ASSESSING THE PHYSICAL IMPACT OF GRAVEL AND SAND EXTRACTION IN KRUENG ACEH RIVER BASIN AREA, ACEH PROVINCE, INDONESIA

DEBI MUTIA
September, 2011

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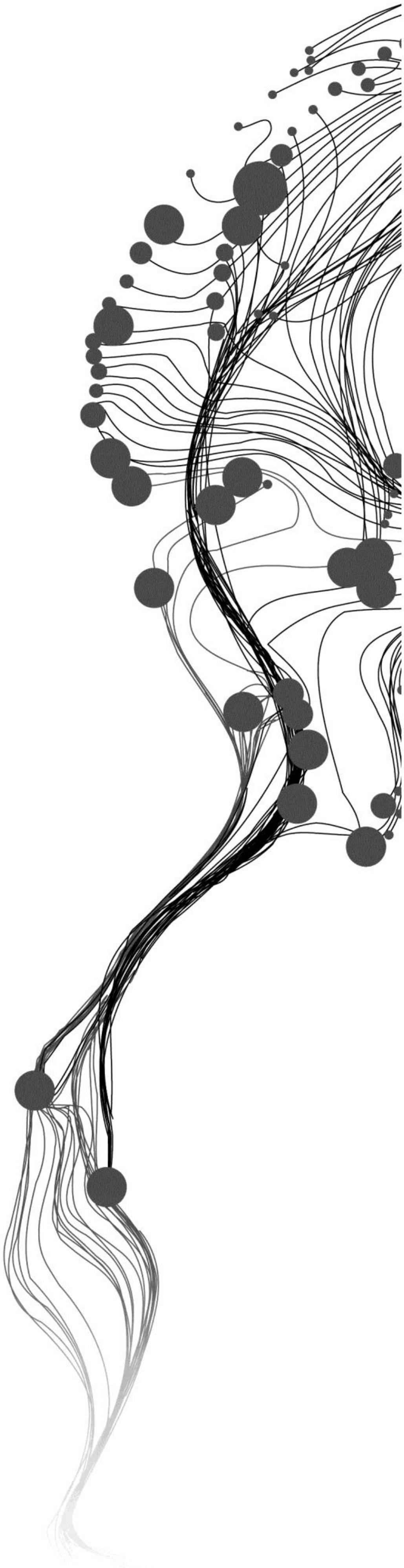

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation in Natural Resources Management Programme and for the degree of Master in Institut Teknologi Bandung in Development Planning and Infrastructure Management.

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ABSTRACT

Gravel and sand is one of the natural resources used as construction material. In the Aceh Besar Regency, Indonesia, it is mostly taken from the river bed and flood plain within Krueng Aceh river basin area. After the Tsunami of 2004, many houses, buildings and other infrastructures were damaged and needed to be reconstructed. Therefore, an increasing demand for gravel and sand occurred. The extensive exploitation of gravel and sand from the river may change or damage the physical environment. In 2006, GTZ carried out an intensive and costly survey to assess the damage of gravel and sand extraction for 32 extraction sites. In this research, the use of remote sensing and GIS is explored as a less expensive approach to assess the physical impact of gravel and sand extraction within the Krueng Aceh river basin area. The assessment was conducted for 14 extraction sites which operated from 2005 to 2009 and which were also assessed by GTZ.

This research focuses on the physical impact of change in land cover, in river morphology and damage to bridges. Therefore, indicators like bare soil expansion, distance from extraction site to road, distance from extraction site to the river, average slope within extraction area, change in river shape and distance from extraction site to bridge were selected. The overall impact of the extraction sites was assessed using multi criteria evaluation. An effect table was created based on the six above mentioned criteria and scores are assigned for 14 extraction sites. Different stakeholders were asked to assign weights to the criteria. Besides an equal vision (all criteria get the same weight), four other visions were created: Mining and Energy Office vision, Environment Office vision, GTZ vision and researcher vision. After standardisation of all the scores and the assignment of weights, an appraisal score was calculated for each extraction site, resulting in a ranking of all the extraction sites, per vision. The Appraisal scores for the 14 extractions sites were classified into three impact classes: low, moderate and high.

As result, two extraction sites (3 and 11) always showed a high physical impact for all visions and six extraction sites (2, 4, 7, 8, 10, and 14) always gave a moderate physical impact. The remaining extraction sites vary in impact for different visions. In terms of legal status, the eight illegal extraction sites never showed a high impact for all visions, but were categorized as having moderate to low physical impacts, while the six legal extraction sites are categorized as having moderate to high physical impact. Based on this result, the local government of Aceh Besar Regency needs to give more attention to monitoring and evaluating the legal extraction sites while enforcing the law at the illegal extraction sites.

Keywords: physical impact assessment, gravel and sand extraction, remote sensing, GIS analysis, multi criteria evaluation

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1. INTRODUCTION

1.1. Background

The Earth has many natural resources that contribute to supporting human life. These resources can benefit humans both directly through their daily uses and indirectly through their services (World Bank, 2000). Natural resources can be defined as a part of environment which is naturally available in the earth (FAO, 1998). Water, soil, air and minerals are examples of natural resources.

Natural resources can be classified as renewable and non-renewable resources. Renewable means that they are continuously available and their quantity is less affected by human consumption, for example are water, air, climate, and soil. In contrast to renewable resources, non-renewable resources cannot be quickly replenished after they exploited because they are formed very slowly over a long period, such as minerals and fossil fuels (Cohen, 2007). Renewable and non-renewable resources sometimes are difficult to distinguish due to time needed to replenish them (Korhonen, 2001). Gravel and sand along the river, for example, cannot be replaced as quickly as river water and other renewable resources when exploited by humans. Gravel and sand need some time to be replenished in the river. Yet the time they need is not as long as for fossil fuels and minerals (non-renewable resources).

Gravel and sand, which is widely used as construction material, are located in different landscapes (Langer, 2003). Glacial and alluvial deposits, streams, floodplains and channels are places where gravel and sand are usually found. They consist of loose materials in different shapes and usually come from sediment rock, andecite, dacite and granodiorite that obsolete and are then transported from their original location into the river (Sudrajat, 1999).

Sand and gravel are used as main construction aggregate for roads and highways (base material and asphalt), pipelines (bedding), septic systems (drain rock), and concrete for buildings (Kondolf, 1997). Gravel and sand from the river is highly preferred because of its high quality. There is no complex purification needed, unlike gravel and sand from hills in the same river system. More over, its rounded shape also makes gravel and sand from the river preferred as construction material (Goldman, 1968 in Bull et al., 1974).

In many countries, including Indonesia, companies or people who have a legal extraction permit from the government must pay retribution to the local government and become one of the sources for local revenue. The amount of retribution to be paid depends on the amount of gravel and sand produced. Another positive impact is that gravel and sand extraction needs some employees which are usually local people. It will help local government to provide more job opportunities and reduce the number of unemployment. Extraction of sand and gravel therefore supports the regional development in general.

Beside its benefit to human life and regional development, mining also has negative impacts. In-stream extraction of gravel and sand can reduce water quality and can destabilize the stream bed and banks, causing a decrease in aquatic species. In addition, gravel and sand extraction will alter the habitat condition that existed before. This alteration can cause major habitat disruption that favors some species over others, but causes overall decline in biological diversity and productivity (Benke, 1990 in Roell, 1999). Another impact is that it can generate channel incision, the coarsening of riverbeds and channel instability (Kondolf, 1994). Other extreme effects produced by gravel and sand extraction include visual impacts and impacts on heritage sites and wildlife (Willis et al., 1999).

From an economic aspect, in the United States, for example, gravel and sand mining in the Missouri River was found to be harmful to Missouri's stream resources, public infrastructure and personal property (Roell, 1999).Destruction of farmland when extraction removes the fertile soil beneath gravel and sand is also another negative economic impact (Jaeger, 2006).From a social aspect, gravel and sand extraction creates land use conflict in populated areas because it causes noise, dust, truck traffic, pollution and visually unpleasant landscape, as it is found in Oregon, United States (Jaeger, 2006).

In Indonesia, according to Government of Indonesia's (GoI) Regulation number 27 in 1980, gravel and sand is classified as non-vital material mining (Type C) together with nitrate, phosphor, grit, and pumice mining. Other classes are strategic mining material like oil, gas, coal, asphalt and nickel (Type A) and vital mining material like gold, iron, copper, and silver (Type B). Each type has its own method, complexity and scale of exploitation. In many areas, gravel and sand is exploited by making pits in river floodplains, or by in-channel or in-stream mining. Heavy equipment is used to directly grab gravel and sand from the river bed (Kondolf, 1997). There are some other way to extract gravel and sand from the river, namely channel dredging, channel diversion, and mining from ephemeral channel. The type of exploitation depends on preference of the mining operator and the condition of deposit of gravel and sand (Langer, 2003).

In Aceh Besar Regency, gravel and sand comes from two different locations, which are the hilly area and the river basin area (along the river). The utilization of these natural resources is managed by the local government of Aceh Besar Regency, according to the Provincial Regulation of Nanggroe Aceh Darussalam (NAD) number 12/2002. The management includes giving license to company or people who want to extract gravel and sand. As compensation, the license holder should pay retribution to the local government and it becomes the revenue of the local government (Local Regulation of Aceh Besar Regency number 19/2003). Up to 2004, the utilization of gravel and sand could be managed well by the local government. There was no illegal extraction and the annual target of revenue from gravel and sand retribution was achieved (Aceh Besar Regency, 2006). In 2005 the condition changed due to the Tsunami and major earthquake which happened at the end of 2004.

The tsunami on 26 December 2004 was the trigger to increase gravel and sand mining in Aceh Besar Regency,. The tsunami damaged infrastructures and many houses. For example, more than 180,000 houses, 2,100 schools and 3000 kilometres of road were damaged (AIPRD, 2006). The rehabilitation and reconstruction process was immediately arranged by the Government of Indonesia by establishing a Rehabilitation and Reconstruction Agency for NAD and Nias Island. While rehabilitation focused more on the improvement of social and economic condition, reconstruction includes particularly the renovation and new construction of building and infrastructure. Automatically, a large amount of construction material was needed. Gravel and sand, as mentioned before, is one of the important construction materials to establish building and infrastructures. Moreover, gravel and sand from river is particularly desirable source of aggregate because weak materials are eliminated by abrasion and attrition, leaving durable, rounded, well-sorted gravels (Barksdale, 1991 in Kondolf, 1997).

The location of Aceh Besar Regency, which directly borders to Banda Aceh City and Aceh Barat Regency, is also another reason why the need of gravel and sand is high. Banda Aceh and Aceh Barat are the two most damaged area because of tsunami. The closer the location of a resource, the less transportation cost will be needed (Kondolf, 1994). After the Tsunami, the population increased for which also extra construction material is needed to build houses and infrastructures. In addition to this, also income per capita and the cheap price of gravel and mining play a role. It is supported by the assumption that that the higher number of population, the higher income percapita and the cheaper price of aggregate will leads to higher demand for aggregate (Jaeger, 2006).

Based on these reasons, gravel and sand extraction, both legal and illegal, along Krueng Aceh River increased and with them the negative impacts increased.

1.2. Research Problem and Justification

Since gravel and sand mining activity occurs intensively due to the high demand, there are also changes in the existing environment. The River adjusted its morphology and behaviour because by removing sediment from the channel, in-stream gravel mining disrupts the pre-existing balance between sediment supply and transporting capacity, typically inducing incision upstream and downstream of the extraction site (Kondolf, 1997). Not only morphology and behaviour of the river change, but also the quality of water in the river. In addition, extraction activities need some land because they will need road (to transport the gravel and sand), an open space as temporary place to collect the gravel and sand, and a place to establish stone crusher or asphalt mixing plant as the following business. These will change the existing land cover. Vegetation like crop and paddy field are the common land cover types found along Krueng Aceh River.

Krueng Aceh River is the primary source of clean water for Banda Aceh and Aceh Besar Regency. Sand and gravel extraction in the river adversely affect the overall quality of the water. In the downstream area, the total suspended solids and turbidity of the water increased markedly exceeding standards (ESP-USAID, 2007). As the land cover change from vegetation to bare land, the ability of soil to absorb water and support the river bank decreased. Erosion of river bank currently happens and it leads to widening and shifting shape of the river. In the rainy season, when there is a high rainfall for quite a long time, the river cannot properly transport the water downstream.

