทยาลัย

National Center of Excellence for Environmental and Hazardous Waste Management

---

แบบสอบถาม การบริโภคน้ำใต้ดินของประชากรในพื้นที่เกษตรกรรม ต.หัวเรือ อ.เมือง จ. อุบลราชธานี ประเทศไทย

กรุณาตอบคาถาม และ/หรือ ทำเครื่องหมาย ✓ ลงในช่องที่กำหนด

1. ชื่อ-นามสกุล _____

2. ที่อยู่ _____

3. เพศ O ชาย O หญิง

4. ระดับการศึกษาสูงสุด

O ประถมศึกษาหรือต่ำกว่า O มัธยมศึกษาหรือเทียบเท่า

O อนุปริญญาหรือเทียบเท่า O ปริญญาตรีหรือสูงกว่า

5. อายุ _____ ปี

6. น้ำหนัก _____ กิโลกรัม

7. ประกอบอาชีพ

O รับราชการ/รัฐวิสาหกิจ O พนักงานเอกชน

O ค้าขาย/ธุรกิจส่วนตัว O เกษตรกรรม

O นักเรียน/นักศึกษา O รับจ้าง

O ว่างงาน O อื่นๆ _____

8. บริโภคน้ำใต้ดินจากบ่อน้ำบาดาลหรือไม่

O บริโภคเป็นประจำ O บริโภคแต่ไม่บริโภคเป็นประจำ O ไม่บริโภคเลย

9. หากบริโภคเป็นประจำ โปรดระบุปริมาณที่บริโภค_____ลิตรต่อวัน

Appendix B Properties of Shallow Groundwater

Table B.1 The pH values of shallow groundwater at Muang district, UbonRatchathani province, Thailand

Station	Wet Season			Dry Season			Ave. All Year Round	pH Standards for Drinking
	June, 2010	August, 2010	Average	November, 2010	January, 2011	Average		
1	4.05	3.80	3.93 ± 0.18	4.12	3.90	4.01 ± 0.16	3.97 ± 0.14	(Pollution Control Department, 2008)
2	3.97	4.06	4.02 ± 0.06	4.10	3.95	4.03 ± 0.11	4.02 ± 0.07	
3	4.30	4.05	4.18 ± 0.18	4.33	5.14	4.74 ± 0.57	4.46 ± 0.47	
4	3.90	4.61	4.26 ± 0.50	4.62	4.65	4.64 ± 0.02	4.45 ± 0.36	
5	4.13	4.26	4.20 ± 0.09	4.95	5.85	5.40 ± 0.64	4.80 ± 0.79	
6	3.69	5.51	4.60 ± 1.29	4.34	4.04	4.19 ± 0.21	4.40 ± 0.49	
7	3.89	4.71	4.30 ± 0.58	4.01	4.46	4.24 ± 0.32	4.27 ± 0.38	
8	4.15	5.20	4.68 ± 0.74	4.16	4.26	4.21 ± 0.07	4.44 + 0.51	
9	4.39	4.89	4.64 ± 0.35	4.74	4.70	4.72 ± 0.03	4.68 ± 0.21	
10	4.05	4.29	4.17 ± 0.17	4.19	5.03	4.61 ± 0.59	4.39 ± 0.44	
11	6.59	7.90	7.25 ± 0.93	9.33	7.25	8.29 ± 1.47	7.77 ± 1.17	
12	4.60	4.87	4.74 ± 0.19	5.23	5.25	5.24 ± 0.01	4.99 ± 0.31	
Mean.			4.78 ± 1.14			4.65 ± 0.57	4.72 ± 1.00	6.5-9.2

Table B.2 The shallow groundwater level at Muang district, UbonRatchathani province, Thailand

