6.3 Conceptual Model of Soil and Groundwater Salinization in the Khorat Plateau

6.3.1 Causes of Salinity in the Study Area

To generate preliminary conceptual models/ideas on soil and groundwater salinity in the Khorat Plateau, the causes of salinity in this region were studied. Based on previous work and present investigations on hydrogeology, geology, this study categorized the causes of salinity into two types;

1) Natural causes including shallow interflow and deep groundwater flow with capillary rise effect, and
2) Human activities causes including deforestation, salt production, reservoir construction and irrigation system.

6.3.1.1 Salinity Caused by Natural Causes

a) Shallow Groundwater Flow or Shallow Interflow, including Runoff

- The salt originated directly from weathering of the Maha Sarakham Formation and/or some salt accumulated in the Upper Clastic Members, was dissolved and transported from nearby uplands through shallow interflow, surface flow or runoff to the low-lying areas. The salinization by shallow groundwater flow and/or surface flow is responsible for a great number of saline areas. Shallow interflow operates mostly on a local scale. It is particularly obvious around the foot slopes of low hills and mounds that consist of the spoil of former salt-making activities, and natural hills and ridges with bed rock containing salt close to the surface.
- Shallow groundwater starting from rain water dissolves the salt from the elevated ground at the interior margins of the basins e.g. Dan Kun Thot, Jaturat and Kham Tha Le Sor District area. Later on, with the mechanism of surface and subsurface water short transportation, the brines migrate to the low-lands and valleys, and lead to salt crusts as results of evaporation.

b) Deep Groundwater Flow

- This salinity mechanism is normally related to the capillary rise effect and artesian pressure flow system. Salt is brought into the aquifer when long distance groundwater under confined condition flows through and dissolves salt in the salt-bearing strata of Cretaceous and Tertiary Maha Sarakham Formation and transports those dissolved salts in form of saline water to the discharge area.
- For saline soils to form, the water table needs to come close enough to the soil surface to allow capillary action to raise the groundwater to the soil surface. In this case, the shallow saline watertable has developed from the rising up of the former deeper groundwater because of increased recharge to the aquifer resulting from forest clearing, mainly in upland areas. In general, the water must be within 2 m (6 ft) of the soil surface for this occur, but the critical depth (the depth beyond which water cannot wick to the soil surface) varies with soil texture.

- Although depth to the upper most rock salt layers in this area ranges from 70 to 100 m, the covering formation is not impermeable because it is weathered and fractured. Therefore, rainwater can penetrate through the formation to dissolve the rock salt. Then the salty water is moved along as groundwater flow from a recharge area to a discharge area, usually a low level area. In the discharge area the groundwater level is close to the surface. Then the capillary force will withdraw groundwater to the surface. The withdrawal distance of the capillary force depends on the space between sediment grains. As water evaporates from the ground surface, the capillary force can replace it by drawing upward the groundwater.
- In case of saline groundwater, dissolved salt cannot evaporate as water. It will be accumulated at the soil surface. If this process continues for longer periods, the salt concentration will be higher until salts can be seen as salt path on the soil surface. After the salt is accumulated on the soil surface, it will removed by rainfall in rainy season to the discharge low-lying area or moves back to the underground with the infiltrate water. The salt path will be formed again in the next dry season if the groundwater level is still close to the ground surface.
- Vegetation also plays an important role to the rise of the groundwater level, causing both shallow groundwater and deep groundwater salinization mechanisms. Under vegetation conditions, water use and evapotranspiration are high, while under deforestation the groundwater use and transpiration are reduced. Therefore, saline groundwater is filled up and move upward close to surface. Due to the presence of a confining clay layer in the plain, the groundwater in this area is under artesian pressure. A perched water table develops during the rainy season and is usually not connected with the main aquifer.
- This salinity mechanism is supposed to occur on the lineaments or long narrow river courses, e.g. at Khong and Kham Sakae Saeng District, Nakhon Ratchasima Province.

6.3.1.2 Salinity Caused by Human Activities

a) Deforestation

- In general, the study area used to have a dense forest in the northern, southern and western part. Most of the former forests were natural forests. However, most part of this forest were deforested for producing cash crops e.g. cassava, sugar cane, maize, etc. In the central part of the study area there are only few forests present, and most of these forests are eucalyptus plantation. Most areas of the central part of the study area are used for rice cultivation and are also suffering from salinization, e.g. in the vicinity of Dan Khun Thot, Non Thai, Non Sung, Khong and Bua Yai District of Nakhon Ratchasima Province, and in Jaturat District of Chaiyaphum Province.

b) Salt Production

- Salt production took place in only some areas of the study area according to the regulations and permissions of the Province. The permission areas in the study area for salt making are at Phi Mai, Non Thai, Non Sung and Kham

Sagae Saeng of Nakhon Ratchasima Province. Some disposal saline water and waste from some small to medium sized salt production enterprises are disposed to the natural streams and, consequently caused salinity.

c) Construction of Reservoirs

- Salinity caused by reservoir construction in the study area can be observed at Lam Chiang Krai Reservoir, Dan Khun Thot District. Local people in this area tell that this area was not saline as today. The area around the Lam Chiang Krai Reservoir became saline after the reservoir was constructed and seems to have become more saline in last decade.

d) Irrigation

- Salinity caused by irrigation can be seen in irrigated areas of Sung Nern District, Nakhon Ratchasima Province, located in the southwestern part of the study area. This irrigated area receives saline water from the Mae Nam Mun River, which received dissolved salt when it runs through saline areas from the east.

6.3.2 Salinity Types in the Study Area

According to the salinity classification in Chapter 3, based on hydrogeology, surface water flow, geology, topography, and soils, and borehole data, this study classified salinity in the study area into three main types:

1) Salinity along weak zones,
2) Salinity in depression areas, and
3) Salinity affected by reservoir and irrigation systems.

Those salinity areas can be observed on the satellite image with its specific features. The simplified block diagram showing each salinity type and their features on the False Color Composite of Landsat 7 image acquired on December 27, 1999 bands 4, 3, 2 as red, green, blue and related topographic and subsurface conditions are shown in Figure 6.33. This part will describe the subsurface conditions, salinization mechanisms of each salinity type and its related geologic features and its reflected features on the False Color Composite image of Landsat 7 acquired on December 27, 1999 bands 4, 3, 2 as red, green, blue, and on the False Color composite image of ASTER image acquired on December 7, 2001, bands 3, 2, 1 as red, green, blue, respectively.