In areas where the river bank is susceptible to erosion, local flooding can happen. On December 14, 2007, for example, flooding occurred in the downstream area of Krueng Aceh River. It was followed by damage of the bridge in Lamsie Village, Aceh Besar Regency. The damage to the bridge is also one of impacts of gravel and sand extraction. Provincial and local government has responded to overcome these impacts of gravel and sand mining along the Krueng Aceh River. In 2007, Governor of NAD Province issued a decree to establish monitoring and supervision team to control the sand and mining activity along Krueng Aceh River. The team consists of many stake holders from both provincial and local levels. Yet this decree is not optimally implemented in the field, because of many reasons, such as lack of law enforcement, lack of coordination between stakeholders, and lack of people awareness about the impact of gravel and sand extraction.

In 2006, GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit/German Agency for Technical Cooperation) conducted a research which assessed the environmental damage due to gravel and sand extraction in Krueng Aceh river basin area based on several indicators. The indicators include mining technique, volume of extraction, depth, slope and size of quarry, characteristics of the rock, distance to river, erosion level and reclamation. Data was collected by GTZ for each extraction site. It was a high cost research. If the local government has to make decision to reduce the impact of gravel and sand extraction, the information produced by GTZ needs to be updated, but local government do not have budget for it. In this situation, the use of remote sensing and spatial data might be a cost-effective alternative to assess the impact of gravel and sand extraction within Krueng Aceh River Basin Area.

Remote sensing data covers a big area in a certain temporal resolution, which is very useful in studying the land dynamics, like land cover change, etc. Since information about a large area can be gathered quickly, the use of remote sensing data will save time, human effort and cost. Therefore, this research focused on physical impact, like land cover change, change of river morphology, and damage of hydraulic structure (bridge) using remote sensing and GIS analysis.

1.3. Research Objectives

This research aims to assess the impacts of gravel and sand extraction from 2005 to 2009 within The Krueng Aceh River Basin Area. Specific objectives are:

1. To define key indicators to assess the physical impact of sand and gravel extraction
2. To analyze the land cover changes due to gravel and sand extraction
3. To analyze change in Krueng Aceh river morphology because of gravel and sand extraction
4. To analyze the damage to hydraulic structures (bridges)
5. To assess the impact of gravel and sand extraction in Krueng Aceh River Basin Area

1.4. Research Questions

1. To define key indicators to assess the physical impact of sand and gravel extraction
   - 1.1. Which indicator used to assess impact due to gravel and sand extraction?
   - 1.2. How does each indicator affect the physical environment?

2. To analyze the land cover changes due to gravel and sand extraction in Krueng Aceh River Basin Area
   - 2.1. What is the land cover type in Krueng Aceh river basin area in 2005 and 2009?
   - 2.2. What type of land cover changes occurred between 2005 and 2009?
   - 2.3. Is there any difference in bare soil expansion between areas with extraction sites and areas without extraction sites?
   - 2.4. What is the bare soil expansion for each extraction site?
   - 2.5. What is the distance from extraction site to road?

3. To analyze change in Krueng Aceh river morphology because of gravel and sand extraction
   - 3.1. What is the distance from an extraction site to the river?
   - 3.2. What is the average slope in the extraction area?
   - 3.3. What is the change of the river shape?
   - 3.4. Does gravel and sand extraction influence the change of river shape?

4. To analyze the damage to hydraulic structures (bridges)
   - 4.1. What is the distance from extraction site to bridges?

5. To assess the impact of gravel and sand extraction in Krueng Aceh River Basin Area
   5.1. How to assign the scale of importance of each indicator (weighting system)?
   5.2. Which sites have a low, moderate, or high impact due to gravel and sand extraction?
   5.3. Is there any difference between legal and illegal extraction sites?

1.5. Conceptual Framework

This research will be conducted based on the conceptual framework below.

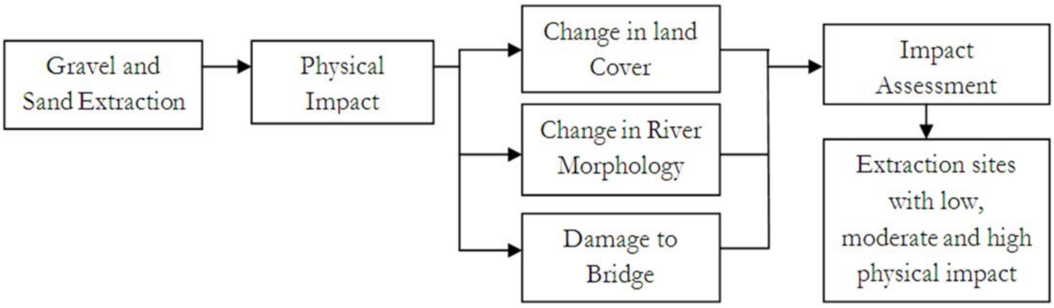


Figure 1-1 Conceptual Framework

Gravel and sand extraction from river changes the physical environment of the river several aspects. It changes the existing land cover type, the river morphology and damage to hydraulic structure like bridge. Key indicators have to be defined for each of those three components. Remote sending and GIS will be used to analyze and assess those impacts. Finally, the overall impact of gravel and sand extraction is assessed using multi criteria evaluation. The result is then examined by their legal status and compared with class of environmental damage assessed by GTZ.

1.6. Research Structure

This chapter is followed by Chapter 2 which discusses the concept and definition used in this research related to gravel and sand extraction and impact assessment. Chapter 3 provides details about the study area, the material and the method used to achieve each specific objective and to answer all research questions. Chapter 4 provides the results of research and it will be discussed further in the following chapter. The last chapter, Chapter 6 provides conclusions of the research and recommendations.

2. LITERATURE REVIEW

2.1. Gravel and Sand Extraction

Gravel and sand are important materials used in many construction activities in all over the world (Santo and Sanchez, 2011). Its availability is widely distributed and in terms of volume and value, gravel and sand becomes the most non-energy mineral resource in the world (Langer, 2003). The use of gravel and sand can be both individually and mixed with other construction materials. Individually, gravel and sand are used as base material (ballast) in highways, railways, roads, pipeline system, septic system and other similar construction. Together with asphalt and other materials, gravel and sand can be used to construct the upper layer of highways and roads, and together with cement and water, concrete and mortar which is important in construction of building, houses and other structures are formed (Kondolf, 1997).

2.1.1. Source and technique of extraction

Gravel and sand can be found in variety of natural settings, like ancient glacial deposits, alluvial deposits, ancient marine terraces, ancient and modern river and stream terraces, flood plains and channels (Langer, 2003). Mostly, gravel and sand are extracted from river flood plains and channels (Santo and Sanchez, 2001). In general, gravel, which has bigger size then sand, occurs in the middle part of the river, while sand is usually found in the lower part of the river system (Roel, 1999). Extraction techniques used to extract gravel and sand differs from one area to the other, depending on the type of river and location of deposits. In an active river channel, extraction is usually done by digging a shallow pit in the channel. Since the river transports sediments including gravel and sand continuously, the shallow pit is always refilled in a certain time. In an inactive river channel, the pits are bigger in size and more permanent. A huge amount of gravel and sand can be extracted from these pits, but it can be done only for a short period because the deposits will not be refilled (Bull and Scott, 1974). Based on the location of deposits, extraction can be done in the river channel (in-stream mining) or in the floodplain. For deposits found in the river bed or inside the river, the extraction can be done directly using traditional tools like small buckets or by using heavy equipment placed near to the river. The sand and gravel extracted can be wet or dry, depending on the elevation of the surface (Sandecki, 1989). Deposits in the floodplain can be directly extracted by removing gravel and sand using heavy equipment (Kondolf, 1997).

2.1.2. The advantages of river gravel and sand

Gravel and sand from the river system are preferred over gravel and sand from hills or mountains. It is including one of high quality material used for construction. Since gravel and sand found in the river has been transported by the river for a long distance until it reaches downstream (see Figure 2-1), unnecessary material has been eliminated. It produces well-sorted, rounded and durable gravel and sand (Barksdale, 1991). The cleanness of gravel and sand makes the impurity process to eliminate clay and calcium carbonate unimportant to be executed. Rounded shape is an advantage of gravel and sand from river when it is used as concrete aggregate (Bull and Scott, 1974). Moreover, gravel and sand from the river have already a proper size and shape to be used for construction because of the natural abrasion process in the river (Langer, 2003).

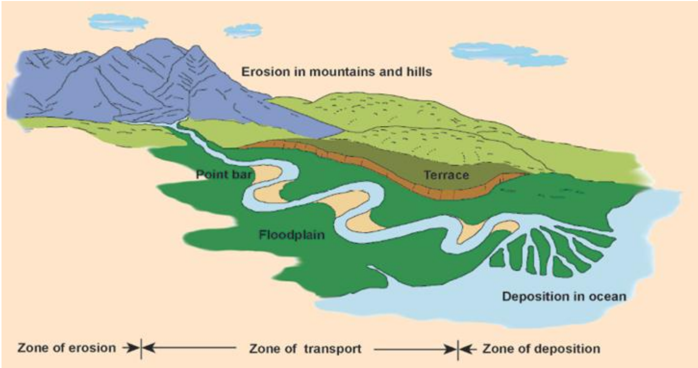


Figure 2-1 Origin, transport, and deposition of stream sediments (Kondolf, 1997)

2.2. Physical Impact of Gravel and Sand Extraction

There are several physical impacts due to gravel and sand extraction, including changes in land cover, in river shape and damage to hydraulic structures.

2.2.1. Change in Land Cover

Gravel and sand extraction from a river channel or flood plain changes the existing land cover (Kondolf, 1997). Access road to the extraction site is an important facility to be built before the extraction activity starts. It is used to utilize heavy equipments and trucks to transport gravel and sand to the market. In several cases where the extraction site is far from the main road, the access road needs to be longer. The further the distance from the extraction site to the main road, the more land is needed for road construction, especially if the extraction is done by heavy equipments. Constructing access road to extraction site means changing the existing land cover type, usually vegetations, into asphalt or bare land indicating roads.

Furthermore, extraction of gravel and sand itself needs an extraction site. In an in-stream mining system, an open space is needed as temporary place to collect the extracted gravel and sand, and a place to establish stone crusher or asphalt mixing plant as the following business. In floodplain extraction, the land needed is bigger, because land is the source of deposits that they extract directly. Both conditions will alter the existing land cover in the flood plain. In some areas where the flood plain mostly consists of forest, extensive gravel and sand extraction may results in deforestation. In Brazil, open pit and supporting extraction installations which is visually seen as bare land, is transformed from grasslands, riparian woodland or agricultural land. The encroachment of mining area indicated by open pit and bare land increases in the active extraction site (Santo and Sanchez, 2002).

In Indonesia, the level of environmental disturbance for several land cover change can be seen in Table 2-1 below. It is based on Government of Indonesia (GoI) Regulation 24/1992 and President Decree 32/1990 about protected area. The highest environmental disturbance occurs when there is change in settlement area, forests and protected forest.

Table 2-1 Environmental disturbance due to land cover change

No	Changed Land cover/Land use	Level of environmental disturbance
1	Bare land, shrub	Low disturbance
2	Paddy field, crops, discharge area	Moderate disturbance
3	Settlement, forest, protected forest	High disturbance

Source: GOI Regulation 24/1992 and President Decree 32/1990

2.2.2. Change in River Morphology

Due to gravel and sand extraction, the morphology and behaviour of river is adjusted. Removing sediments from the channel disturbs the natural balance of sediment supply and also disrupts the ability of the river in transporting water and sediments (Kondolf, 1997). In addition, it will lead to channel incision or river bed degradation. Gravel and sand extraction lowers the river bed and generates a nick point in the river bed. The nick points generally have a steeper slope than the original river bed. This steeper slope induces bigger energy in the river flow. In the rainy season when the average river flow increases, erosion of river bed has a big probability to occur. The erosion will move gradually upstream and at a bigger scale, causing river bank erosion. The movement of river bed to upstream is also widely called as head cutting (Roell, 1999). The direction of channel incision is not only going upstream (head cutting), but also downstream (down cutting). It can take place up to one or more kilometres from the extraction site (Kondolf, 1994).