Station	Shallow Groundwater Level (m. MSL)					
	Wet Season			Dry Season		
	June, 2010	August, 2010	Average	November, 2010	January, 2011	Average
1	123.75	124.00	123.88 ± 0.18	126.50	125.00	125.75 ± 1.06
2	123.30	123.50	123.40 ± 0.14	125.00	123.99	124.50 ± 0.71
3	125.90	125.80	125.85 ± 0.07	127.50	126.10	126.80 ± 0.99
4	119.10	121.25	120.18 ± 1.52	120.10	119.40	119.75 ± 0.49
5	125.30	125.50	125.40 ± 0.14	126.50	126.00	126.25 ± 0.35
6	122.95	121.95	122.45 ± 0.71	124.20	123.12	123.66 ± 0.76
7	128.40	127.00	127.70 ± 0.99	129.00	128.88	128.94 ± 0.08
8	127.80	129.00	128.40 ± 0.85	130.00	127.74	128.87 ± 1.60
9	127.50	127.25	127.38 ± 0.18	128.00	127.40	127.70 ± 0.42
10	121.20	121.50	121.35 ± 0.21	122.20	121.50	121.85 ± 0.49
11	132.10	133.00	132.55 ± 0.64	133.20	132.20	132.70 ± 0.71
12	112.00	111.15	111.58 ± 0.60	113.00	112.32	112.66 ± 0.48
Mean.			124.18 ± 5.23			124.95 ± 5.17

Table B.3 Conductivity of shallow groundwater at Muang district, UbonRatchathani province, Thailand

Conductivity of shallow groundwater (µS/cm)							
St.	**June, 2010**	**August, 2010**	**Ave. Wet**	**November, 2010**	**January, 2011**	**Ave. Dry**	**All Year Round**
1	174.00	218.40	196.20 ± 31.40	209.00	202.00	205.50 + 4.95	200.85 + 19.12
2	98.20	156.70	127.45 ± 41.37	105.60	116.00	110.8 + 7.35	119.13 +26.09
3	236.00	272.00	254.00 ± 25.46	352.00	246.00	299.00 + 74.95	276.50 + 52.57
4	78.00	92.00	85.00 ± 9.90	89.90	101.60	95.75 + 8.27	90.38 + 9.70
5	87.50	82.60	85.05 ± 3.46	90.40	94.60	92.50 + 2.97	88.78 + 5.04
6	171.80	247.20	209.50 ± 53.32	185.50	173.60	179.55 + 8.41	194.53 + 35.64
7	206.80	265.00	235.90 ± 41.15	215.00	232.00	223.50 + 12.02	229.70 + 25.77
8	119.20	75.40	97.30 ± 30.97	83.70	77.70	80.70 + 4.24	89.00 + 20.44
9	57.50	68.00	62.75 ± 7.42	50.90	59.00	54.95 + 5.73	58.85 + 7.04
10	129.80	152.40	141.10 ± 15.98	157.50	261.00	209.25 + 73.19	175.18 + 58.47
11	994.00	1215.00	1104.50 ± 156.27	1425.00	1015.00	1220.00 + 289.91	1162.25 + 201.5
12	94.70	117.80	106.25 ± 16.33	94.70	108.90	101.80 + 10.04	104.03 + 11.36
Ave.			225.42 + 284.13			239.44 + 317.36	232.43 + 9.92

Table B.4 Well depths of shallow groundwater at Muang district, UbonRatchathani province, Thailand