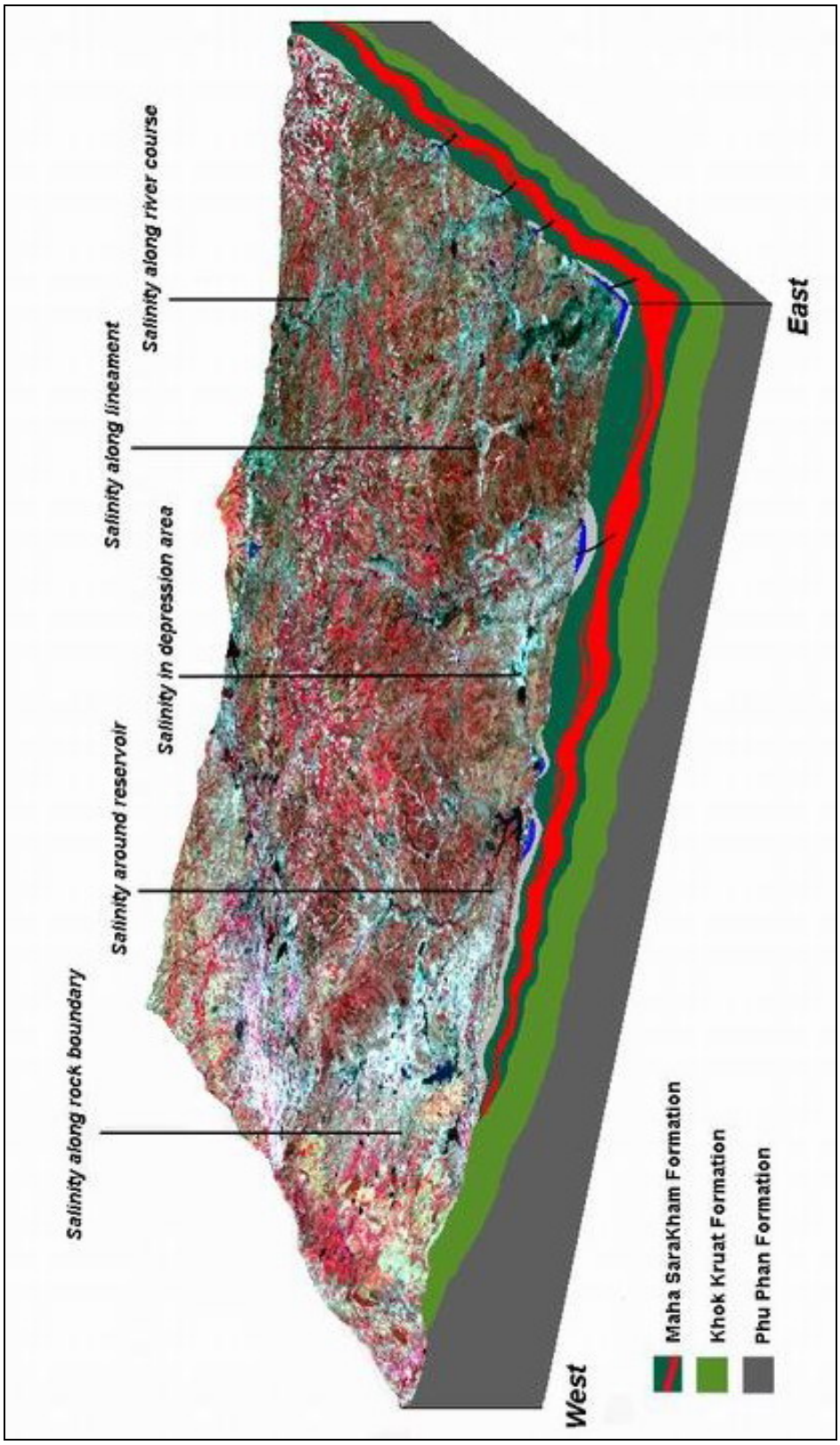

Figure 6.33 Simplified block diagram showing each type of salinity in the study area and its related topographic and subsurface geologic conditions

6.3.2.1 Salinity along Weak Zones

Salinity along weak zones occurs where a permeable, water-bearing layer, such as a sandy layer, coal seam or fractured bedrock layer, outcrops at or near the surface. The salinity process takes place in the weak zone such as the bedding plains between two rock types, river courses, fractures, faults, and fissures. Saline seeps occur in rows along a slope at similar elevations. In most cases, this form of salinity is a form of primary salinity (i.e. it has developed naturally over geologic time). Salinity along a weak zone may be categorized into subclasses as salinity along a rock boundary, salinity along a lineament and salinity along a river course.

a) Salinity along a Rock Boundary

- Salinity along a rock boundary can be seen as a white long narrow area at the same elevation in between the boundary of rock formations on the False Color Composites images of Landsat 7 and of ASTER, respectively.
- Salinity along rock boundaries in the study area normally takes place at the west rim of the Khorat Plateau as presented at the vicinity of Dan Khun Thot District, Nakhon Ratchasima Province, or at the circular feature located at Jaturat District south of Chaiyaphum Province where semi- to unconsolidated young sediments are attached to the underneath lying older solidated rocks of the Khorat Group such as the Khok Kruat and the Phu Phan Formations. The groundwater flows from the elevated area of Khok Kruat or Phu Phan rocks downward to the lower lying area of alluvial deposits where the Maha Sarakham Formation lies underneath.
- The salinity process is believed to be the mixing of shallow interflow and capillary rise together with evapotranspiration at the surface. The preliminary simplified model of the salinized mechanism along a rock boundary is shown in Figure 6.34.
- The False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the rock boundary salinity is presented in Figure 6.35a. The green dots are the ground truth locations where salt crust can be seen at the surface. The land use classification showing salt–affected areas is presented in yellow color in Figure 6.35b. The three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering rock boundary salinity at Dan Khun Thot District located in the western part of the study area is shown in Figure 6.36. The photograph showing the salt-affected area along the rock boundary, which is observed as low-lying area in the satellite image is presented in Figure 6.37.

- In the False Color Composites images of Landsat 7 the rock boundary salinity appears as circular and dome-like feature at Jaturat District located in the northern part of the study area and is shown in Figure 6.38 and Land use classification showing salt–affected area in yellow area in Figure 6.39. The three dimensional surface image derived from the False Color Composite of Landsat 7 covering the rock boundary salinity and showing as circular and dome-like feature at Jaturat District north of the study area is also presented in Figure 6.40. The photograph showing the salt-affected area along the trough, which is observed as circular feature in the satellite image is shown in Figure 6.41.
- Salt accumulations can be seen in trough or low-lying area and salinity occurring in this area is mostly the severe type.

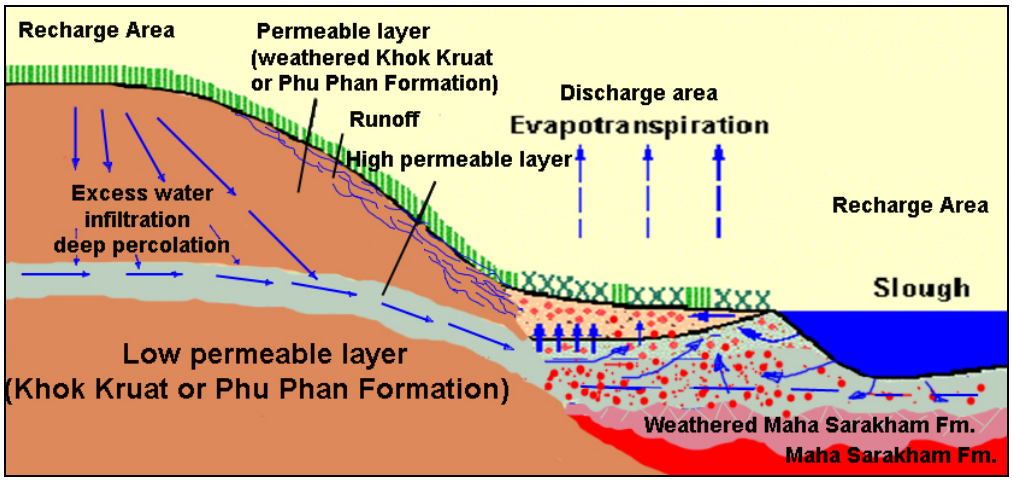

Figure 6.34 A simplified model showing salinity mechanisms along rock boundary.