Gravel and sand extraction from a river also deepens the river channel and increases the height of the river bank. River deepening increases the water holding capacity of the river. Since water flow has energy which can erode the river bank, the bigger amount of water, increasing of river flow make and higher river bank height make the river bank more vulnerable to erosion. In short it can be stated that deepening of the river channel due to gravel and sand extraction can increase erosion river bank (Bull and Scott, 1974).

River channel incision causes channel instability, both vertically and laterally. Lowering river bed and deepening river channel as mentioned above is an example of vertical channel instability. Example of lateral channel instability is channel widening (Roel, 1999) and the change of river shape or river shape modification (Sausen, 1988 in Santo and Sanchez, 2002); see Figure 2-2. Channel widening causes shallowing of the river bed, change the river flow direction (Roel, 1999), and changes in channel position (Mossa and McLean, 1997).

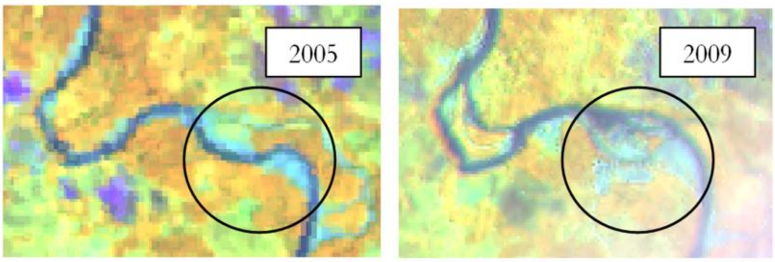


Figure 2-2 SPOT Image Showing Change in River Shape due to Gravel and Sand Extraction

In Indonesia, the government established the President Decree 23/1990 about protected area management. Particular distance from both sides of river that should be protected is assigned as 100 meter for big river and 50 meter for a small river. The purpose of the decree is to protect the river from all human activities that can disturb and reduce the river water quality, the physical condition of the riverbed and river stream, including river channel incision.

2.2.3. Damage to Hydraulic Structures

As mentioned previously, the removal of gravel and sand from a river bed causes the bed degradation or channel incision that potentially leads to lowering of the river bed. The condition becomes worse if gravel and sand is extracted in big amount and exceeds the rate of replenishment of gravel and sand in natural river basin area (Bull and Scott, 1974). Bridges and other hydraulic structures upstream and downstream of the extraction site can be scoured or undermined by channel incision. Sediments around the bridge piers can be eroded and results in undermining of the bridge (see Figure 2-3). In Kaoping River, Taiwan, for example, gravel and sand extraction threatens the existence of the Kaoping Bridge which is located 7 meter from the extraction site. The local government protected the bridge by putting gabions and massive coastal concrete jacks around the piers (Kondolf, 1997).

Figure 2-3 Erosion of River Bed at Bridge Abutment (Langer, 2003)

In Aceh Besar Regency, flooding occurred after one full day of heavy rain on December 2007. One of the bridges, the Lamsie bridge, was broken. According to the local people, besides of rainfall, gravel and sand extraction after the Tsunami of 2004 was another cause. It is based on reason that before tsunami, even if heavy rain occurred more than one day, the bridge was still in a good condition.

To reduce the impact of gravel and sand extraction on damage to bridges, the Government of Indonesia through Directorate General of Irrigation established Decree number 176/KPTS/1987 about procedure of type C Material extraction from the river. In this decree, it is stated that the extraction site should be located more than 500 meter upstream and 1000 meter downstream from a hydraulic structure. Hydraulic structures include dike, flood control structures, and bridges.

2.2.4. Study on Impact of Gravel and Sand Extraction in Krueng Aceh River Basin Area

A study about environmental damage due to gravel and sand extraction in Aceh Besar Regency has been conducted by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit/German Agency for Technical Cooperation) in 2006. In general, the study focused on two sources of gravel and sand, which are gravel and sand extraction from hilly area in the northern part of the regency, and gravel and sand extraction from the Krueng Aceh River. The study covered 15 extraction sites in the hilly area, and 32 extraction sites along the river. The level of environmental damage was assessed based on valuing on several indicators with certain scoring and weighting system. The indicators used, the scoring and weighting system are presented on Table 2-2.

Table 2-2 Indicators used in valuing the level of environmental damage due to gravel and sand extraction from the river

Indicators		Score (S)	Weight (W)
Mining technique	Right	1	0.15
	Moderate	2	
	Wrong	3	
Volume of Extraction Rate	Slow (<6 m^3 per day)	1	0.15
	Moderately fast (7-18 m^3 per day)	2	
	Fast (> 18 m^3 per day)	3	
Characteristics of rock in the pit's edge	Compact	1	0.15
	Moderate	2	
	Loose	3	
Depth of the pit	<3 meters	1	0.15
	3-6 meters	2	
	>6 meters	3	
Slope of the pit's edge	Flat (0^0-15^0)	1	0.15
	Moderately flat (16^0-40^0)	2	
	Steep (41^0-90^0)	3	
Size of pit	<1000 m^3	1	0.10
	1000 – 5000 m^3	2	
	>5000 m^3	3	
Distance to river	Safe	1	0.10
	Moderately	2	
	Hazardous	3	
Erosion level	Low	1	0.05
	Moderate	2	
	High	3	
Reclamation	Already applied	1	0.15
	Start to be applied	2	
	Not yet applied	3	
Total			1.00

Most of the indicators are relative indicators, based on expert judgement. The data were collected for each extraction site. The total score $\Sigma(Si \times Wi)$ gave an environmental damage index, ranging from 1 to 3. This index was classified into three classes: 1-1.66 (low), 1.67-2.33 (moderate) and 2.34-3 (high). 8 sites were categorized as low damage, 18 sites as moderate damage, and 6 sites as high damage. Specifically in 14 extraction sites studied in this research, 5 extraction sites (site 5, 6, 7, 13, and 14) are categorized as high environmental damage and 9 extraction sites (site 1, 2, 3, 4, 8, 9, 10, 11, and 12) are categorized as moderate environmental damage.

2.3. Multi Criteria Evaluation

2.3.1. Definition

In decision making process, decision maker and other stakeholder of ten has difficulties in handling number of option or alternatives to be selected. Multi Criteria Evaluation provides several methods and analysis which can deal with condition where alternatives should be selected based on several competing criteria (Department for Communities and Local Government of UK, 2009). MCE not only results in a single best option or alternative, but also can be applied to make a short list of alternatives for certain purposes or to put a set of alternatives in an order (rank) that can be classified in the end. MCE becomes an interesting tool because it can accommodate both quantitative and qualitative data. Nowadays, MCE has been broadly used in many field of study, such as regional planning, agriculture, land and water resources management, and environment assessment. In Environmental Impact Assessment, for example, MCE is used to select number of alternatives to limit the scope of assessment and then evaluate the selected alternatives (Janssen, 2001).

In this case, MCE used to assess the overall impact of 14 extraction sites based on a number of physical criteria and taking into account different stakeholder perception. The process of MCE includes the creation of an affect table, standardization, assigning weights based on decision actors, examine each alternative from different perspectives and analyse the robustness of the ranking with uncertainty and sensitivity analysis (Beinat, E. and Nijkamp, P., 1998).

2.3.2. Steps in MCE

The first step in MCE is identifying the problem from which a decision needs to be made. Basically, the problem is structured in to a two dimensional matrix or table which consists of alternatives to be compared and criteria used to assess the alternatives. A score is given for each criterion per alternative (Rana, 2004). The score for each criterion is given for each criterion can be in a different unit of measurement, so that standardization needs to be carried out. After all the scores are standardized, they have the same range of values, for example, 0 to 1.

The next step is assigning weights and computing the ranking of the alternatives. Weighting shows the relative importance of the criteria to the decision. The most important criteria will have the highest weight, while the least important ones the lowest weight (Department for Communities and Local Government of UK, 2009). Decision makers' or any other stakeholder's perspectives are widely used in assigning weights, since every stakeholder has their own perception on the scale of importance of one criterion. It will result in a different ranking of the alternatives. Based on the score and assigned weight for each criterion, aggregation of alternatives can be generated, resulting in a ranking of the alternatives. One of the methods used in aggregation the alternatives is weighted summation. In weighted summation, the scores for each criterion based on weight are accumulated. Therefore, a low performance of one criterion can be compensated by a high performance of another criterion (Rana, 2004). The ranking of the alternatives shows priority of alternatives considered in the decision making process. Before it is used to make a decision, it is better to examine the robustness of the rank to deal with uncertainty and rank reversal. The examination is called sensitivity analysis. There are two types of uncertainty considered in this analysis: uncertainty in score and uncertainty in weight. Certain number to show uncertainty is assigned and re-aggregation is carried out. When the resulted rank does not change, decision makers and other stake holders have a strong supporting explanation to decide the prioritized alternative(s).

2.3.3. Strengths and weakness

MCE has many advantages in supporting the decision making process. It has the ability to accommodate complex problem with many criteria that comes from different stake holders and decision makers in various scientific fields (Raaijmakers et. al, 2007). From the start of MCE process, various perspectives from different stakeholders can be involved, in defining the problem, selecting the relevant criteris, and in assigning weight to the different criteria. Unlike another method like Cost Benefit Analysis where criteria used should be measured in monetary units (Tiwari et al, 1999), MCE can be applied for criteria measured in non-monetary units and qualitative data. Moreover, its structured and transparent analysis generates an objective and reliable decision. It makes this method easy to be adapted in various field of studies (Bonte et al, 1997 in Janssen, 2001).

Beside its strengths, there are also some weaknesses of MCE. Even though MCA can accommodate multiple criteria, it is better to select only criteria which are appropriate and significant enough so that stke holder can understand the criteria accurately. Selection of many irrelevant criteria will confuse the stake holder and potentially lead to a wrong decision. In assigning weight by stakeholder, manipulation that will lead to a false sense of objectivity is easy to be accomplished (Janssen, 2001). In reality, it is rather difficult to create a credible and justifiable weight (Yeh et. al, 1999).

3. STUDY AREA , MATERIALS AND METHODS

3.1. Study Area

Krueng Aceh River Basin Area covers an area of about 1,760 km^2, with the main river length of 138 km, consisting of Krueng Inong River (75 km) and Krueng Aceh River (63 km). This is the biggest river basin area in Nanggroe Aceh Darussalam (NAD) province. It consists of ten sub-river basin areas, (see Table 3-1 namely Krueng Inong, Krueng Agam, Krueng Keumireu, Alue Lhok II-Lamkabeu, Alue Bithak, Krueng Lebuee, Krueng Jreue, Krueng Lingka, Banda Aceh Left and Banda Aceh Right (Sea Defence Consultant/SDC, 2009).

Table 3-1 Krueng Aceh Sub River Basin Area

No	Sub River Basin Area	Size (Km^2)
1	Krueng Inong	412
2	Krueng Agam	244
3	Krueng Keumireu	270
4	Lhok II-Lamkabeu	86
5	Alue Bithak	29
6	Krueng Lebuen-Penganpet	127
7	Krueng Jreue	233
8	Krueng Lingka	71
9	Banda Aceh Left	234
10	Banda Aceh Right	56

Source: SDC, 2009

Administratively, it is located in the two districts of NAD province, which is Banda Aceh Municipality and Aceh Besar Regency. As is shown in Figure 3-1, only a small area of the Krueng Aceh River basin Area belongs to Banda Aceh Municipality (northern part of the river basin area). The deposits of gravel and sand are found in Aceh Besar Regency, so that the gravel and sand extraction within this area is managed by the Aceh Besar Regency through the Mining and Energy Office.

Geographically, Aceh Besar Regency is located between 5.2^0-5.8^0 north latitude and 95.0^0-95.8^0 east longitude, with Malacca Strait and Banda Aceh City in the North, Aceh Jaya Regency in the South, Pidie Regency in the East, and Indonesia Ocean in the West. The regency covers 297,412 hectares, which is mostly land and some small islands. Aceh Besar Regency has also 195 kilometers coastline to the West and East. The regency is divided into 23 sub districts covering 68 mukims (small villages), 615 villages, with Jantho as the capital city. In mid of 2004 the total population reached the number of 320,553 persons (www.acehbesarkab.go.id).