St.	June, 2010	August, 2010	Wet Season (m)	November, 2010	January, 2011	Dry Season (m)	All Year Round (m)
1	4.25	4.00	4.13 ± 0.18	1.50	3.00	2.25 ± 1.06	3.19 ± 1.33
2	3.70	3.50	3.60 ± 0.14	2.00	3.01	2.51 ± 0.71	3.06 ± 0.77
3	3.10	3.20	3.15 ± 0.07	1.50	2.90	2.20 ± 0.99	2.68 ± 0.67
4	2.90	0.75	1.83 ± 1.52	1.90	2.60	2.25 ± 0.49	2.04 ± 0.30
5	2.70	2.50	2.60 ± 0.14	1.50	2.00	1.75 ± 0.35	2.18 ± 0.60
6	3.05	4.05	3.55 ± 0.71	1.80	2.88	2.34 ± 0.76	2.95 ± 0.86
7	2.60	4.00	3.30 ± 0.99	2.00	2.12	2.06 ± 0.08	2.68 ± 0.88
8	4.20	3.00	3.60 ± 0.85	2.00	4.26	3.13 ± 1.60	3.37 ± 0.33
9	2.50	2.75	2.63 ± 0.18	2.00	2.60	2.30 ± 0.42	2.47 ± 0.23
10	2.80	2.50	2.65 ± 0.21	1.80	2.50	2.15 ± 0.49	2.4 ± 0.35
11	4.90	4.00	4.45 ± 0.64	3.80	4.80	4.30 ± 0.71	4.38 ± 0.11
12	3.00	3.85	3.43 ± 0.60	2.00	2.68	2.34 ± 0.48	2.89 ± 0.77
Ave.			3.24 ± 0.73			2.46 ± 0.66	2.85 ± 0.79

Appendix C Concentrations of Heavy Metals

Table C.1 The concentrations of arsenic in shallow groundwater wells located in vicinity agricultural areas

Station	As (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	1.050	0.572	0.81 ± 0.34	0.510	0.640	0.58 ± 0.09	0.69 ± 0.16
2	0.991	0.373	0.68 ± 0.44	<0.17**	<0.17**	0.17 ± 0.00	0.43 ± 0.36
3	0.783	0.815	0.80 ± 0.02	0.490	<0.17**	0.33 ± 0.22	0.56 ± 0.33
4	0.639	0.237	0.44 ± 0.28	<0.17**	<0.17**	0.17 ± 0.00	0.30 ± 0.19
5	<0.22*	0.425	0.32 ± 0.02	<0.17**	<0.17**	0.17 ± 0.00	0.25 ± 0.11
6	1.170	1.120	1.15 ± 0.04	0.580	<0.17**	0.63 ± 0.07	0.89 ± 0.36
7	1.260	0.744	1.00 ± 0.36	<0.17**	<0.17**	0.17 ± 0.00	0.59 ± 0.59
8	0.326	5.80	3.06 ± 3.87	<0.17**	0.350	0.26 ± 0.13	1.66 ± 1.98
9	0.218	0.570	0.39 ± 0.25	<0.17**	<0.17**	0.17 ± 0.00	0.28 ± 0.16
10	0.410	0.311	0.36 ± 0.07	<0.17**	<0.17**	0.17 ± 0.00	0.27 ± 0.13
11	8.380	8.980	8.68 ± 0.42	5.870	2.510	4.19 ± 2.38	6.44 ± 3.17
12	0.481	0.637	0.56 ± 0.11	<0.17**	<0.17**	0.17 ± 0.00	0.36 ± 0.28
Mean.			1.52 ± 2.37			0.60 ± 1.14	1.06 ± 1.74

*Detection Limit of ICP-MS analysis during wet season was 0.22 µg/L
**Detection Limit of ICP-MS analysis during dry season was 0.17 µg/L
*,**Calculated at detection limit.

Table C.2 The concentrations of cadmium in shallow groundwater wells located in vicinity agricultural areas