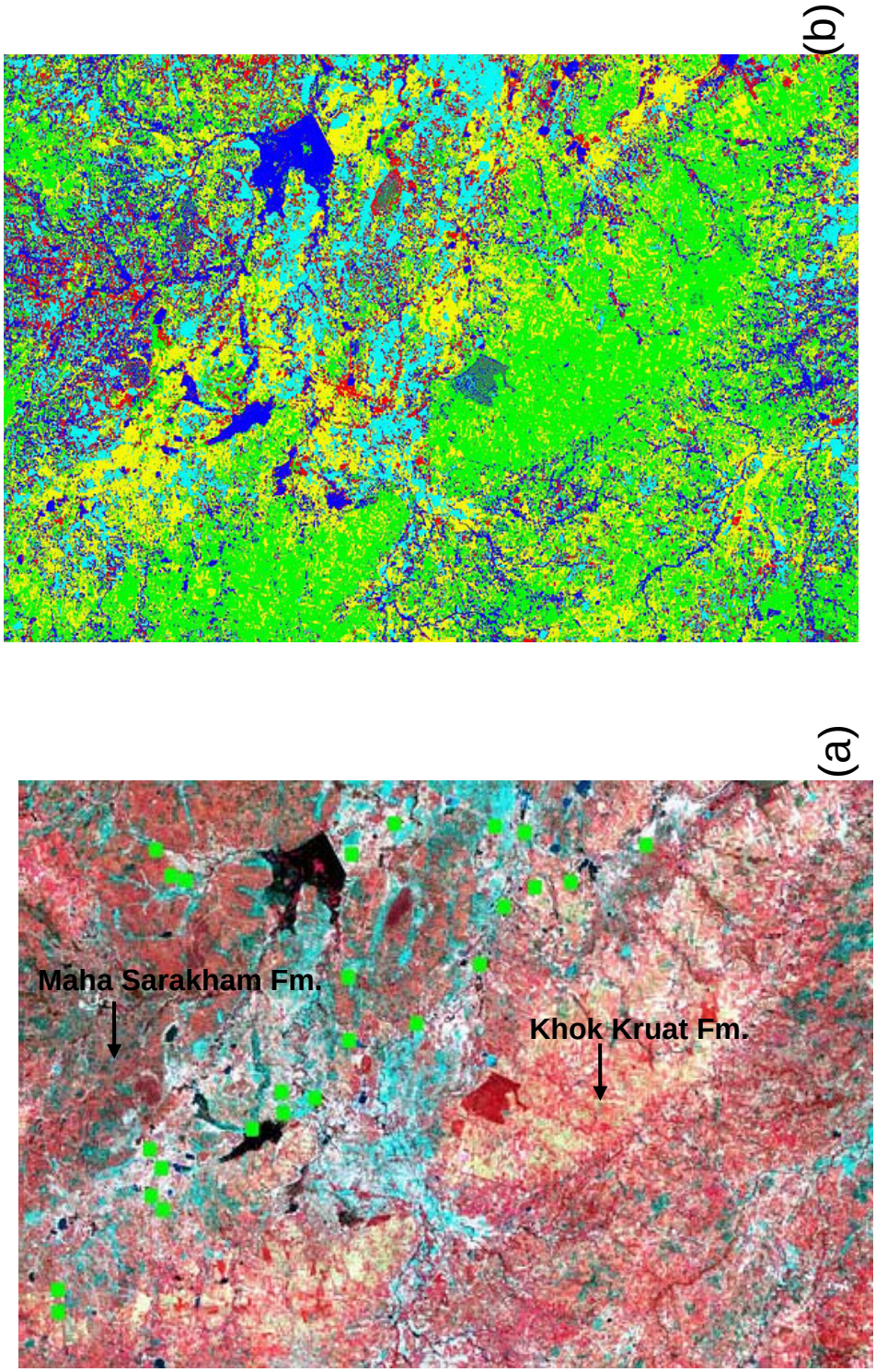

Figure 6.35 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue (a) covering the rock boundary salinity in the vicinity of Dan Khun Thot district and its land use classification showing the salt –affected area in yellow color (b)

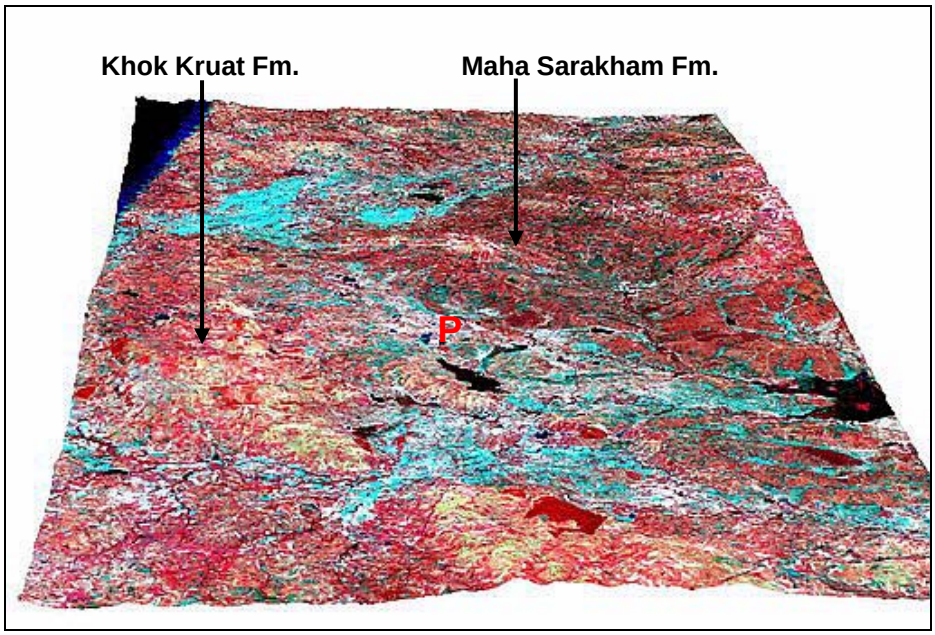

Figure 6.36 Three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering rock boundary salinity at Dan Khun Thot District located in the western part of the study area shows salt-affected area in bright/white color.

Figure 6.37 Photograph showing the salt-affected area along the rock boundary (point "P" in Figure 6.36) which is seen as low-lying area in the satellite image in the vicinity of Dan Khun Thot District.

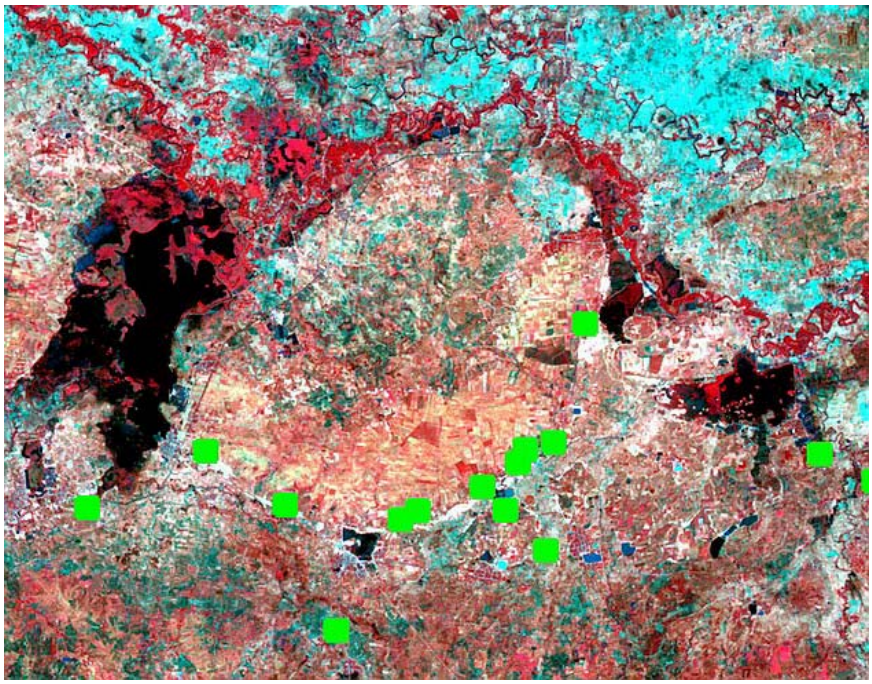

Figure 6.38 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the rock boundary salinity and showing the circular and dome-like feature at Jaturat District located in the northern part of the study area. The green dots are ground truth locations.