Aceh Besar Regency has a tropical climate with temperature between 25^{0}and 28^{0}C.There are two seasons, which are dry and rainy season. Dry season commonly occurs between March and August, while rainy season mostly occurs from September to February. Krueng Aceh River is located in the middle of Aceh Besar Regency, streaming from south east (upstream) to north east (downstream). The slope of flood plain area is ranging from 0^0 to 10^0, and is surrounded by hills (slope 10^0- 25^0) and mountains (slope more than 25^0) in the North, East, and South. In general, the land use in Aceh Besar Regency is dominated by forest (34%), bare land (18.66%) and plantations (16.67%). The remaining land cover types are agriculture (12.31%), shrub (9.49%), urban area (6.73%), fish ponds (1.16%) and other land use (0.08%) (www.acehbesarkab.go.id)

Aceh Besar Regency possesses type-C and type-B mining materials, spreading over several sub districts. There are 17 kinds of Type-C mining materials available in Aceh Besar, including limestone which is potential to develop in Lhoknga, Leupung and Peukan Bada sub districts, as well as sand which is potential to develop in the Krueng Aceh River Basins, covering the area of Seulimeum, Kuta Cot Glie, Indrapuri, Kuta Malaka, Sukamakmur, Montasik and Ingin Jaya sub districts. In addition, many other type-

C mining materials such as trass are available in Mesjid Raya, Montasik and Seulimeum sub districts, and phosphate in Lhoong, Lhoknga, Sukamakmur and Pulo Aceh sub districts. The strategic group-B mining materials are spread over Aceh Besar, including cooper, gold, iron in Lhoong District, gold deposits in Pulo Aceh, and sand deposits in Seulimeum and Mesjid Raya sub districts along the east coastline. (www.acehinvestment.com, 2009).

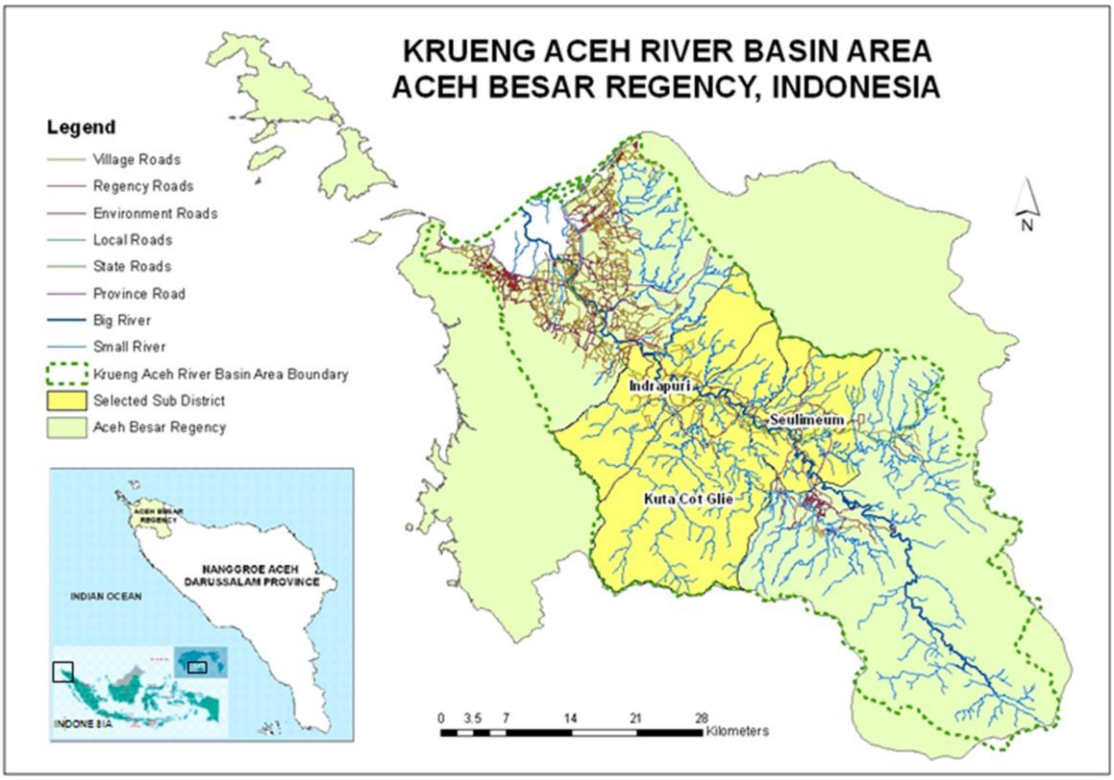


Figure 3-1 Study Area

Table 3-2 Gravel and Sand Deposit in Aceh Besar Regency

No	Sub District Name	Deposits (ton)	Area (ha)
1	Seulimum	1,288,350	155.0
2	Indrapuri	2,736,570	71.7
3	Kota Cot Glie	1,638,932	90.3
4	Montasik	646,000	13.6
5	Mesjid Raya	2,723,900	33.0
6	Lhoknga-Leupung	712,500	25.0
7	Lhoong	2,493,750	87.5
	Total	**12,240,002**	**476**

Different with Type-A and Type-B mining material, Type-C mining material is managed by the local government of Aceh Besar Regency. It means that the license or permit to do extraction comes from the head of local government (Bupati) with recommendation of the Mining and Energy Office of Aceh Besar Regency. After 2009, through Bupati Aceh Besar Regulation number 12/2007, the government established an Integrated Service Office (Kantor Pelayanan Terpadu Satu Pintu) to handle the license in related with utilization of local resources, including gravel and sand extraction. The license application is submitted directly to the Integrated Service Office, and an integrated team consisting of officer from the Mining and Energy Office, the Environment Office and the Irrigation office, do the field survey to the proposed area and give the technical recommendation whether a license can be given or not. If the recommendation is positive, the Integrated Service

Office with agreement of the head of regency (Bupati), will issue the license for gravel and sand extraction. The deposits of gravel and sand are located in 7 sub districts in Aceh Besar Regency; see Table 3-2. This research focuses on three sub districts, namely Seulimuem, Kota Cot Glie and Indrapuri sub districts.

3.2. Data Description

In order to assess the environmental impact of gravel and sand extraction in Krueng Aceh River basin Area, data used are classified into remote sensing data, spatial data and non-spatial data (Table. 3-3).

Table 3-3 Data Source

Type of data	No	Data	Year/ Month	Format/ scale	Source
Spatial Data	1	Extraction sites and volume of extraction	2006	.shp	GTZ
	2	Extraction sites and license status	2005, 2007, 2009	.shp	Mining and Energy Office of Aceh Besar
	3	River map	2005 and 2009	.shp	Aceh Besar GIS Centre
	4	Road map	2006	.shp	Aceh Besar GIS Centre
	5	Topographic Map of NAD Province	1978	1 : 50.000	National Survey and Mapping Agency of Indonesia
Remote Sensing Data	1	SPOT5 Image	2005/August	.img	Aceh Besar GIS Centre
	2	SPOT5 Image	2009/March	.img	Aceh Besar GIS Centre
	3	ASTER GDEM	2005/May	.img	*www.gdem.aster.ersdac.or.jp*
	4	Google Earth Image	2005 and 2010	.jpeg	*www.earth.google.com*

3.2.1. Spatial Data

3.2.1.1. Extraction sites and volume of extraction

Gravel and sand extraction site, including 14 locations (points) and the volume of gravel and sand extracted for each site (m^3/day). This data is taken from GTZ, from the report of project done in Aceh Besar Regency in May-September of 2006 (Hendratno, 2006).

3.2.1.2. Extraction sites and license status

Extraction data for 14 extraction sites also comes from Mining and Energy Office of Aceh Besar Regency in 2005, 2007 and 2009. This data includes the name of owner and legacy status for each extraction site.

3.2.1.3. River map

River maps of 2005 and 2009 were produced by GIS Centre office of Aceh Besar Regency. Both data were digitized from the image of 2005 and 2009, taking in the middle of river. They were checked in the field, but there is no information is available about the accuracy assessment. The river linesinthe two different years are selected in order to see the change of river shape after tsunami of 2004.

3.2.1.4. Road map

A road map was produced by GIS centre of Aceh Besar Regency in 2006. The road maps consist of several road types, which are village road, regency road, local road, provincial road and state road.

3.2.1.5. Topographic Map

The topographic map of Nanggroe Aceh Darussalam Province produced in 1978 by the National Agency of Survey and Mapping was used. The scale of the map was 1:50.000. This map was used as reference map for all remote sensing and spatial data.

3.2.2. Remote Sensing Data

3.2.2.1. SPOT Image of 2005 and 2009

The SPOT5 (Système Probatoire d'Observation de la Terre) image comes from two different years, 2005 and 2009 and different pixel size (10 m x 10 m and 2.5 m x 2.5 m). The two different years are selected to analyse the land cover change (bare soil) after the Tsunami of 2004. The assumption is that the bare soil (land cover type that indicates gravel and sand extraction site) in 2005 is smaller than it is in 2009.

3.2.2.2. ASTER GDEM Image

The ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer – Global Digital Elevation Model) image of 2005 was downloaded from*www.gdem.aster.ersdac.or.jp*. It provides the elevation (height) in 30 x 30 meter spatial resolution.

3.2.2.3. Google Earth Image

The Google Earth image was downloaded from *www.earth.google.com* using Stitch Maps software. The image was taken on May 19, 2005 and April 14, 2010. It is one of high resolution image, so that in this research, it was used to interpret land cover type derived from SPOT image. SPOT image of 2005 was interpreted by using Google Earth image taken on May 19, 2005 and SPOT image of 2009 was interpreted by using Google earth image taken on April 14, 2010.

3.2.3. Software

Several softwares used in this research:

- ERDAS IMAGINE ver. 2010.1 for image processing and ArcGIS ver. 10 for GIS analysis
- ILWIS ver. 3.7.1 for generating slope map based on ASTER DEM image
- R ver. 2.12 for statistical analysis on change of river shape
- DEFINITE ver. 3.1 for executing the multi criteria evaluation
- Microsoft Excel, Microsoft Visio and Microsoft Word for simple calculation and thesis writing.

3.3. Method description

This research was conducted through several steps, aiming to assess the physical impacts of gravel and sand extraction in Krueng Aceh River Basin Area. The physical impacts examined are change in land cover, change in river morphology and damage of hydraulic buildings (bridges). Extraction site selection was done before the assessment of each indicator was executed. The general flowchart is shown in Figure 3-2. The following sections describe the detailed method in selecting the extraction data, determining changes in land cover, change in river morphology, damage to bridge, and multi criteria analysis to assess the overall physical impacts of gravel and sand extraction.