Station	Cd (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	0.138	<0.13*	0.13 ± 0.01	<0.13*	0.14	0.14 ± 0.01	0.14 ± 0.01
2	0.313	<0.13*	0.22 ± 0.13	<0.13*	<0.13*	0.13 ± 0.00	0.18 ± 0.06
3	<0.13*	<0.13*	0.13 ± 0.00	0.14	<0.13*	0.14 ± 0.01	0.14 ± 0.01
4	<0.13*	<0.13*	0.13 ± 0.00	0.13	<0.13*	0.13 ± 0.00	0.13 ± 0.00
5	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	0.20	0.16 ± 0.05	0.15 ± 0.02
6	0.284	0.207	0.25 ± 0.05	0.17	0.17	0.17 ± 0.00	0.21 ± 0.06
7	0.461	0.157	0.31 ± 0.21	<0.13*	0.15	0.14 ± 0.01	0.23 ± 0.12
8	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	<0.13*	0.13 ± 0.00	0.13 ± 0.00
9	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	<0.13*	0.13 ± 0.00	0.13 ± 0.00
10	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	<0.13*	0.13 ± 0.00	0.13 ± 0.00
11	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	<0.13*	0.13 ± 0.00	0.13 ± 0.00
12	<0.13*	<0.13*	0.13 ± 0.00	<0.13*	<0.13*	0.13 ± 0.00	0.13 ± 0.00
Mean.			0.16 ± 0.06			0.14 ± 0.01	0.15 ± 0.03

*Detection Limit of ICP-MS analysis during wet and dry season was 0.13 µg/L
*,**Calculated at detection limit.

Table C.3 The concentrations of chromium in shallow groundwater wells located in vicinity agricultural areas

Station	Cr (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	0.613	0.40	0.51 ± 0.15	<0.44**	<0.44**	0.44 ± 0.00	0.48 ± 0.05
2	0.154	0.14	0.15 ± 0.01	<0.44**	<0.44**	0.44 ± 0.00	0.30 ± 0.21
3	7.41	0.27	3.84 ± 5.05	<0.44**	<0.44**	0.44 ± 0.00	2.14 ± 2.40
4	<0.14*	0.14	0.14 ± 0.00	<0.44**	<0.44**	0.44 ± 0.00	0.29 ± 0.21
5	<0.14*	0.16	0.15 ± 0.01	<0.44**	<0.44**	0.44 ± 0.00	0.30 ± 0.21
6	0.25	0.25	0.25 ± 0.00	<0.44**	<0.44**	0.44 ± 0.00	0.35 ± 0.13
7	0.287	0.24	0.26 ± 0.03	<0.44**	<0.44**	0.44 ± 0.00	0.35 ± 0.13
8	1.14	0.72	0.93 ± 0.30	<0.44**	<0.44**	0.44 ± 0.00	0.69 ± 0.35
9	<0.14*	0.36	0.25 ± 0.15	<0.44**	<0.44**	0.44 ± 0.00	0.35 ± 0.13
10	<0.14*	0.14	0.14 ± 0.00	<0.44**	<0.44**	0.44 ± 0.00	0.29 ± 0.21
11	1.14	0.42	0.78 ± 0.51	<0.44**	<0.44**	0.44 ± 0.00	0.61 ± 0.24
12	1.14	1.14	1.14 ± 0.00	<0.44**	<0.44**	0.44 ± 0.00	0.79 ± 0.49
Mean.			0.71 ± 1.04			0.44 ± 0	0.44 ± 0.00

*Detection Limit of ICP-MS analysis during wet season was 0.14 µg/L
**Detection Limit of ICP-MS analysis during dry season was 0.44 µg/L
*,**Calculated at detection limit.

Table C.4 The concentrations of copper in shallow groundwater wells located in vicinity agricultural areas