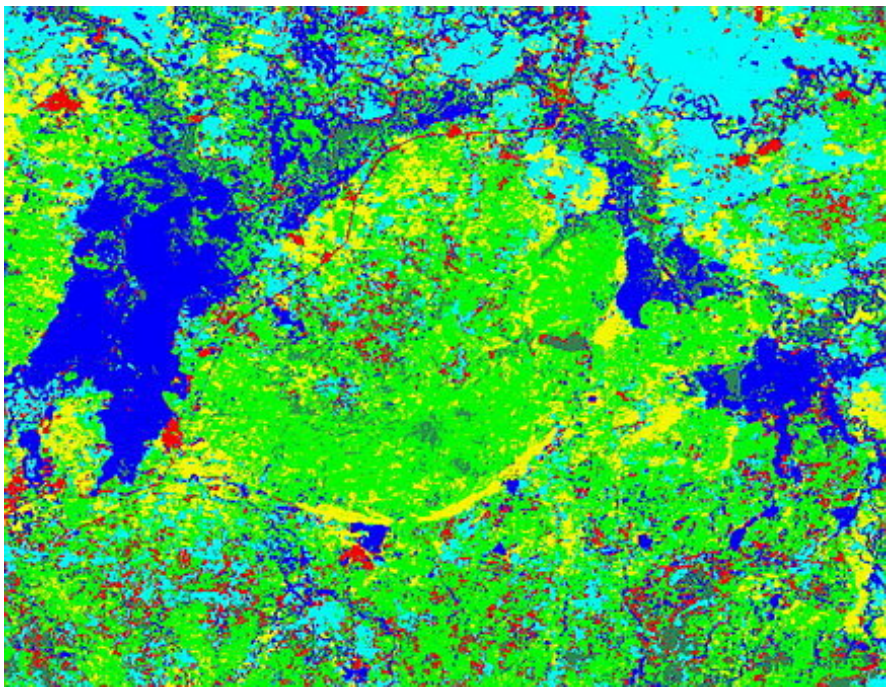

Figure 6.39 Land use classification showing salt–affected area in yellow color around the circular feature, Jaturat District, Chaiyaphum Province.

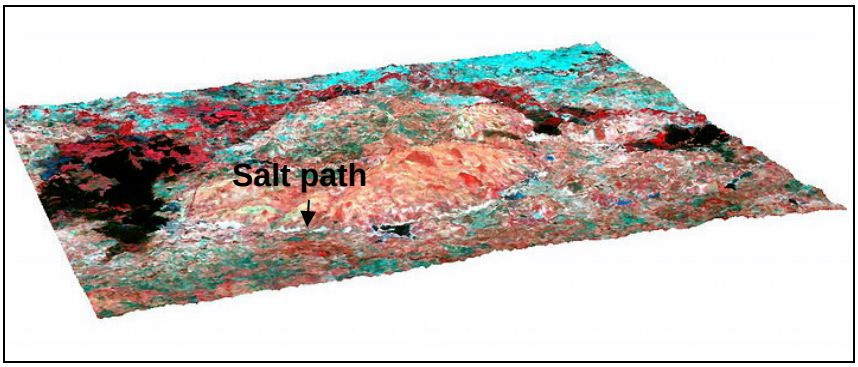

Figure 6.40 Three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the rock boundary salinity and showing as circular and dome-like feature at Jaturat District north of the study area.

Figure 6.41 Photograph showing a salt-affected area along the trough, which appears as circular feature in the satellite image in Jaturat District, Chaiyaphum province.

b) Salinity along Lineaments

- Salinity along a lineament can be seen as a white elongate strip located mostly in between rolling structures or in the trough on the False Color Composite image of Landsat 7 and on the False Color Composite image of ASTER, respectively.
- Salinity along lineaments occurs where water from a pressurized aquifer rises to or near the ground surface. Therefore this sort of salinity may also be called artesian salinity. It is usually associated with intermediate or regional groundwater flow (deep groundwater flow) systems. In this case, fractures or faults may act as artesian wells and let saline solution migrate easily along this high permeability zone break through the above low or impermeable bed as shale or clay to the surface. Then, where the groundwater reaches the capillary fringe zone, about 1 to 1.5 m deep, the saline is brought up to the surface by evapotranspiration processes. The simplified model showing salinity mechanism along the lineament is shown in Figure 6.42.
- A good example of this salinity type can be seen in the vicinity of Khong District, Nakhon Ratchasima Province, northeast of the study area. Lineaments trending NE-SW and its crossing NW-SE direction in this area show the long-narrow salt path as can be observed both on ground surface and on the satellite image as the bright/white long-narrow lineament on the False Color Composite image of Landsat 7 shown in Figure 6.43.
- On the land use classification, the salt-affected area is shown in yellow color shown in Figure 6.44. The three-dimensional surface image derived from False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the lineament salinity at this area is also shown in Figure 6.45 and the photograph showing the salt-affected area along the trough which is seen as lineament feature in the satellite image in this area is shown in Figure 6.46, respectively.
- The salinity in this area is mostly of the moderately to severely salinity type.

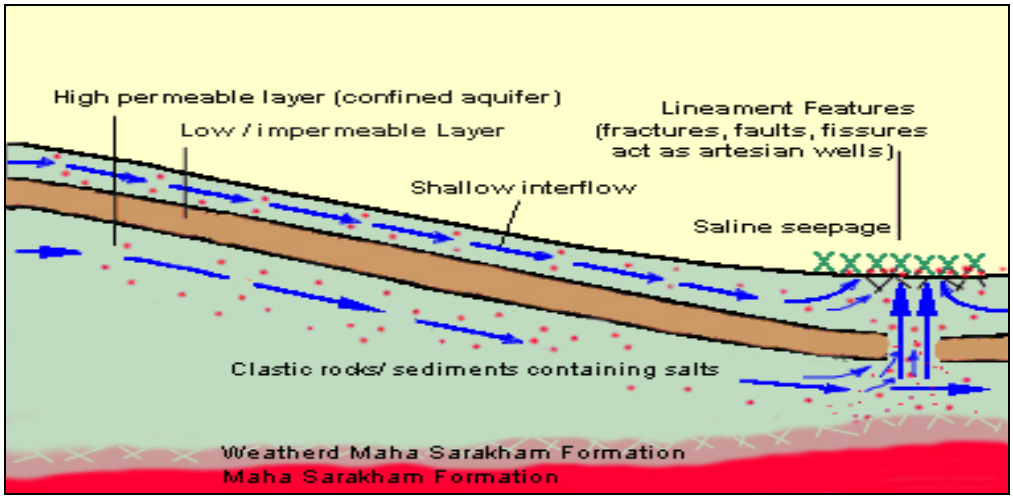

Figure 6.42 A simplified model showing salinity mechanisms along a lineament (or artesian salinity) and along a river course.

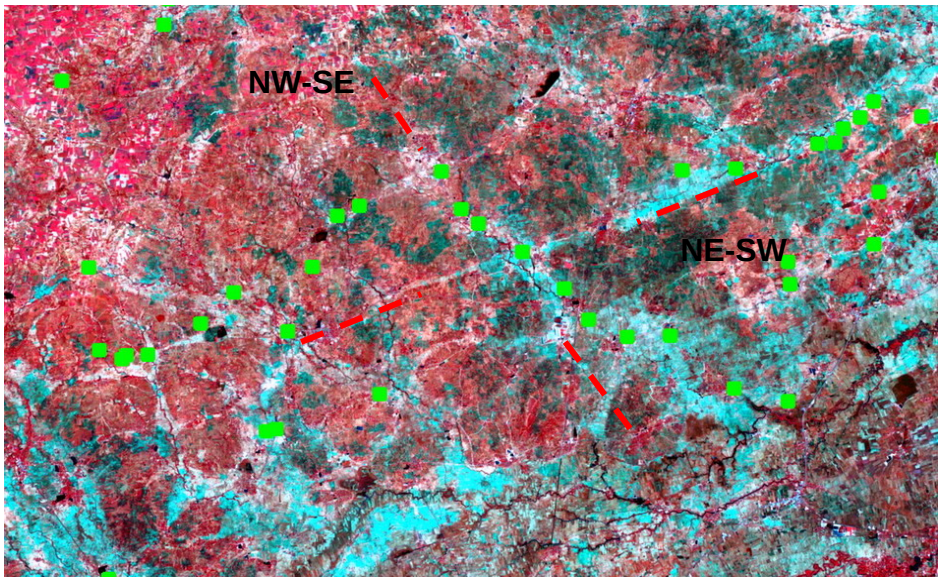

Figure 6.43 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the lineament salinity at Khong District in the northeastern part of the study area. Red dash lines indicate directions of lineaments. The green dots are ground truth locations.