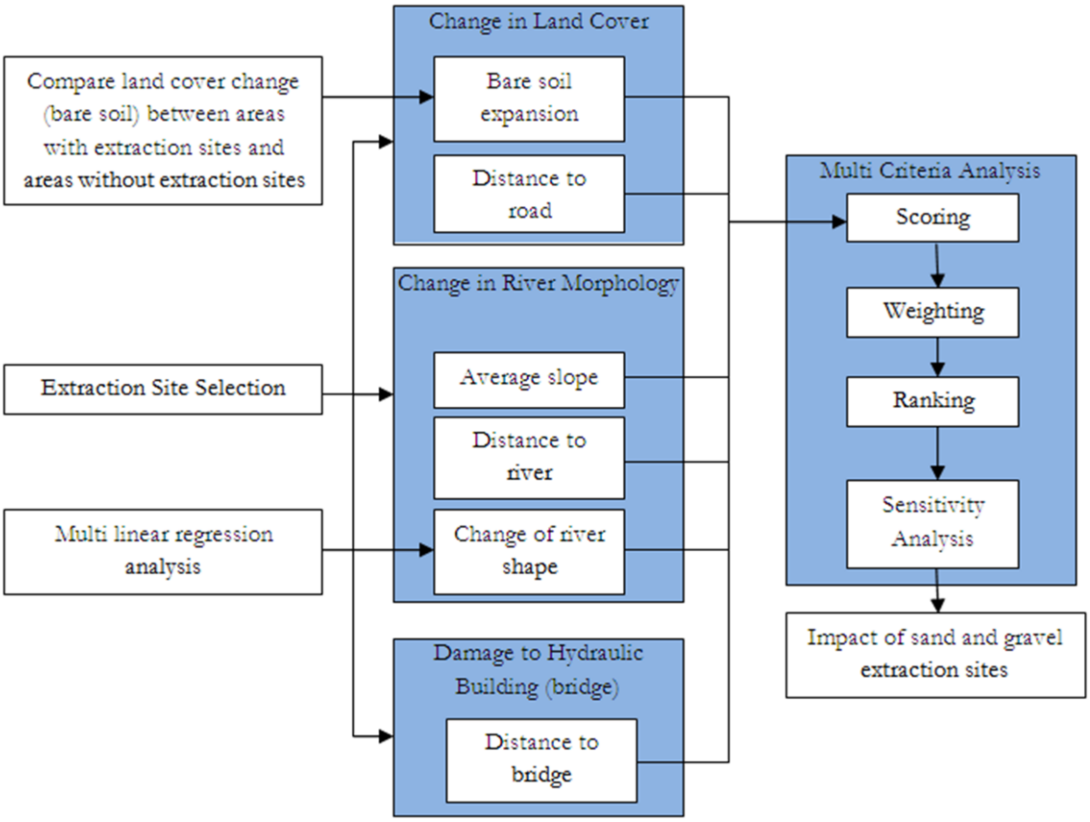


Figure 3-2 Flowchart of method

3.3.1. Extraction Site Selection

The purpose of extraction data selection is to limit the study area to specific extraction sites that operated from 2005 to 2009 and have information on volume of extraction and legacy status. This period of operation between 2005 and 2009 was chosen because this research is aimed to assess the impact after the Tsunami of 2004.

The data from GTZ and the Mining and Energy Office of Aceh Besar gave different information. GTZ provide the volume of extraction without legacy status, while Mining and Energy Office gives information about the legacy status. The GTZ extraction sites (points) were compared with the Mining and Energy Office extraction sites in ArcGIS. Common sites, 14 in total, were selected for the assessment in this research. These 14 sites are distributed over 3 sub districts (Indrapuri, Seulimuem and Kota Cot Glie Sub District).

To determine the extraction areas, SPOT imagery of 2009 was used. Each extraction area was digitized and using Feature to Points analysis in ArcGIS, new extraction sites (points) were generated. The information from GTZ and the Mining and Energy Office was added to extraction site map (points) as attribute data. These extraction sites data was used to assess physical impacts of gravel and sand extraction in this research.

3.3.2. Change in Land Cover

In assessing the impact of gravel and sand extraction on changes in land cover, two criteria were used: bare soil expansion and distance to roads. Each criterion will be explained in the following sub section.

3.3.2.1. Bare Soil Expansion

The change of a specific land cover type, like forest, crop, paddy field or shrub, into bare soil can indicate the existing of an extraction activity. Yet, there is also possibility that the changes were due to other activities, for example land clearing for building construction. Therefore, the land cover change in area where there is extraction activity was compare to area where there is no extraction activity. Since extraction takes place on one side of the river bed, the comparison in this case was the comparison of two riverside areas (north and south).If the change of any land cover type to bare soil (bare soil expansion) is higher in areas with an extraction activity, bare soil expansion can be used as a criterion to assess the physical impact of gravel and sand extraction.

For this assessment, two spatial buffer zones were generated: 100 meter and 250 meter from river line. A 100 meter was selected based on the government regulation which stated that the buffer zone of a big river like Krueng Aceh River is 100 meter (President Decree 23/1990). The area within 100 meter from river line to both left and right side should be free from human activity that can potentially disturbed the river system, including gravel and sand extraction. A 250 meter was selected based on the size of extraction site. The 250 meter buffer zone area covers the biggest extraction area.

This analysis included several steps, which are data preparation, land cover classification, accuracy assessment and bare soil expansion comparison.

3.3.2.1.1. Data Preparation

Satellite images used in this research were SPOT imagery of 2005 and 2009 for Aceh Besar Regency. Making mosaic of SPOT 2009 was done to combine two scenes of image, so that the image covered the whole study area. The spatial resolution of two images is different. SPOT of 2005 has 10 x 10 meter pixel size, while SPOT of 2009 has 2.5 x 2.5 meter pixel size. Since the images will be compared to see the changes in land cover, the resampling process was done before the image was used to interpret the land cover type. SPOT image was resampled into 10 x 10 meter pixel size in ERDAS.

The image of 2005 and 2009 were then clipped into specific buffer zone area, which is 100 and 250 meter from river line. The boundary of the buffer zone is 1 kilometre upstream and downstream of the first and last of the extraction site respectively.

3.3.2.1.2. Land Cover Classification

The clipped images for 2005 and 2009 were interpreted and classified into seven land cover types: built up area, bare soil, crop, paddy field, shrub, forest, and water. The image was interpreted by comparing the image in 342 RGB band combinations with the Google Earth image from the same area and year. The land cover classification method used is on-screen digitizing, because the original bands of imagery was not available. The classification process was done in ArcGIS and the result was then analyzed in Microsoft Excel.

3.3.2.1.3. Accuracy Assessment

Accuracy assessment is a way to validate the result of land cover classification. Land cover validation (reference) points were collected from the field. These points were compared to the result of the land cover classification, resulted in producer, user and overall accuracy. Producer accuracy is calculated by dividing the total number of correctly classified points for a land cover type by the total number of reference points for that land cover type. The user accuracy is calculated by dividing the number of correct accuracy points for a land cover type by the total number of accuracy assessment points that were classified in that land cover type. The overall accuracy is calculated by dividing the number of correct points (from the classification result and field observation) by the sum of validation points. All accuracies are shown in percentage (ITC, 2010).

Accuracy assessment was conducted for result of the land cover map of 2009 only, because there is no field data available for 2005. In order to check whether the land cover classification of 2009 was valid enough or not, 89 points and its land cover type were collected from the field on June 27, 2011 (validation points). There is little difference of land cover type found between validation points of 2011 and Google Earth imagery of 2010 in the same area. The selection of the area to be visited was based on stratified sampling method. The land cover map produced was overlaid with road map, and several areas representing each land cover type and accessible were selected. In these areas, validation points were observed randomly. The coordinates and land cover types were recorded for each point.

3.3.2.1.4. Bare Soil Expansion Comparison

The result of land cover classification was then divided into two parts, the north and south side of the river line. The division was aimed to see the land cover change and bare soil expansion in areas where there are extraction sites compare to areas where there is no extraction site. 12 of the 14 extraction sites are located in the Southern part of the river and therefore, more changes in land cover and bare soil expansion is expected to occur than in the Northern part.

The method used to define the bare soil expansion along Krueng Aceh River due to gravel and sand extraction is described in Figure 3-3.

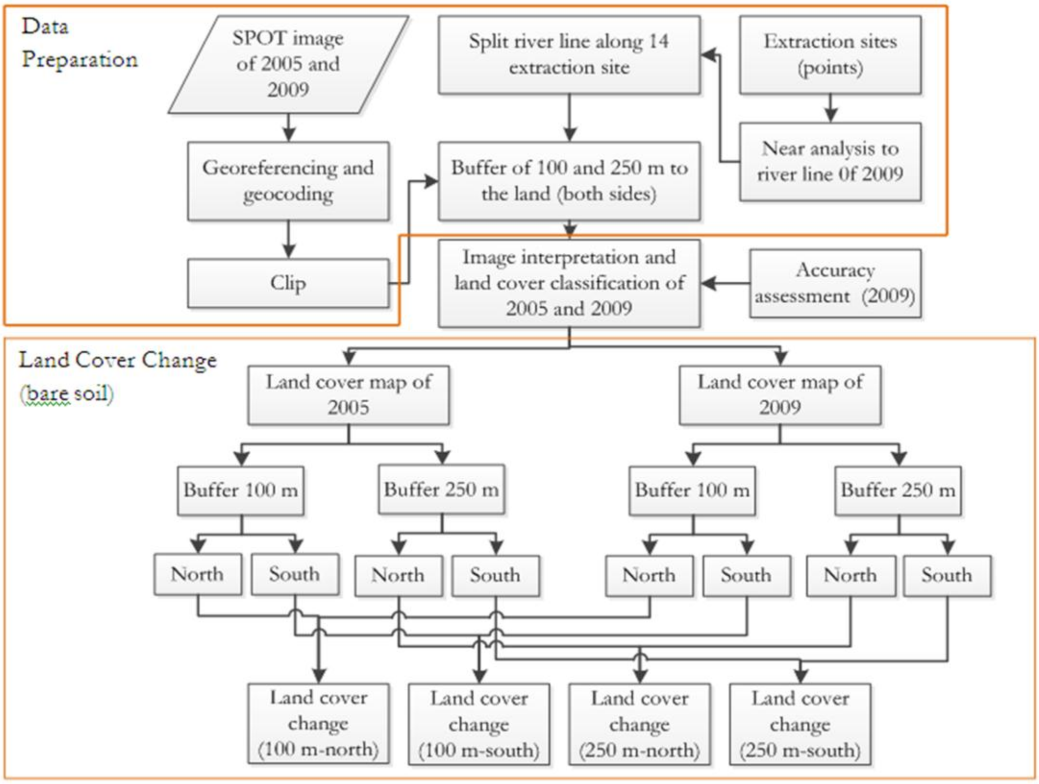


Figure 3-3 Flowchart of Land Cover Change Analysis

3.3.2.1.5. Bare Soil Expansion of Each Extraction Site

In the previous part, the comparison of bare soil expansion was done for the whole area covering 14 extraction sites within the 100 meter and 100 – 250 meter buffer zone. In order to use bare soil expansion as one criterion to assess the environmental impact of gravel and sand extraction on land cover change, the spatial extent narrowed into each extraction site. The spatial extent used was 200 meter upstream and downstream along the river. The detail method is explained in Figure 3-4. The river line is firstly split into 200 m to up and downstream, and the buffer area of 100 to north and south was obtained. 200 meter to up and downstream of the river was chosen to avoid overlap between two extraction sites, since the closest distance between two extraction sites was 467 meter.

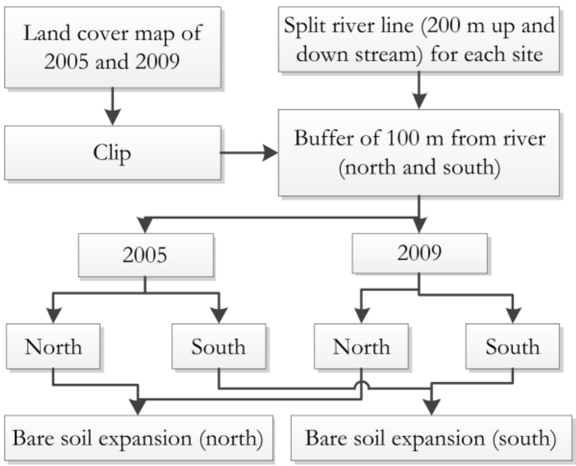


Figure 3-4 Flowchart of Bare Soil Expansion Calculation

The land cover map of 2005 and 2009 was clipped to this buffer area and the bare soil expansion (in percent) was calculated. It is expected that the bare soil expansion in the part with extraction site was bigger than in another part without extraction site. Percentage of bare soil expansion was used as one criterion in multi criteria evaluation (see section 3.3.6). The illustration of buffer zone was shown in Figure 3-5.