Station	Cu (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	192.00	83.70	137.85 ± 76.58	15.70	13.10	14.40 ± 1.84	76.13 ± 87.29
2	38.90	61.70	50.30 ± 16.12	11.60	22.50	17.05 ± 7.71	33.68 ± 23.51
3	10.10	12.10	11.10 ± 1.41	16.40	7.94	12.17 ± 5.98	11.64 ± 0.76
4	22.80	28.30	25.55 ± 3.89	14.30	9.48	11.89 ± 3.41	18.72 ± 9.66
5	9.39	12.40	10.90 ± 2.13	4.62	13.70	9.16 ± 6.42	10.03 ± 1.23
6	47.40	42.10	44.75 ± 3.75	19.30	34.50	26.90 ± 10.75	35.83 ± 12.62
7	439.00	751.00	595.00 ± 220.62	16.50	86.40	51.45 ± 49.30	323.23 ± 384.35
8	118.00	150.00	134.00 ± 22.63	59.90	234.00	146.95 ± 123.11	140.48 ± 9.16
9	6.19	40.60	23.40 ± 24.33	0.58	1.41	0.99 ± 0.59	12.20 ± 15.85
10	61.70	27.30	44.50 ± 24.32	14.50	26.20	20.35 ± 8.27	32.43 ± 17.08
11	4.27	28.10	16.19 ± 16.85	4.07	23.30	13.69 ± 13.60	14.94 ± 1.77
12	8.00	24.60	16.30 ± 11.74	9.46	13.20	11.33 ± 2.64	13.82 ± 3.51
Mean.			92.49 ± 164.27			28.03 ± 39.47	60.26 ± 90.98

Detection Limit of ICP-MS analysis during wet season was 0.7 µg/L
Detection Limit of ICP-MS analysis during dry season was 0.089 µg/L

Table C.5 The concentrations of lead in shallow groundwater wells located in vicinity agricultural areas

Station	Pb (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	27.70	20.90	24.30 ± 4.81	15.80	28.00	21.90 ± 8.63	23.10 ± 1.70
2	9.26	9.65	9.46 ± 0.28	10.50	15.60	13.05 ± 3.61	11.26 ± 2.54
3	7.15	6.89	7.02 ± 0.18	11.80	7.17	9.49 ± 3.27	8.26 ± 1.75
4	6.97	7.42	7.20 ± 0.32	10.10	6.44	8.27 ± 2.59	7.74 ± 1.76
5	14.20	1.41	7.81 ± 9.04	2.40	20.20	11.30 ± 12.59	9.56 ± 2.47
6	31.30	32.90	32.10 ± 1.13	23.70	24.60	24.15 ± 0.64	28.13 ± 5.62
7	111.00	74.10	92.55 ± 26.09	34.20	48.10	41.15 ± 9.83	66.85 ± 36.35
8	29.30	20.70	25.00 ± 6.08	23.80	38.70	31.25 ± 10.54	28.13 ± 4.42
9	1.11	1.37	1.24 ± 0.18	<0.65*	<0.65*	0.53 ± 0.17	0.95 ± 0.42
10	16.60	10.40	13.50 ± 4.38	8.95	15.30	12.13 ± 4.49	12.82 ± 0.97
11	0.80	4.47	2.64 ± 2.60	<0.65*	2.31	1.48 ± 1.17	2.06 ± 0.82
12	0.84	0.80	0.82 ± 0.03	<0.65*	1.91	1.28 ± 1.89	1.05 ± 0.33
Mean.			18.64 ± 25.38			14.67 ± 4.38	16.66 ± 18.52

Detection Limit of ICP-MS analysis during wet season was 0.8 µg/L
*Detection Limit of ICP-MS analysis during dry season was 0.65 µg/L
*Calculated at detection limit.

Table C.6 The concentrations of mercury in shallow groundwater wells located in vicinity agricultural areas

Station	Hg (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	<0.05*	<0.05*	0.05 ± 0.00	1.41	0.51	0.96 ± 0.64	0.51 ± 0.64
2	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
3	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
4	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
5	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
6	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
7	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
8	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
9	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
10	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
11	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
12	<0.05*	<0.05*	0.05 ± 0.00	<0.070**	<0.070**	0.07 ± 0.00	0.06 ± 0.01
Mean.			0.05 ± 0.00			0.14 ± 0.26	0.10 ± 0.13

*Detection Limit of ICP-MS analysis during wet season was 0.05 µg/L
**Detection Limit of ICP-MS analysis during dry season was 0.07 µg/L
*,**Calculated at detection limit.