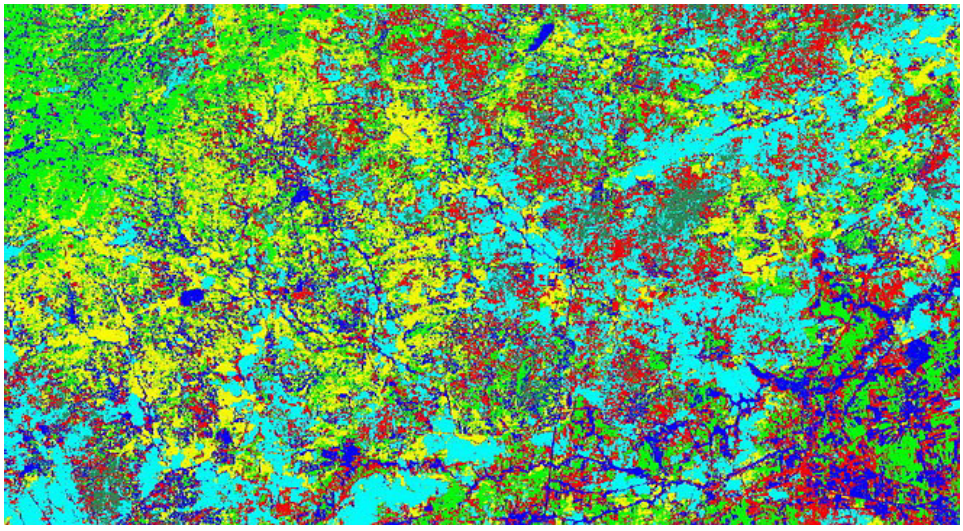

Figure 6.44 Land use classification of the salt-affected area which is observed as lineament feature on satellite image at Khong District in the northeastern part of the study area and the saline area is shown in yellow color.

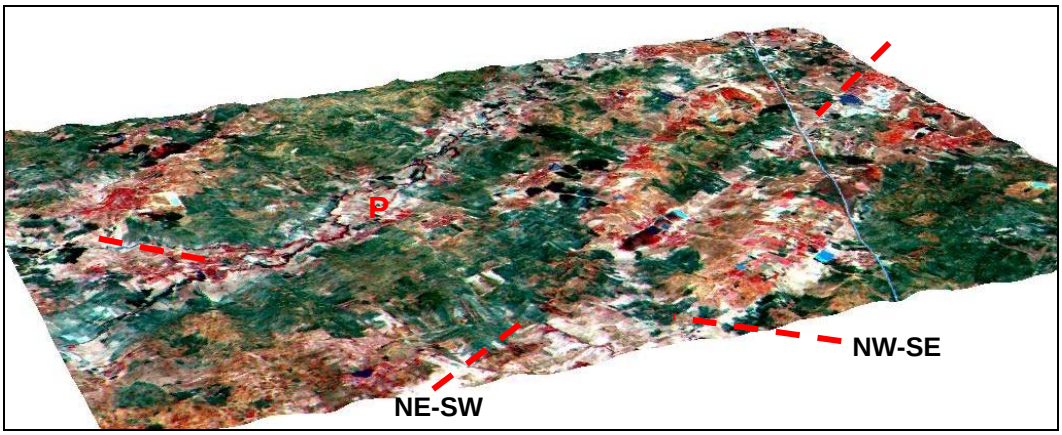

Figure 6.45 Three-dimensional surface image derived from the False Color Composites of Landsat 7 bands 4, 3, 2 as red, green, blue covering The lineament salinity at Khong District in the northeastern part of the study area. Red dash lines indicate directions of lineaments.

Figure 6.46 Photograph showing the salt-affected area along the trough (point "P" in Figure 6.45), which appears as a lineament feature in the satellite image in Khong District area.

c) Salinity along a River Course

- Salinity along a river course can be seen as a white area along a terrace of a river course on the False Color Composite image of Landsat 7 and on the False Color Composite image of ASTER, respectively.
- The salinity along a river course has the same origin as salinity along fractures or faults. This is because most rivers are developed along weak zones like faults or fractures. This salinity mainly occurs along narrow straight rivers or streams. However, the salinity along rivers that have broad valleys may be classified into this type accompanied by the shallow interflow salinity process, especially in the rainy season. A simplified model of salinity along river courses is shown in Figure 6.42.
- An example of this salinity type is Huai Yai River located at Ban Luam District, Chaiyaphum Province north of the study area were salt accumulation can be seen along the river terraces and also in rice fields parallel to the river. However, salinity along rivers that have broad valleys may be classified into this type accompanied by the shallow interflow salinity process, especially in rainy season e.g. at Mae Nam Mun River in the southern part of the study area and Mae Nam Chi River in the northern part of the study area. The False Color Composite of Landsat 7 covering the Huai Yai River, Chaiyaphum Province is presented in Figure 6.47a, and its land use classification showing salt –affected area in yellow area is also presented in Figure 6.47b. The three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the river course salinity in the study area is shown in Figure 6.48 and the photograph showing the salt-affected area along the terrace of this river is also shown in Figure 6.49.
- The salinity in this area is mostly of the moderately salinity type.

