V. CONCLUSION AND RECOMMENDATION

This chapter summarizes the main findings of the present research and draws their implications on the research into the land and water interaction on lowlands. It thereby pertains to answer every formulated research objective. The developed theoretical framework, the data acquisition, and the modelling result underline each of the answers as the conclusion of the research work. After highlighting these findings, the chapter poses some directions for future research of the land and water interaction due to the human activities, generally in SEE Asia and mainly in the Siak river basin, Sumatra.

The research focuses on investigating the relation of phenomena that cause the hazards, such as lowland conditions, land conversion, land subsidence, sea level rise, and tide propagation. It starts with exploring each phenomenon separately to identify direct and indirect related factors that cause the phenomenon, to begin with. Then, the research investigates the collection of these related factors for constructing a general idea to pinpoint the most dominant related factors that induce the hazard in the Siak river basin, which can raise the possibility of a higher-order integrative meta-analysis of the relation of phenomena that cause the hazard in lowland areas.

These following descriptions answer the objectives of this research:

1. To understand the changing and occurring on Siak river basin in Riau province, Sumatra peatland forest which is located in lowland areas.

Theories have defined the primary cause of the flood as the combination of high intensity and duration of the rainfall and climate change (that induces even higher intensity of annual rainfall). The combination leads to a rising sea level. However, the present research finds that land subsidence is also one of the main factors that exacerbate water inundation in Siak river basin. As evidence, the water surface elevation data shows that the water inundation elevation level with respect to the sea level is descending each year. Logically, this fact also reduces the risk of flooding. Nevertheless, the findings show that the floodwater level with respect to the land surface level is ascending each year. For example, in 1988 the water surface elevation level was 4.4 meters and in 2004 was 3.3 meters, although in 1988 any flood risk was unknown. Annual flood hazards began since 2002 with 3.5 meters of the water surface elevation level, and the worst was in March 2008 with 2.1 meters (March) of-, 1.8 meters (September) of- and 1.76 meters (November) of the water surface elevation level.

The analysis of the interview results shows that 86% of the participants stated that floods were due to the combination of heavy rainfall and tide at the same period of time, 10% were the only tide, and 4% were only heavy rainfall. As most floods were not flash floods, 98% of the participants mentioned that they could expect the incoming floods. However, 76% of these participants did not do any necessary preparation for facing the floods. The decision might be because they had to face the floods more than once each year, i.e., 1-2 times per year (84% of the participants), 3-5 times per year (13%), and 5 times per year (3%). According to 37% of the participants, the duration of the floods were usually more than 7 days, while for 57% of the participants were 4-7 days and the rest of the participants were less than 3 days. Nevertheless, 60% of these participants decided to stay rather than move to safer places. Furthermore, most of the participants (93%) used groundwater for their daily necessities. This last finding could influence to subsiding landmasses in the area.

The present research finds that the local government has implemented some control measurement techniques around the most affected areas, such as dikes, water gates, water pumps, flood canals, and riverbank flood protections, and has updated the city drainage system. However, the efforts seem to give low impact on reducing the flood risks. In some areas, the floods are more severe as can be seen from the level, the area coverage, and the duration of the inundation. One of the reasons is the land use change.

The satellite maps show that nearly 60% of the Riau lowlands were mostly covered by tropical peatland forests in 1990. However, in 2008 during the worst flood event, the forests covered only 10% of the areas, while nearly 40% of the areas were already oil palm plantation field and about 30% were agricultures. Moreover, the maps also show that Riau has a broad distribution of peatland areas with about 4 meters' depth of peat soil. The unique characteristic yields serious flood control management. This research finding shows that besides heavy rainfall and tide, such a surface of the land characteristic and a soil surface characteristic should be taken into consideration as the essential cause of flooding along the Siak river basin.

Based on the type of- and the cause of the circumstances along Siak river basin, from this research point of view, the analysis result shows that 70% of the land subsidence and flooding were a man-made activity, which is majority due to the widely land use conversion to the agriculture practices included palm plantation, and other supporting land uses such as urban developments and industries.

2. To identify the land and water characteristics from the upstream, middle stream to the downstream area of Siak river basin, through observation and analytical process.

The SRTM 57 12 from grid 90 m, 30 m from USGS and 5 m data from DEMNAS has produced information about the detail characteristics of Siak river basin. The combination of data from SRTM and Rainfall Measurement has been developed into a GIS-based hydrological model. The model generates a flood model by estimating the stream flow rate from the pattern of rainfall. Furthermore, Arc Hydro has been used to extract the SRTM data into information about DEM, flow direction, fill the sink, flow accumulation (i.e., stream order, stream link, and streamline), snap pour, and watershed delineation. By using the D8 model, the identification of the flow direction of river basin has been made by following the water flow based on the form of their surface. The ArcGIS simulation result shows that the waterline flows and accumulates 160 kilometres upstream from the sea. By comparing the identified inundation on the simulation with the real-life evidence, it is found that the area that is always inundated despite structure protection measures have been implemented, is Pekanbaru (the capital city of the province Riau in Sumatra). This city is situated 160 kilometres from the sea.