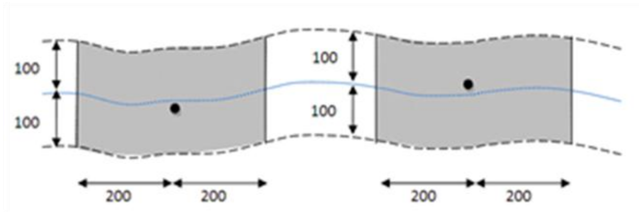


Figure 3-5 Buffer Zone Area Determinations

3.3.2.2. Distance from Extraction Site to Road

Land cover change due to gravel and sand extraction is associated with the distance from extraction site to the main road. Opening of a new extraction site is preceded by the construction of access road from the main road. The further the extraction site to the existing main road, the more access road is needed, and the higher the impact of on land cover occurred. It is the reason why distance from extraction site to road was taken into consideration as one criterion to be used in assessing the overall impacts using multi criteria evaluation Distance from extraction sites (14 points) to the nearest road was determined by using proximity analysis (near analysis) in ArcGIS, resulted in distance in meter.

3.3.3. Change in River Morphology

Change in river morphology is one of the possible physical impacts of gravel and sand extraction used in this research. The criteria used to represent the change of river morphology were distance from extraction site to river, average slope within extraction area and change of river shape.

3.3.3.1. Distance from Extraction Site to River

The President of Government of Indonesia (GoI) Decree Number 23/1990 about protected area management stated that an area within 100 meter from both sides of a big river should be protected. The purpose is to protect the river from all human activities, including gravel and sand extraction that can disturb river morphology. It means that distance from extraction site to river plays a role in changing the river morphology in general. The further the extraction site from the river, the less impact on change in river morphology occurred. Proximity analysis (near analysis) was done in ArcGIS to determine the distance from extraction sites (14 points) to river line of 2005. River line of 2005 was selected because it was the existing river line before the construction of the extraction sites, and therefore potential impacts. The result was distance in meter from each extraction site points.

3.3.3.2. Average Slope in Extraction Site

Average slope was derived from ASTER GDEM image which has 30 x 30 meter pixel size. This operation was done in ILWIS software to compute the slope (Hengl, T et. al, 2003). The slope map was clipped to extraction areas and the average slope for each extraction site was calculated by crossing the clipped slope map and extraction area map.

The slope map was generated from the image using filter operations to compute elevation differences in X and Y directions (first derivatives), as illustrated below:

Z1	Z2	Z3
Z4	Z5	Z6
Z7	Z8	Z9

(a)

$$Zx = \begin{matrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{matrix}$$

(b)

$$Zy = \begin{matrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{matrix}$$

(c)

The pixel value (elevation) of image was shown as Z1 to Z9 in (a), and (b) and (c) was the filtering matrices of x and y direction. The first derivative in x direction (dz/dx or G) and first derivative in y direction (dz/dy or H) need to be computed using the formula (1) and (2). The slope (in percentage) was then calculated based on the formula (3) (Hengl, T et. al, 2003). In this research, the slope in degree was used, so that the percentage of slope was converted to degree.

$$G = dz/dx = (Z3 + Z6 + Z9 - Z1 - Z4 - Z7)/6.p \quad (1)$$

$$H = dz/dy = (Z1 + Z2 + Z3 - Z7 - Z8 - Z9)/6.p \quad (2)$$

$$\text{Slope} = \sqrt{(H^2 + G^2)} \quad (3)$$

3.3.3.3. Change of River Shape

3.3.3.3.1. Change of River Shape

In this research, GIS analysis was done to calculate the change of the river shape for each extraction site. The change can be explained by calculating the distance between two river maps from different year (Llyod, et. al., 1987). In this case, the change was determined as the average distance from points (made from segmented 2009 river line) to the same points along the 2005 river line. Since the impact of gravel and sand extraction is different to upstream and downstream, the change considered for each extraction site is the change which happened between 500 meter upstream and 1000 meter downstream. This is based on The Directorate General of Irrigation Decree 176/KPTS/1987 about procedure of type C Material extraction from the river which stated that the extraction site should be located more than 500 meter upstream and more than 1000 meter downstream from a hydraulic building. It indicates the different upstream and downstream impact of gravel and sand extraction from an extraction site.

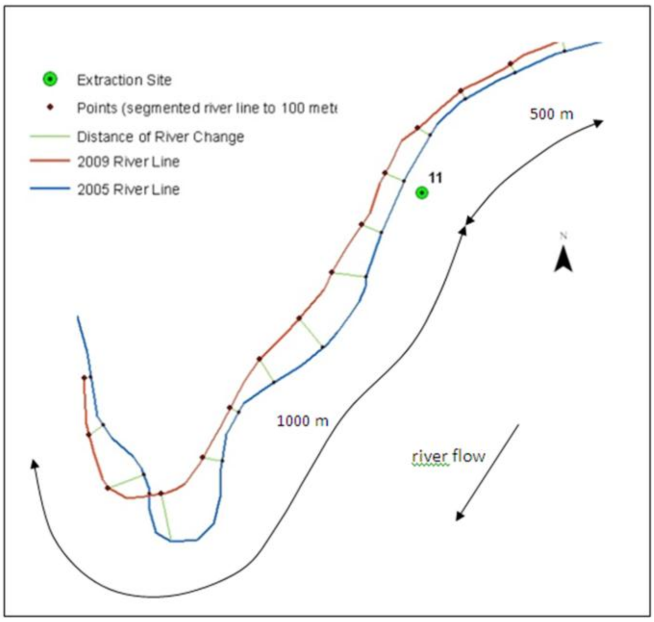


Figure 3-6 Change in River Shape

The method used is illustrated in Figure 3-6. River line of 2009 (red line) for each extraction site was split into a specific extent (1500 meter = 1000 meter downstream and 500 meter upstream). Points were generated in every 100 meter of river line. The near analysis was done to calculate distance from points in the 2009 river line (black dot) to the 2005 river line (blue line). This distance identified as change. To obtain one value of change per extraction site, the average distance was calculated.

3.3.3.3.2. Multivariate Linear Regression

Statistical analysis was used to check the significance of river shape change due to gravel and sand extraction activity. A significant result means that the change in river shape can be used as a criterion in assessing the physical impact of gravel and sand extraction. A hypothesis was used and tested here. The hypothesis was 'There is a relationship between change of river shape and gravel and sand extraction activity, which is represented by volume of extraction, size of extraction area, distance to river line and average slope of extraction area'.

Multivariate linear regression was carried out in R software. Multiple linear regressions explain the relationship between several independent variables (X) and one dependent variable (Y), by assuming that the relationship between variables is linear (Wilcox, 2009). The general idea is to fit the points of variables into a line, but since the multivariate has more than one independent variable, the line is calculated by the formula:

$Y = a + b_1*X_1 + b_2*X_2 + ... + b_p*X_p$ (Statsoft, 2011)

Nature is a very dynamic system, so that the perfect data of variable is often difficult to obtain. This leads to variation of points along the regression line, which is called as residual value. The level of correlation between dependent and independent variables is represented by Coefficient of Determination (R-Square), which is computed based on the residual variability (Statsoft, 2011). It ranges between 0 and 1, where 1 shows the perfect relationship.

The dependent variable used in this project is the average change of river shape (meter), and the independent variables are volume of extraction (cubic meter/day), distance to river (meter), average slope (degree) and size of extraction area (square meter). Volume of extraction data were taken from GTZ (Hendratno, 2006). Size of each site can be directly calculated based on extraction area map (see also section 3.3.1)

3.3.4. Damage to Hydraulic Building (Bridge)

Gravel and sand extraction from river can affect the existence of hydraulic structures such as bridges. The Directorate General of Irrigation Decree 176/KPTS/1987 about procedure of type C Material extraction from the river stated that the extraction site should be located more than 500 meter upstream and 1000 meter downstream from a hydraulic structure. The nearer the extraction sites to the river, the more impact on damage to bridges may be expected.

3.3.4.1. Distance from Extraction Site to Bridge

Since downstream impact on damage to bridge was bigger than the upstream one, criterion considered in this research was the distance from extraction site to the downstream bridge. Proximity analysis (near analysis) was conducted to define the nearest distance from extraction sites to river line of 2005 and generate the points along the river line. The distance from those points to downstream bridge was then calculated (in meter).

3.3.5. Multi Criteria Evaluation

Multi criteria evaluation was done using DEFINITE software, a tool to support the decision making process (Janssen, R and Van Herwijnen, M, 1994). The purpose is to assess the physical impact of gravel and sand extraction between 2005 and 2009, using six criteria which are: bare soil expansion, distance from extraction site to road, distance from extraction site to river, average slope in extraction area, change in river shape, and distance from extraction site to a bridge.

3.3.5.1. Effects Table

An effect table was created showing the 14 extraction sites as columns and the six criteria as rows. A score was assigned for each extraction site and corresponding criteria. For each criterion, the measurement scale, measurement unit and direction of the criteria score should be determined. In terms of physical impact, the higher the value, the higher physical impact for bare soil expansion, distance from extraction site to road, average slope and change in river shape. For distance from extraction site to the bridge and river, the lower the value means the higher the physical impact.

3.3.5.2. Multi Criteria Analysis (MCA)

The next step is executing the multi criteria analysis. This part consists of three steps, which are standardization, weighting and ranking.

a. Before MCA can be applied, the effect table has to be standardized, to normalize the different scores. In DEFINITE, the standardized scores are ranging between 0 and 1. The standardization method chosen for all criteria was maximum method where every score is divided by the maximum score, because all the scores are ratio data.
b. In assigning weight, there are five kinds of weights (visions) obtained in this research. They are equal weight and 4 other weights representing different stakeholder perceptions (Mining and Energy Office, Environment Office, GTZ and researcher). Weight from the Mining and Energy Office and the Environment Office was obtained by interviewing the officer, while weight from GTZ was derived from the indicator used in the research conducted by GTZ (Hendratno, 2006). In DEFINITE, the method used to assigned weight was the expected value method, where the weights are ranked based on the importance of the criteria compare to all criteria used. A ranking was carried out for each of the five visions. This method was chosen because it is easier to be understood and answered by stakeholders via e-mail.
c. After the weight assigned for each vision, the ranking process was executed. The 14 extraction sites are placed in rank of their appraisal score ranging from 0 to 1. A high appraisal score means the high physical impact of gravel and sand extraction site.

Table 3-4 Appraisal Score Classification

Score	Class of Physical Impact
0 – 0.33	Low
0.34 – 0. 67	Moderate
0.67 – 1	High

GTZ classified the environmental damage of extraction sites into 3 classes, which are low, moderate and high in environmental damage (Hendratno, 2006). In order to compare the result of this research with GTZ result, the appraisal score was also classified into three classes as is shown in Table 3.4.

3.3.5.3. Sensitivity Analysis

Sensitivity analysis was conducted to examine the sensitivity of the obtained rankings to uncertainty in score and weight and to assess the possibility of rank reversal between two extraction sites that show similar appraisal score. In this research, the sensitivity analysis was performed in two parts:

a. Sensitivity of weight and score uncertainty. Different percentage of uncertainty was determined for weight and score in order to examine whether the uncertainty affects the rankings and level of physical impact.
b. Sensitivity of weight and score to rank reversal. In this analysis, the focus of sensitivity analysis was on the rank reversal of sites which can affect the reversal of physical impact class (Table 3.4). The rank reversal between 2 extraction sites within the same class was not considered as the important matter. For each score and weight examined, the ranking was stable if a rank reversal occurs at a score or weight which is within 10% interval of the original score.

4. RESULTS

4.1. Change in Land Cover

The impact of gravel and sand extraction on land cover change was assessed by using two indicators: bare soil expansion and distance from extraction site to road. The higher the value of bare soil expansion and distance to road, the more physical impact occurred on gravel and sand extraction site.

4.1.1. Bare Soil Expansion

Before bare soil expansion is used as one criterion to assess the impact of gravel and sand mining on land cover change, a hypothesis that 'bare soil expansion in riverside area with extraction site is bigger than bare soil expansion in riverside area without extraction site' was tested. If the hypothesis is proved, it means that the bare soil expansion was due to gravel and sand extraction, and it can be used as one criterion to assess the impact. Land cover map was produced for 2005 and 2009, and the land cover change, focused on bare soil expansion was identified.

4.1.1.1. Land Cover Classification of 2005

The study area covers 14 extraction sites along 31.8 km of river, with a maximum buffer zone of 250 meter along both sides of the river. In order to visualize the result better, the land cover map of 2005 and 2009 was shown per sub district, as illustrated by Figure 4.1. The land cover map of 2005 for Seulimuem, Kota Cot Glie and Indrapuri sub district is provided in Figure 4-2, 4-3 and 4-4 respectively. Different extraction sites are also presented within each sub district. There are six extraction sites in Seulimuem and and Kota Cot Glie sub districts, and the other two extraction sites are located in Indrapuri sub district.