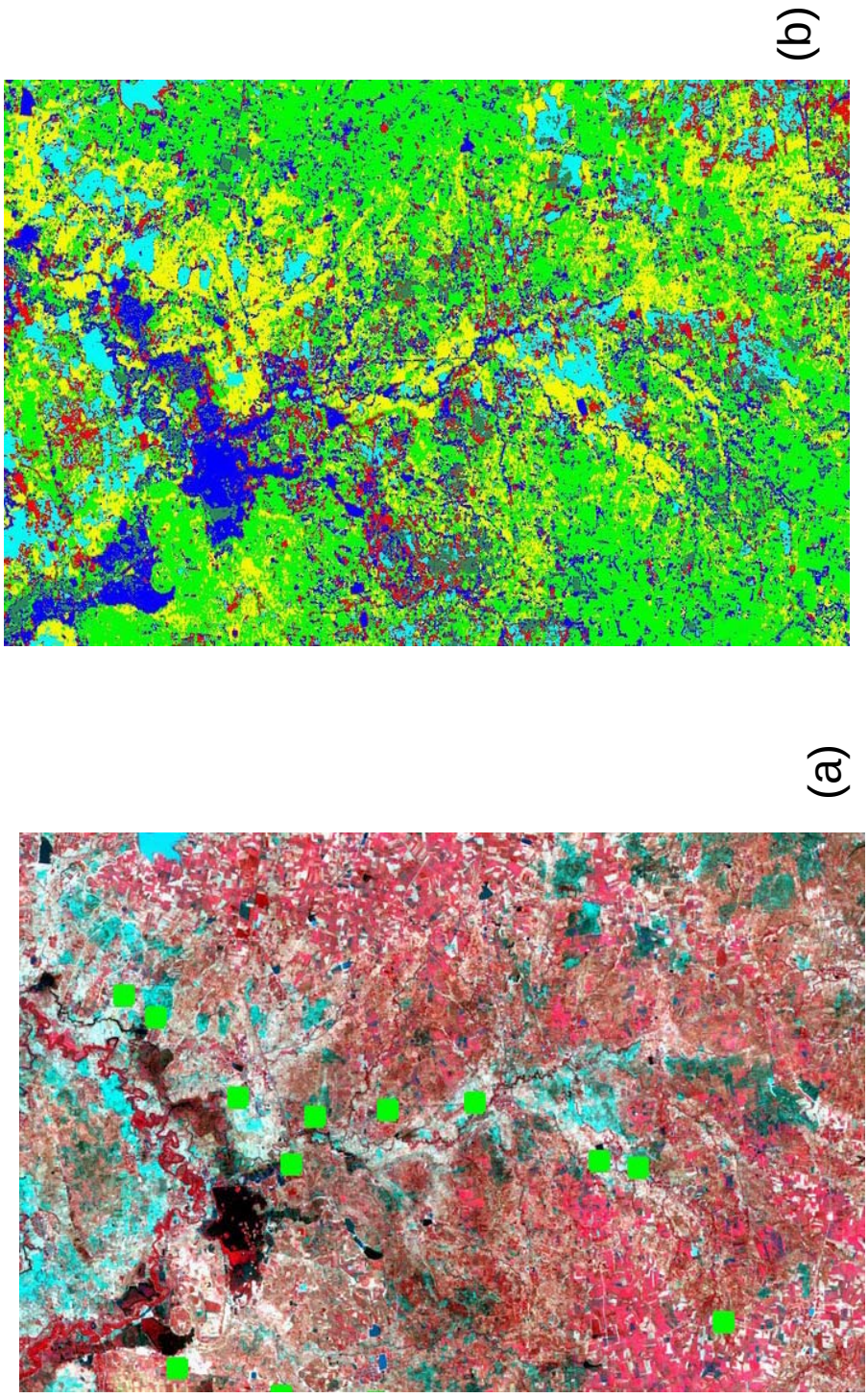

Figure 6.47 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue (a) covering the Huai Yai River, Ban Luam District, Chaiyaphum Province and its land use classification showing salt –affected areas in yellow color (b).

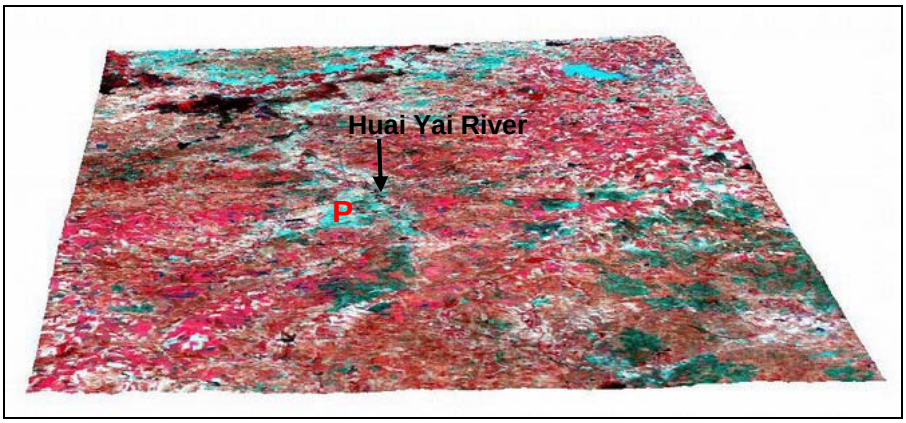

Figure 6.48 Three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the Huai Yai River, Ban Luam District, Chaiyaphum Province, northern part of the study area.

Figure 6.49 Photograph showing a salt-affected area in a paddy field along the terrace of the Huai Yai River (point "P" in Figure 6.48), Ban Luam District, Chaiyaphum Province.

6.3.2.2 Salinity in Depression Areas

- Salinity in depression areas coincides with natural ponds or swamps. Salinity in depression areas can be seen as a white rounded area or as a white ring around natural ponds or swamps on the False Color Composite images of Landsat 7 and of ASTER, respectively.
- This type of salinity occurs in depressions or drainage courses. The area is salinized by a shallow interflow system in that surface water flows slowly over and is trapped temporarily in the low lying areas until the water drains off and/or infiltrates the soil. Once the surface water has disappeared, groundwater from the water table rises by capillary action to the surface into the previous pond area. When the water table reaches the capillary fringe, capillary action and evapotranspiration play important roles to bring up saline water to the surface.
- A similar form of depression salinity is slough ring salinity. This type of salinity occurs as a ring of salt immediately adjacent to a permanent water body. Water infiltrates from the pond into the permeable upper soil layer and moves laterally upslope, as shallow groundwater in an unsaturated state circulates through this layer. The water may also flow downward, raising the water table. Water from the lateral unsaturated flow and capillary rise from the water table emerges at the surface where it evaporates, leaving salts at the edge of the slough. The preliminary simplified model showing the depressions salinity mechanism is show in Figure 6.50.
- An example of this salinity type is found in the vicinity of Non Sung District. The landform of this area is composed of scattered small ponds and swamps, which are believed to be the results of underlying rock salt dissolution. The ponds in this area contain salty water most of the time except during the rainy season when they are filled up with fresh water from rainfall. The False Color Composite image of Landsat 7 covering the depression salinity at Non Sung District located in the northeastern part of the study area is shown in Figure 6.51 and its land use classification showing the salt-affected area in yellow color is shown in Figure 6.52. The three dimensional surface image covering this area is shown in Figure 6.53 and the photograph shows the salt-affected area along this depression area is shown in Figure 6.54.
- The slightly to the moderately salinity type is the major salinity type in this depression area.

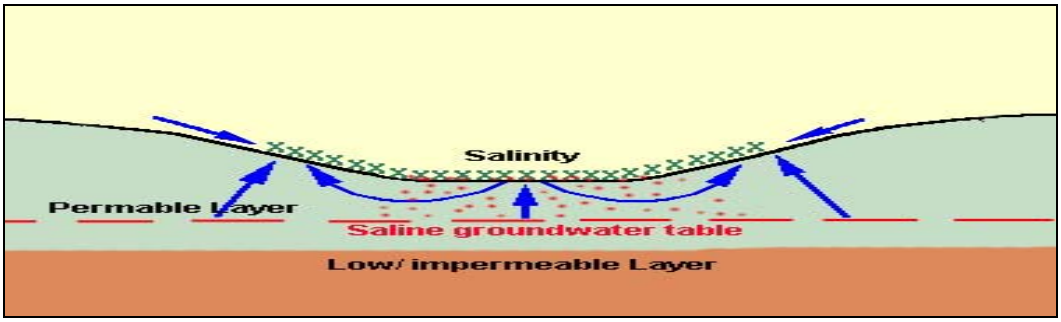

Figure 6.50 A simplified model showing depression salinity mechanism.

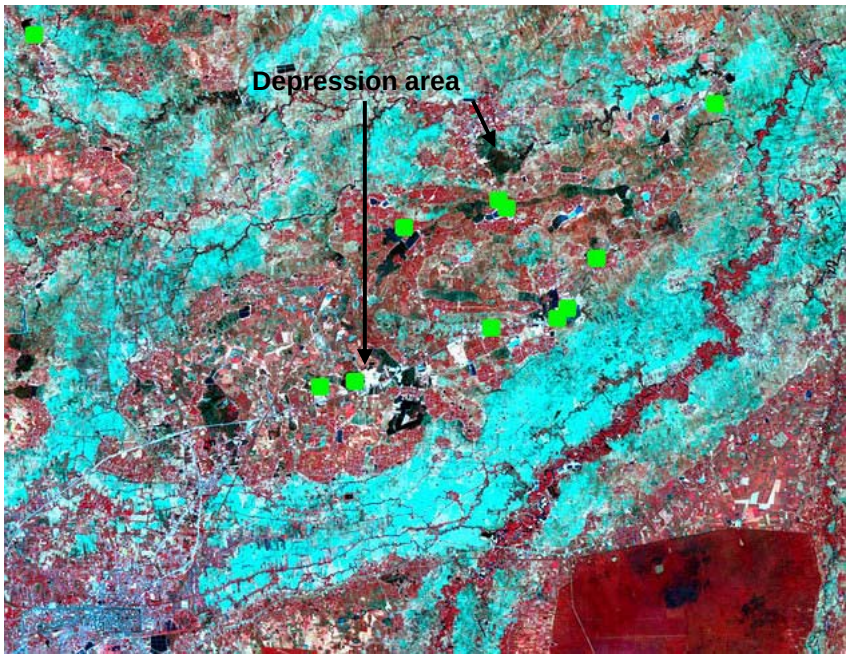

Figure 6.51 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the depression salinity at Non Sung District located in the northeastern part of the study area.