The combination of field measurement data has been used for rainfall-runoff modelling. As the most affected area is situated 160 kilometres from marine estuaries and is affected by tide, information about tide is necessary. However, since the present research does not have such information, the model does not consider the tidal dynamics. Instead, the rainfall-runoff model is based on two locations of a sub-basin, such as upstream (where a river is affected by tidal fluctuations) and downstream (where a river is not affected by any tidal fluctuation). It is found that rainfall is the critical factor of discharge flow in the upstream location; while in the downstream location, the tidal fluctuation is the critical factor. The two locations are indeed correlated with the conversion of a large area of tropical peatland forest areas into agriculture fields.

3. To develop and establish Adaptive modelling using the Empirical method and Spatial approach.

To strengthen the evidence supporting the hypothesis about the correlation between land subsiding and the high occurrence of floods in Siak river basin, besides the GIS-based hydrological modelling through the spatial analysis and D8 model, the research has collected measurement data of ground level, groundwater level, and soil temperature for a year during both dry and wet session in for different locations with distinctive peat soil characteristics. Based on the data taken, an adaptive land subsidence model has been developed. The model takes the assumption that water component and peat soil are integrated into a volume, and both of them will react to evaporation and oxidation due to year-round temperature change.

Using an analogy of water reservoir for the integration of water and peat soils, the adaptive land subsidence model applies the linear reservoir concept adopted from the field of hydrology for calculating the capacity rate of peat soils in the wetland. In this case, the peat soils act as a vast water reservoir. The concept follows the water balance concept for assessing the current status and trends in water resource availability in a reservoir over a specific period of time. To illustrate this concept, consider a reservoir with the water inflow (input) for this reservoir is precipitation and the water outflow (output) is evaporation outflow, any exploitation of water resource from the reservoir will change in the water volume in the reservoir. The model applies a similar approach to wetlands, where the inflow is rainfall and stream flow, and the outflow is evaporation, groundwater extraction, and oxidation. The evaporation and the groundwater extraction are factors that cause the initial groundwater level reduction, while the oxidation causes the subsidence of peat soils. In this case, the peat soils characterized for the deep thickness and sub ordo by *Hermist, Fibrist and Saprist.*

In order to see the correlation between the groundwater level reduction and the temperature, the present research has compared and analysed the model using two conditions: (a) evaporation and oxidation are treated as one parameter and (b) evaporation and oxidation are two separate parameters. The results show that the lower groundwater level and the higher temperature will create a higher annual amount of the subsidence rate.

Based on the empirical method, the land subsidence at the soil temperature T can be written in $S_{(T)} = (a + bD).e^{k[T_o - T]}$, where S(T) is the annual rate subsidence (cm) at the soil temperature T (ºC) and groundwater level D (cm). ΔT = To-T is taken from the difference between the highest and lowest hourly soil temperature data at 10 cm depth for a year, and the coefficient k is adjusted from Table III 2, a and b are constants. The variant of peat soils is also a critical factor that causes rapid subsidence of peat soils. The more in-depth groundwater resources from the surface discharge and the higher soil temperature will accelerate the annual rate of land subsidence. The present research projects the annual rate of land subsidence in lowlands, which will be 12.5 cm per year. The proposed adaptive land subsidence model can be applied in all areas by entering the relevant variables, namely: (a) the lowest and the highest temperature values in a year, (b) the soil sample, and (c) the soil characteristic, i.e., the chemical reaction of peat. Based on the simulation result of the model, to avoid the rapid acceleration of land subsidence, it is recommended to maintain the groundwater level about 20 cm deep from the soil surface.

4. To Predict the long-term impact as consequences of the tropical peatland forest conversion into the agriculture practices; in certain points and spatially on land and water interaction.

To analyse land-water interaction in the lowland areas the following information has been taken into account: (a) observation, identification, assessment and analysis of land practices, (b) river basin characteristics, (c) rainfall rate-to-stream flow relation, and (d) land subsidence. It is assumed that the sea level rise is 2 cm per year and is used as an additional parameter. This model has also been approached based on the water balance concept.

Flood has always been a scourge for the inhabitants of Pekanbaru city. Especially when there are a heavy-rain and long duration, certainly flood will hit some places in Pekanbaru. The analysis created based on two conditions such as before land subsidence and after land subsidence occurs, in case of the heavy rain occurs as well. Based on the topography of the Pekanbaru, the scenarios of inundated areas without land subsidence phenomena and with the land subsidence phenomena in threatened areas which are predicted around next 10 years is figured out with scenario of water level below and equal to 6 m as shown as the current condition.

From the statistical analysis, it can be found, if the water level rises up until 6 m, the areas in Pekanbaru will be inundated for nearly 10,500 hectares compared to the total areas of Pekanbaru of 63,220 hectares. The next scenario is the future prediction in case of the total land subsidence 1 m for the future 10 years' prediction. According to the statistical analysis, the extended areas will reach up to 16,511 hectares.

In facing these circumstances, the land and water management strategies need to take into consideration in order to reduce the short and long term impacts. As a consequence of forest conversion to the agriculture practices, the minimum of water level requirements is not lower than 20 cm. In this case, water management for the whole activities needs to be controlled by local stakeholder, including the government.