Table C.7 The concentrations of nickel in shallow groundwater wells located in vicinity agricultural areas

Station	Ni (µg/L)						
	Wet Season			Dry Season			All Year Round
	June, 2010	August, 2010	Average±SD	November, 2010	January, 2011	Average±SD	Average±SD
1	11.00	6.77	8.89 ± 2.99	4.82	7.24	6.03 ± 1.71	7.46 ± 2.02
2	4.42	5.04	4.73 ± 0.44	3.64	4.81	4.23 ± 0.83	4.48 ±0.35
3	7.41	4.88	6.15 ± 1.79	6.02	6.55	6.29 ± 0.37	6.22 ± 0.10
4	5.67	5.93	5.80 ± 0.18	6.59	4.68	5.64 ± 1.38	5.72 ± 0.11
5	8.01	3.01	5.51 ± 3.54	3.73	2.77	3.25 ± 0.68	4.38 ± 1.60
6	20.50	17.30	18.90 ± 2.26	12.30	12.40	12.35 ± 0.07	15.63 ± 4.63
7	12.90	12.40	12.65 ± 0.35	10.60	14.90	12.75 ± 3.04	12.70 ± 0.07
8	5.28	3.26	4.27 ± 1.43	5.20	5.23	5.22 ± 0.02	4.75 ± 0.67
9	2.04	5.72	3.88 ± 2.60	0.49	2.02	1.26 ± 1.08	2.57 ± 1.85
10	10.70	7.44	9.07 ± 2.31	4.52	8.18	6.35 ± 2.59	7.71 ± 1.92
11	0.40	1.42	0.91 ± 0.72	<0.38*	<0.38*	0.38 ± 0.00	0.65 ± 0.37
12	2.17	1.10	1.64 ± 0.76	1.04	1.01	1.03 ± 0.02	1.34 ± 0.43
Mean.			6.87 ± 4.99			5.40 ± 3.95	6.13 ± 4.38

Detection Limit of ICP-MS analysis during wet season was 0.14 µg/L
*Detection Limit of ICP-MS analysis during dry season was 0.38 µg/L
*,**Calculated at detection limit.

Table C.8 The concentrations of zinc in shallow groundwater wells located in vicinity agricultural areas

Station	Zn (µg/L)						
	Wet Season			Dry Season			All Year Round
	June,2010	August,2010	Average±SD	November,2010	January,2011	Average±SD	Average±SD
1	119.00	52.70	85.85 ± 46.88	57.30	37.30	47.30 ± 14.14	66.58 ± 27.26
2	80.80	31.70	56.25 ± 34.72	10.80	50.60	30.70 ± 28.14	43.48 ± 18.07
3	25.90	15.70	20.80 ± 7.21	22.40	16.50	19.45 ± 4.17	20.13 ± 0.95
4	24.70	20.90	22.80 ± 2.69	18.30	11.50	14.90 ± 4.81	18.85 ± 5.59
5	13.50	6.60	10.05 ± 4.88	8.54	35.50	22.02 ± 19.06	16.04 ± 8.46
6	57.20	48.50	52.85 ± 6.15	32.10	69.60	50.85 ± 26.52	51.85 ± 1.41
7	494.00	525.00	509.50 ± 21.92	18.70	172.00	95.35 ± 108.40	302.43 ± 292.85
8	137.00	94.00	115.50 ± 30.41	37.50	424.00	230.75 ± 273.30	173.13 ± 81.49
9	6.97	15.00	10.99 ± 5.68	<1.7*	4.07	2.89 ± 1.68	6.94 ± 5.730
10	54.10	13.30	33.70 ± 28.85	15.50	44.60	30.05 ± 20.58	31.88 ± 2.58
11	8.79	35.40	22.10 ± 18.82	<1.7*	23.90	12.80 ± 15.70	17.45 ± 6.58
12	14.50	13.50	14.00 ± 0.71	12.50	9.05	10.78 ± 2.44	12.39 ± 2.28
Mean.			79.53 ± 139.27			47.32 ± 62.89	63.43 ± 87.75

Detection Limit of ICP-MS analysis during wet season was 4.3 µg/L
*Detection Limit of ICP-MS analysis during dry season was 1.7 µg/L
*Calculated at detection limit.