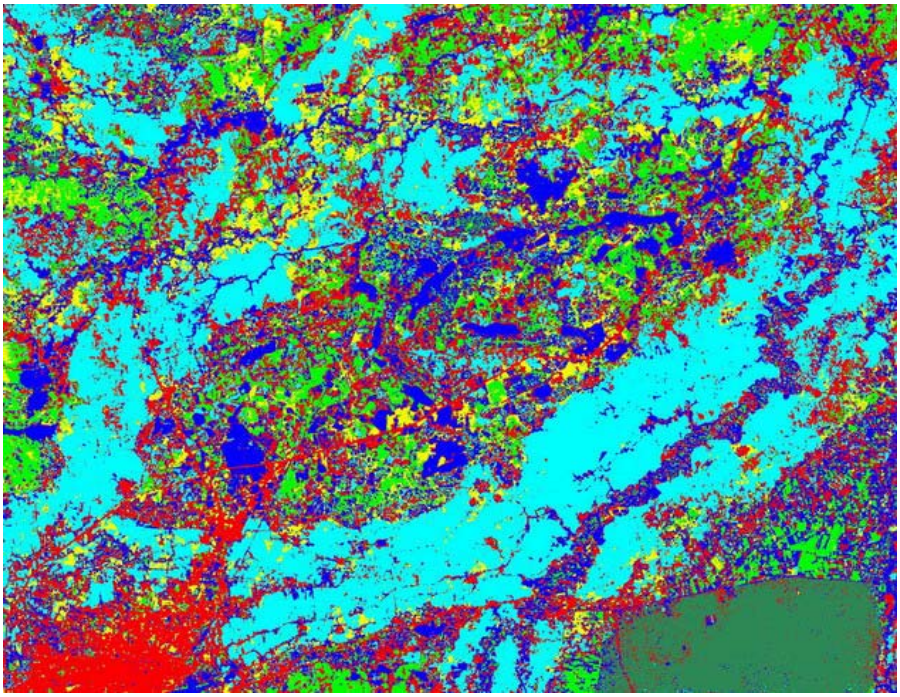

Figure 6.52 Land use classification for the salt-affected area of the depression salinity type at Non Sung District located in the northeastern part of the study area. The saline area is shown in yellow color.

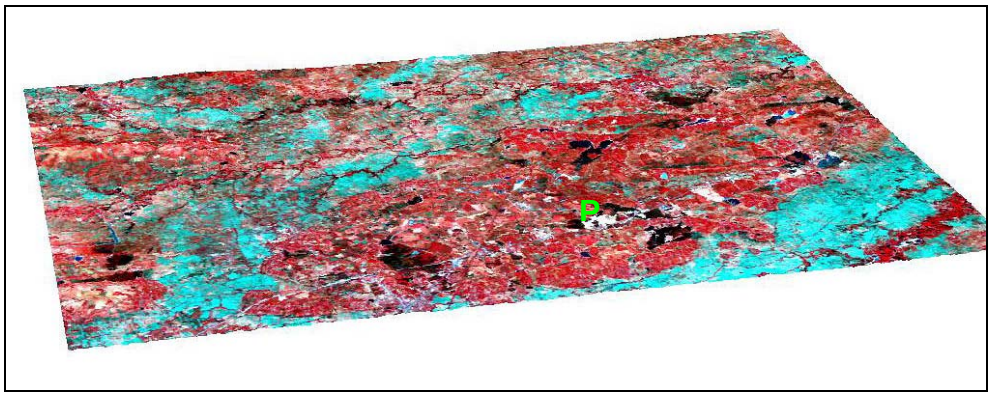

Figure 6.53 Three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the depression area salinity at Non Sung District located in the northeastern part of the study area.

Figure 6.54 Photograph showing the salt-affected area around the depression area at Non Sung District (point "P" in Figure 6.53) located in the northeastern part of the study area.

6.3.2.3 Salinity affected by Reservoir and Irrigation Systems

- Salinity affected by reservoir and irrigation system is dominant where leakage from reservoirs contributes to seeps. This type of salinity can be seen as a white rounded area around a reservoir or behind a dam site on the False Color Composite images of Landsat 7 and of ASTER, respectively.
- This salinity type is dominant where leakage from reservoirs contributes to seeps. In case of reservoirs causing salinity, because reservoirs or dams are mostly constructed and located in large low lying horizontal plane where water table is not too deep, leakage water from reservoir would add to the groundwater. Thus, saline groundwater underneath reservoir site is disturbed and emerged to surface causing salinity to surrounding areas. These salinity types mainly occur in reservoirs and dam sites throughout the study area and the Khorat Plateau. A simplified model showing the salinity affected by reservoir water leakage is shown in Figure 6.55.
- For the salinity around a reservoir, the salt accumulations can be seen at the surface, and also can be seen as bright/white areas around a water body on the satellite image. A good example of this salinity type is at the Lam Chiang Krai Reservoir, located at Dan Khun Thot District, where it contains salty water all of the year.
- In case of canal seepage salinity, leakage water from canals contributes to seeps as occurred in reservoir case. This is because canals are normally dug and located along topographic breaks. Fresh water, or sometimes salinized water, from canals infiltrates the surrounding area and causes salinity as in the reservoir salinity case. A simplified model showing the salinity affected by canal water leakage is shown in Figure 6.56. This salinity type can not be detected directly from satellite image, but it could be traced and predicted the possible salinized area by the presence of the irrigation canals originated from the reservoir containing salty water e.g. in the irrigated canal system in Mae Nam Mun River plain in the vicinity of Nakhon Ratchasima Province where it irrigates salty water to its irrigated area.
- The False Color Composite image of Landsat 7 covering the Lam Chiang Krai Reservoir at Dan Khun Thot District located in the western part of the study area is shown in Figure 6.57 and its land use classification showing the salt-affected area in yellow color is shown in Figure 6.58. The three-dimensional surface image derived from the False Color Composite image of Landsat 7 band 4, 3, 2 as red, green, blue covering the Lam Chiang Krai Reservoir at Dan Khun Thot District is shown in Figure 6.59, and the photograph showing the salt-affected area around this reservoir is shown in Figure 6.60. The salt crust on the canal concrete pavement and the salt crust in paddy field which is irrigated by salty water in Sung Nern District, Nakhon Ratchasima Province is shown in Figure 6.61 and Figure 6.62, respectively.
- The salinity occurring around the reservoir or in irrigated canals is mostly of the slightly to the moderately type.

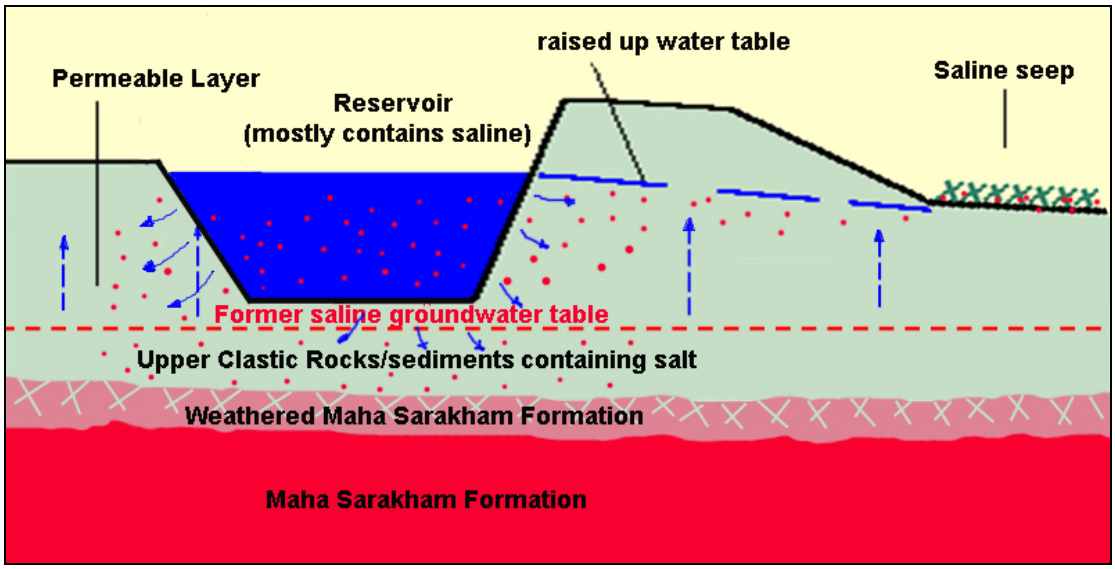

Figure 6.55 A simplified model showing reservoir water leakage salinity.