From Figure 4-2, 4-3 and 4-4, it can be seen that in 2005, cropland and forest were the dominant land cover types in Seulimuem and Indrapuri sub districts, while Kota Cot Glie sub district was dominated by paddy fields. Bare soil indicated that gravel and sand deposits were found the most in Seulimuem sub district. In Seulimuem sub district, bare soil already existed in the surroundings of all six extraction sites. In Kota Cot Glie sub district, bare soil can be seen only in two extraction sites, which are site 8 and 12, while in Indrapuri sub district, bare soil existed only in one extraction site, which is site 14. The land cover type for each sub district can be seen in Annex 1.

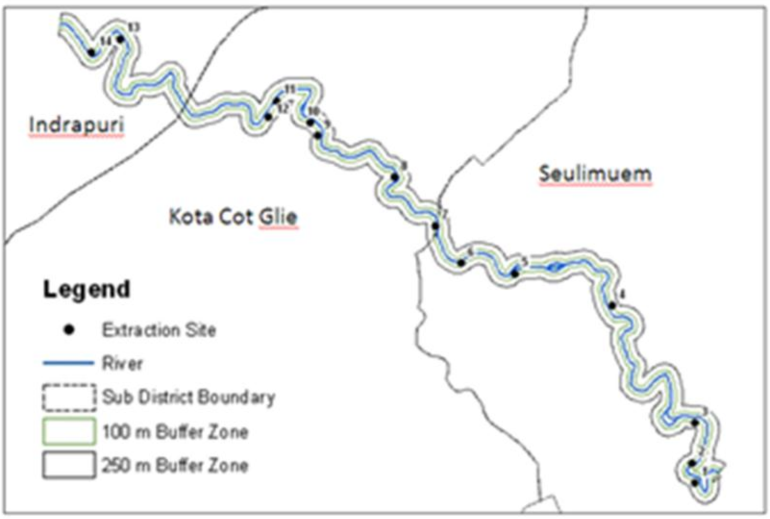


Figure 4-1 Division of Land Cover Map

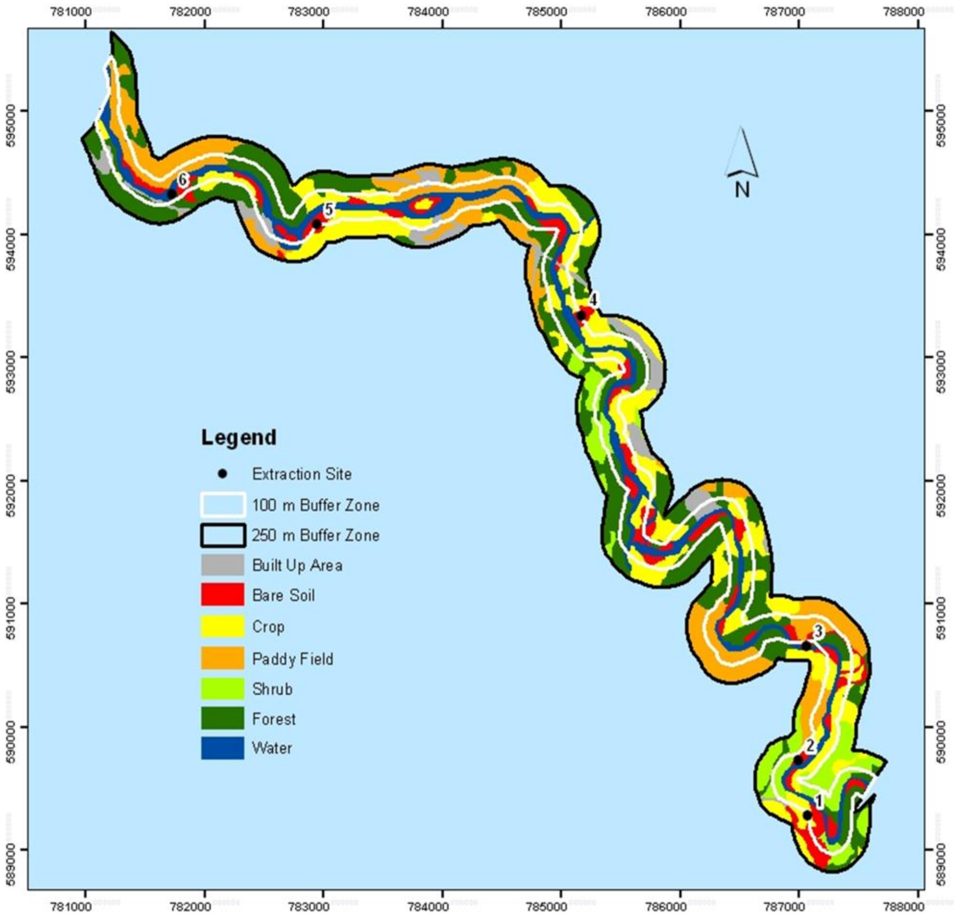


Figure 4-2 Land Cover Map of 2005 in Seulimuem Sub District

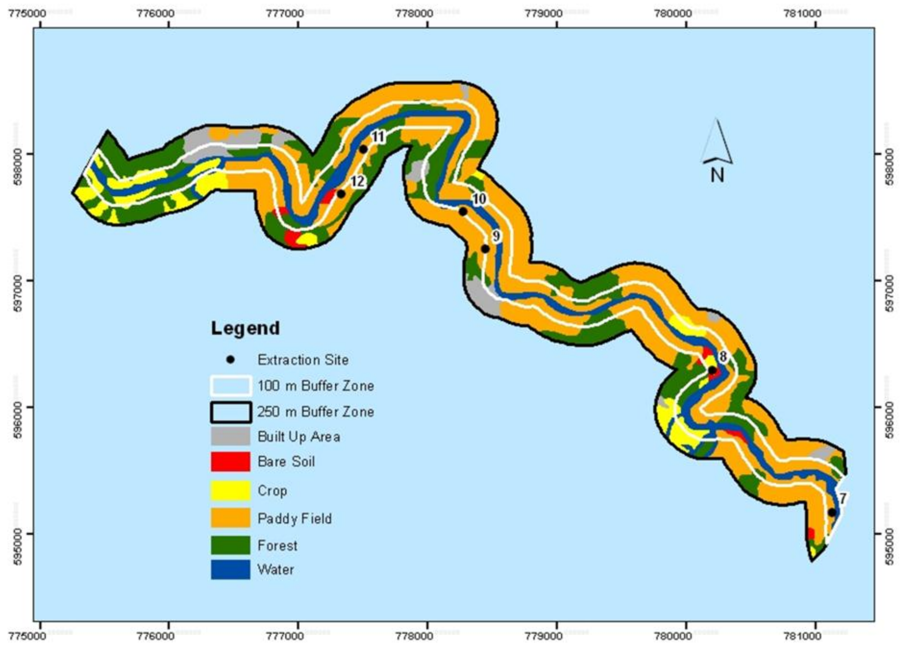


Figure 4-3 Land Cover Map of 2005 in Kota Cot Glie Sub District

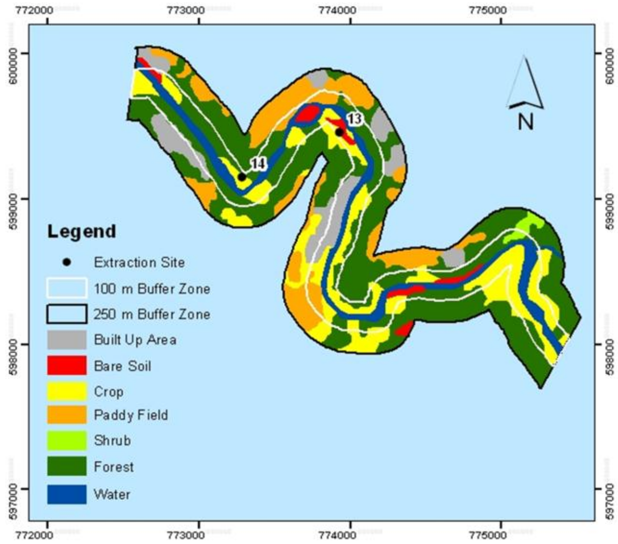


Figure 4-4 Land Cover Map of 2005 in Indrapuri Sub District

An overview of land cover type in the whole study area, for the100 m and 100-250 m buffer zones can be seen in Table 4.1.

Table 4-1 Land Cover of 2005

No	Land Cover Type	Size (ha)			
		100 m	%	100-250 m	%
1	Water	150.1	24.83	8.0	0.95
2	Bare Soil	52.2	8.63	15.7	1.85
3	Shrub	14.9	2.46	41.2	4.86
4	Crop	110.8	18.33	126.6	14.93
5	Forest	129.7	21.46	318.4	37.55
6	Paddy Field	129.5	21.42	268.1	31.62
7	Built Up Area	17.3	2.86	69.9	8.25
		604.3	**100**	**847.8**	**100**

Within the 100 m buffer zone, water (river) dominated the area, followed by forest, paddy field and crop. Bare soil that indicates the extraction site of gravel and sand covered 8.63% of the total area. In 100-250 m zone area, forest and paddy field were the land cover with the highest proportion. The percentage of bare soil is 1.85%. Of the total bare soil area of 67.9 ha, 77% is located within 100 meter buffer zone.

4.1.1.2. Land Cover Classification of 2009 and Accuracy Assessment

Similar to the land cover map of 2005, the land cover map of 2009 was divided into three sub district to visual the result better. The land cover maps of 2009 for Seulimuem, Kota Cot Glie and Indrapuri sub district is shown in Figure 4-5, 4-6 and 4-7 respectively.