Appendix D Heavy Metals in Fertilizers

Table D.1 Concentrations of heavy metals in Fertilizers

Name	Concentrations (mg/kg)								
	Al27	**Cr52**	**Ni60**	**Cu63**	**Zn66**	**As75**	**Cd114**	**Hg202**	**Pb207**
Yara Mila_S1	36.700±0.160	0.501±0.011	0.254±0.0078	0.606±0.0102	1.280±0.021	0.165±0.0028	<0.0013	0.000738±0.00002	0.131±0.006
Yara Mila_S2	40.200±0.570	0.521±0.0023	0.263±0.0045	0.660±0.0092	1.730±0.035	0.173±0.0037	<0.0013	<0.00070	0.129±0.012
กระต่าย_S1	0.862±0.014	0.0408±0.0006	0.0295±0.00064	0.0209±0.00053	0.240±0.0064	0.00987±0.00070	<0.0013	<0.00070	0.0356±0.0013
กระต่าย_S2	1.060±0.025	0.0340±0.0002	0.0254±0.00093	0.0284±0.00088	0.224±0.0068	0.00985±0.00012	<0.0013	<0.00070	0.0283±0.0009
Top One_S1	96.500±0.680	1.120±0.003	0.405±0.005	0.299±0.013	9.670±0.039	0.629±0.0075	<0.0013	0.00132±0.00004	0.176±0.002
Top One_S2	71.600±0.930	0.751±0.026	0.246±0.0086	0.222±0.021	6.820±0.145	0.420±0.015	<0.0013	0.000761±0.00016	0.103±0.001
อะโกรเฟต_S1	1920.000±37.000	2.750±0.042	0.799±0.023	0.478±0.0064	2.160±0.024	0.483±0.0042	<0.0013	0.000925±0.00011	0.501±0.01
อะโกรเฟต_S2	1990.00±13.50	2.22±2.9	0.647±0.0072	0.0391±0.0039	1.87±0.022	0.376±0.0032	<0.0013	0.000773±0.00008	0.380±0.002

BIOGRAPHY

Name:	Miss Pokkate Wongsasuluk
Date of Birth:	October 26, 1985
Hometown:	Bangkok, Thailand
Nationality:	Thai
Education:	Primary School: Mater Dei School
	Lower Secondary School: Mater Dei School
	High School: Triam Udom Suksa School (2002-2004)
	Bachelor's Degree: Department of Marine Science, Faculty of Science, Chulalongkorn University (2005-2008)
Presentation :	Pokkate Wongsasuluk, Srilert Chotpantarat, Wattasit Siriwong. *Human Health Risk Assessment Associated with Arsenic (As) in Drinking Shallow Groundwater Wells at Ubon Ratchathani Province, Thailand*. The 2nd International Conference on Environmental Science and Technology-ICEST 2011. Peninsula Hotel, Songapore Febuary 26-28, 2011. Organized by Asia-Pacific Chemical, Biological & Environmental Engineering Society (APCBEES) and IEEE.
	Pokkate Wongsasuluk, Srilert Chotpantarat, Wattasit Siriwong. *Human Health Risk Assessment Associated with Arsenic (As) in Drinking Shallow Groundwater Wells at Ubon Ratchathani Province, Thailand*. International Workshop on Environmental Exposures and Disease Markers. College of Public Health Sciences, Chulalongkorn University, Bangkok, Thailand, March 25, 2011. Organized by Thai Fogarty ITREOH and College of Public Health Sciences, Chulalongkorn University