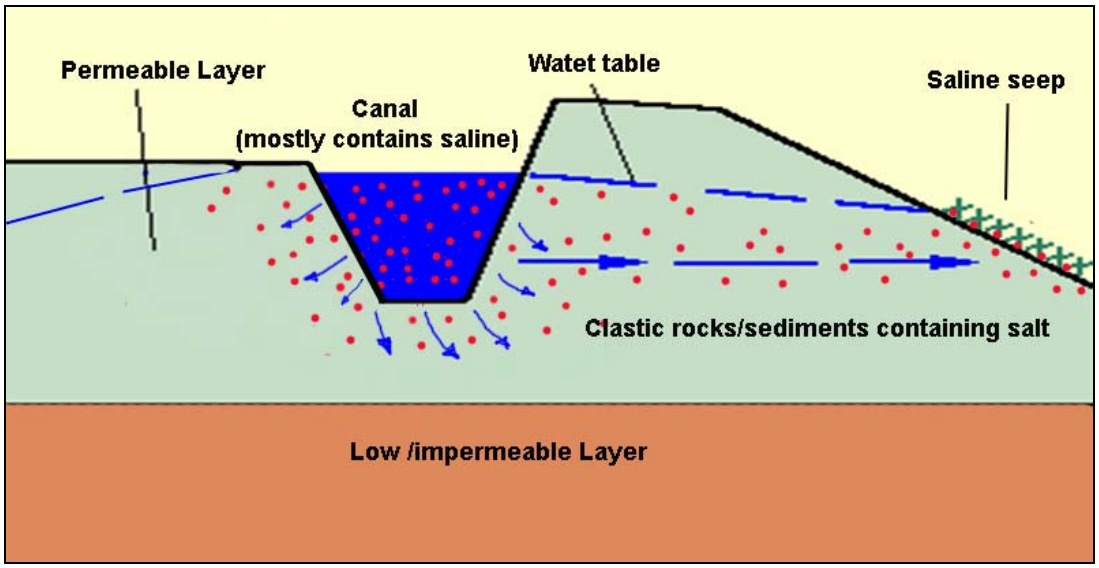

Figure 6.56 A simplified model showing canal water leakage salinity.

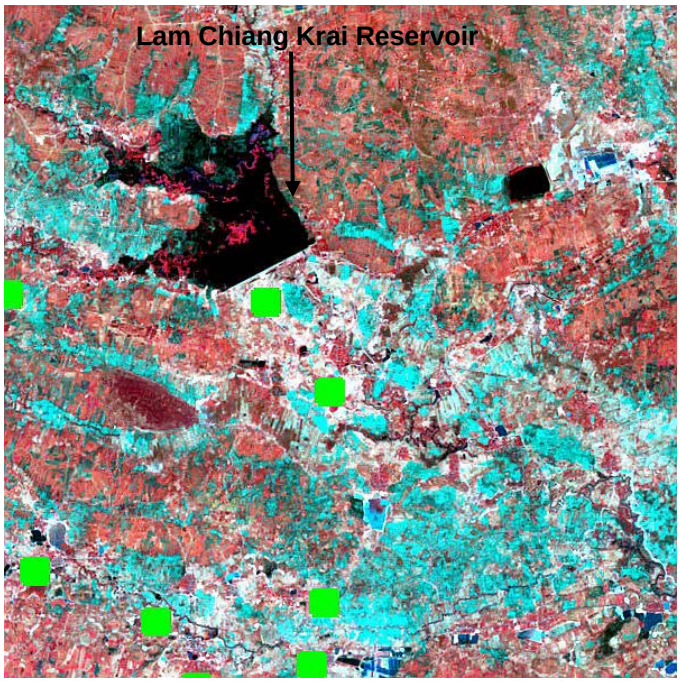

Figure 6.57 False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the reservoir salinity area at the Lam Chiang Krai Reservoir, Dan Khun Thot District located in the western part of the study area.

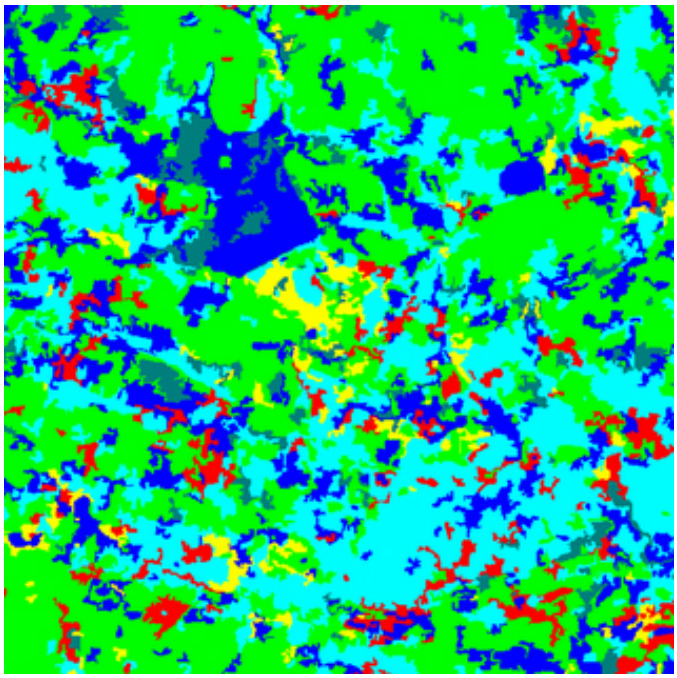

Figure 6.58 Land use classification of the salt-affected area of the reservoir salinity at the Lam Chiang Krai Reservoir, Dan Khun Thot District, located in the western part of the study area. The saline area is shown in yellow color.

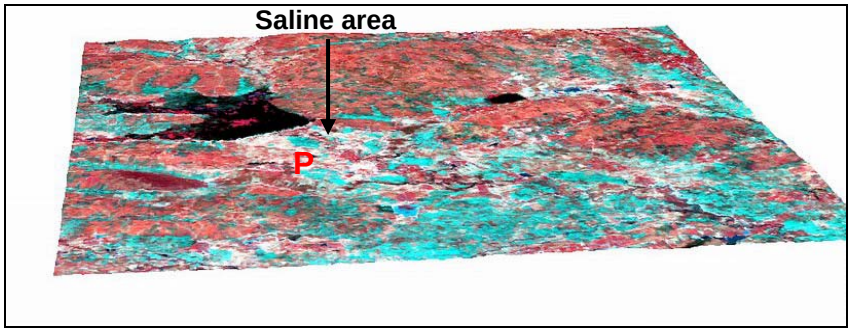

Figure 6.59 Three-dimensional surface image derived from the False Color Composite of Landsat 7 bands 4, 3, 2 as red, green, blue covering the reservoir salinity area at the Lam Chiang Krai Reservoir, Dan Khun Thot District, located in the western part of the study area.

Figure 6.60 Photograph showing the salt-affected area around the reservoir area at Dan Khun Thot District (point “P” in figure 6.59), located in the western part of the study area.

Figure 6.61 Salt crust on canal pavement in an irrigated area of the Sung Nern District, Nakhon Ratchasima Province.

Figure 6.62 Salt crust in rice field irrigated by salty water in the Sung Nern District, Nakhon Ratchasima Province.