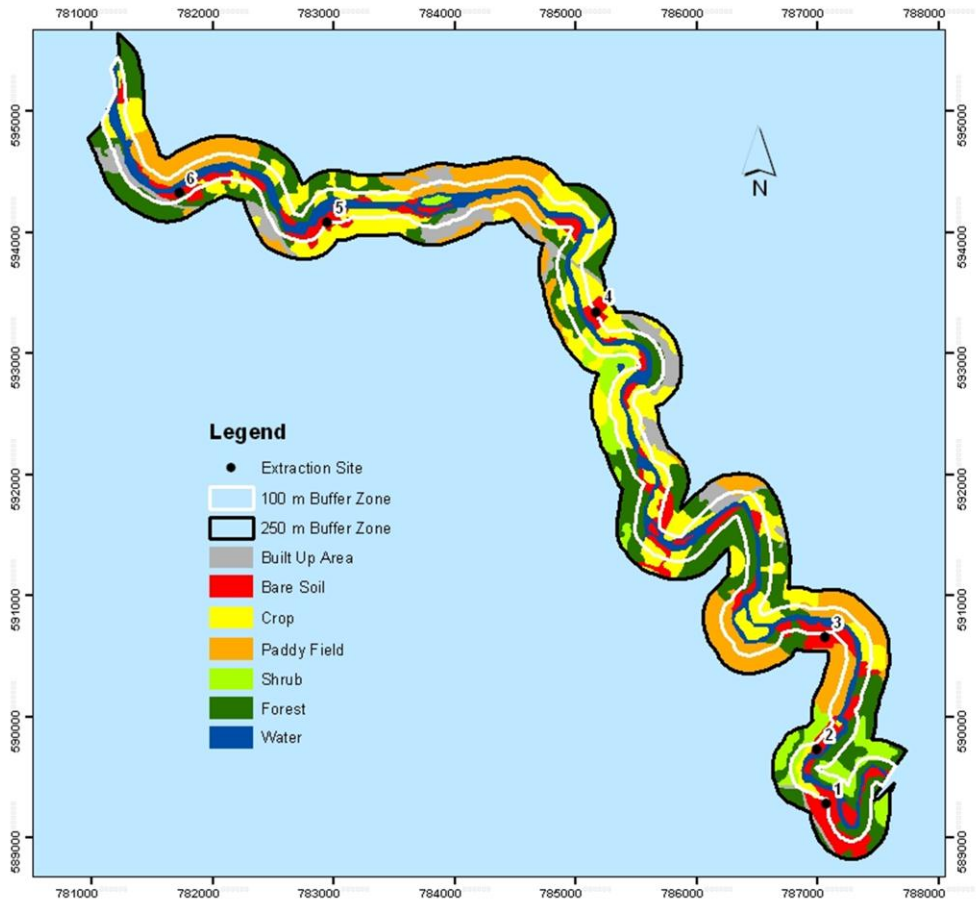


Figure 4-5 Land Cover Map of 2009 in Seulimuem Sub District

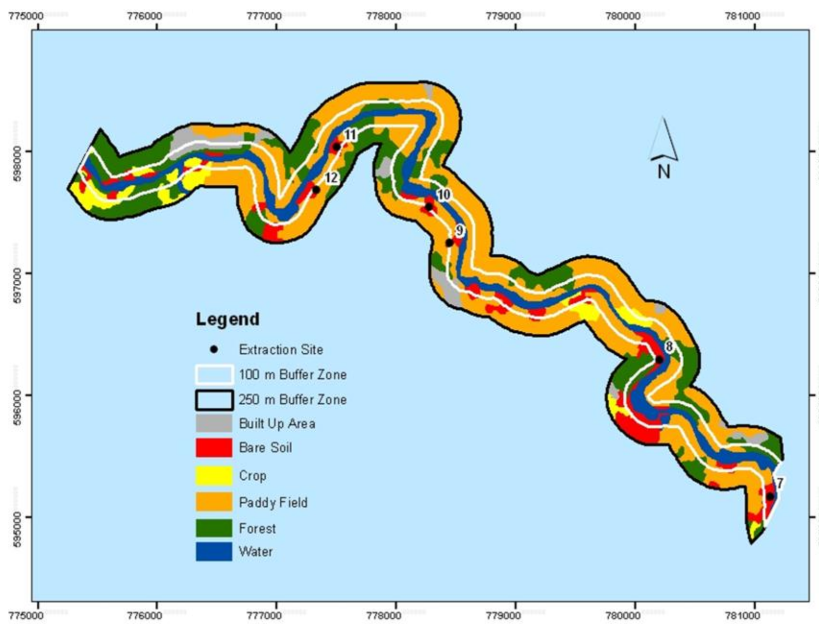


Figure 4-6 Land Cover Map of 2009 in Kota Cot Glie Sub District

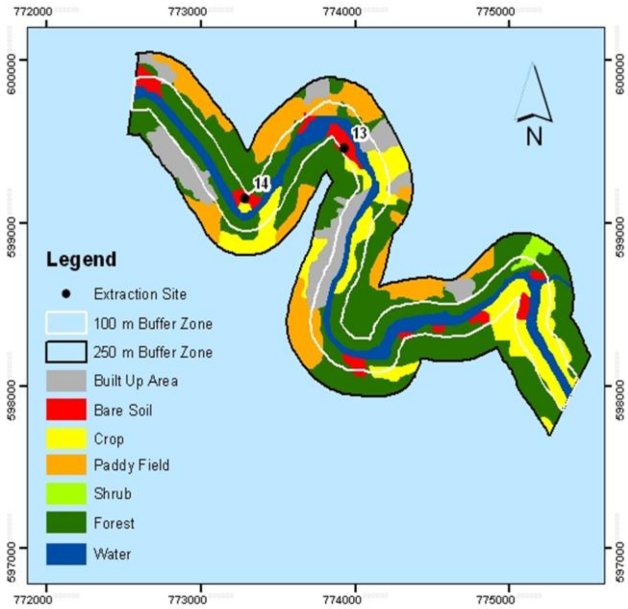


Figure 4-7 Land Cover Map of 2009 in Indrapuri Sub District

Compared to the land cover map of 2005, there was no significant change in forest, cropland, shrub and paddy fields. Seulimuem and Indrapuri sub districts were still dominated by forest and crops, while Kota Cot Glie sub district was dominated by paddy fields. The most significant change was in bare soil and the built up area, which expanded in the three sub districts. In 2009, bare soil can be seen in all extraction sites, while in 2005, it can be seen in 9 of 14 extraction sites. It clearly shows that bare soil expansion occurred between 2005 and 2009. The land cover type for each sub district can be seen in Annex 1.

Table 4-2 Land Cover of 2009

No	Land Cover Type	Size (ha)			
		100 m	%	100-250 m	%
1	Water	165.9	27.46	1.7	0.19
2	Bare Soil	75.7	12.52	43.3	5.11
3	Shrub	9.4	1.55	34.4	4.05
4	Crop	96.1	15.90	119.4	14.08
5	Forest	122.9	20.33	284.7	33.59
6	Paddy Field	112.3	18.58	281.5	33.20
7	Built Up Area	22.1	3.66	82.87	9.77
		604.3	**100.00**	**847.8**	**100.00**

From Table 4-2, within 100 m zone, water has the biggest proportion compare to other land cover types, followed by forest and paddy fields. In 100-250 m zone, forest and paddy fields were the highest proportion. More bare soil can be found within 100 meter buffer zone than within 100 – 250 meter buffer zone. Compared to 2005, there is increase of bare soil in 100 m and 100-250 m buffer zone. Within 100 m buffer zone bare soil increase from 8.6 to 12.5% and within 100-250 m buffer zone, it increases from 1.9 to 5.1%.

<u>Accuracy Assessment</u>

The land cover map of 2009 was validated using 89 points from the field. The overall accuracy of that land cover map was 83.15%, as is shown in Table 4-3. Water has the highest accuracy (100%) for both producer and user accuracy, followed by built up area (92.86% producer accuracy and 100% user accuracy). For bare soil, the producer accuracy was 83.33% and the user accuracy was 100%. This means that even although there are several validation points in bare soil class that are misclassified to other land cover types, there are no other land cover types that are classified as bare soil. Based on this result, the land cover map of 2009, including bare soil, was considered to be accurate and can therefore be used for further analysis.

Table 4-3 Accuracy Assessment of 2009 Land Cover Map

No	Land Cover Type	Reference Total	Classified Total	Number Correct	Producer Accuracy (%)	User Accuracy (%)
1	Water	5.00	5.00	5.00	100.00	100.00
2	Bare Soil	18.00	15.00	15.00	**83.33**	**100.00**
3	Crop	15.00	16.00	11.00	73.3	68.75
4	Shrub	9.00	8.00	7.00	77.78	87.50
5	Forest	12.00	13.00	9.00	75.00	69.23
6	Paddy Field	16.00	19.00	14.00	87.50	73.68
7	Built Up Area	14.00	13.00	13.00	92.86	100.00
	Total	89.00	89.00	74.00		
	Overall Accuracy	**83.15 %**				

4.1.1.3. Land Cover Change and Bare Soil Expansion Comparison

In order to see the land cover change between 2005 and 2009, the land cover map for two zones (100 m and 100 - 250 m) was divided into 2 parts, which are the north and south sides of the river line. From 14 extraction sites studied in this research, 12 of them are located in the Southern part, and only 2 that are located in the Northern part. The result is presented in Table 4-4

Table 4-4 Land Cover Change 2005 - 2009

No	Land Cover Type	North				South			
		100 m		100-250 m		100 m		100-250 m	
		Size (ha)	%	Size (ha)	%	Size (ha)	%	Size (ha)	%
1	Water	13.50	4.38	-0.91	-0.22	3.47	1.12	-4.81	-1.11
2	Bare Soil	1.98	0.64	1.39	0.33	19.96	6.45	22.36	5.14
3	Crop	-7.73	-2.51	5.60	1.32	-6.30	-2.04	-8.51	-1.96
4	Shrub	-0.74	-0.24	-5.34	-1.26	-3.43	-1.11	-0.93	-0.21
5	Forest	-1.63	-0.53	-9.37	-2.22	-10.44	-3.38	-24.27	-5.58
6	Paddy Field	-9.40	-3.05	6.03	1.43	-7.35	-2.38	7.47	1.72
7	Built Up Area	0.77	0.25	2.60	0.61	4.10	1.32	8.69	2.00

In general, there is a similar land cover change pattern between the north and south parts of the river line. There is a decrease in forest, crops and paddy fields and increase in bare soil and built up area from 2005 to 2009. Water increased in 100 m buffer zone and decreased in the 100-250 m buffer zone, while paddy field decreased in 100 m buffer zone and increased in 100-250 m buffer zone. The increase of bare soil in the northern part (highlighted as yellow) was less than the increase of bare soil in the southern part of the river (highlighted as red), for both 100 m and 100-250 m buffer zone.

A more detailed bare soil expansion for each extraction site is provided in Table. 4-5. For this purpose, the bare soil expansion was calculated specifically within 100 m zone, 200 meter upstream and downstream. The highlighted value indicates the location of extraction sites. Bare soil expansion within sections where the extraction sites are located is higher than in other sections.

Table 4-5 Bare Soil Expansion in Each Extraction Site

No	Site	N/S	Size of Bare Soil (ha)									
			North					South				
			2005	2009	Change	Total area	Percentage of change	2005	2009	Change	Total Area	Percentage of change
1	Site 1	S	1.2	1.3	0.1	4.3	2.0	2.2	2.4	0.2	3.6	**5.2**
2	Site 2	S	0.4	0.4	0.0	3.6	0.1	1.1	1.3	0.2	4.3	**4.6**
3	Site 3	S	0.6	0.0	-0.6	4.3	-13.4	1.3	2.2	0.9	3.7	**24.3**
4	Site 4	N	0.6	1.6	0.9	3.8	**24.9**	0.0	0.0	0.0	4.3	0.0
5	Site 5	S	0.0	0.0	0.0	4.9	0.0	2.1	2.5	0.4	5.1	**7.9**
6	Site 6	S	0.7	0.4	-0.3	3.5	-7.7	1.5	2.1	0.6	4.5	**13.0**
7	Site 7	S	0.0	0.9	0.9	4.2	20.5	0.0	2.1	2.1	3.8	**53.5**
8	Site 8	S	0.0	0.0	0.0	4.9	0.0	1.0	1.7	0.7	3.1	**22.1**
9	Site 9	S	0.0	0.1	0.1	4.3	1.7	0.0	1.1	1.1	3.7	**30.9**
10	Site 10	S	0.0	0.0	0.0	4.3	0.0	0.0	1.1	1.1	3.7	**30.5**
11	Site 11	S	0.0	0.0	0.0	4.2	0.0	0.0	1.1	1.1	3.8	**29.3**
12	Site 12	S	0.0	0.0	0.0	4.0	0.0	0.8	1.2	0.3	4.0	**7.8**
13	Site 13	S	0.0	0.0	0.0	4.5	0.0	1.1	1.9	0.8	3.5	**23.2**
14	Site 14	N	0.0	0.9	0.9	3.0	**30.3**	0.0	0.0	0.0	4.9	0.0

The result from Table 4-4 and 4-5 supports the assumption that 'bare soil expansion in riverside area with extraction site is bigger than bare soil expansion in riverside area without extraction site'. Therefore, bare soil expansion was a significant indicator or criterion used to assess the impact of gravel and sand extraction on land cover change. The higher the bare soil expansion, the bigger the physical impact it caused, because it changed the previous land cover types which are mostly vegetation (crops, shrubs, paddy fields or forest) to bare soil.

Table 4-6 shows the type of bare soil change for each extraction site. In general, the bare soil in 2009 was come from paddy field, water, crop and forest. The change from water to bare soil might be because of the change in river shape and different season when the imageries used for land cover classification were taken. The unchanged bare soil is existed in almost all extraction sites, except for the site 7, 9, 10, 11, and 14. The existence of unchanged bare soil indicates that the gravel and sand extraction already existed before the imagery used to derive the land cover map was recorded. In contrast to sites 7, 9, 10, 11 and 14, in these extraction sites, no gravel and sand extraction existed in 2005.

Table 4-6 Land Cover Changed into Bare Soil

No	Type of Change	Size of change (ha) per site														Total (ha)
		1 (S)	2 (S)	3 (S)	4 (N)	5 (S)	6 (S)	7 (S)	8 (S)	9 (S)	10 (S)	11 (S)	12 (S)	13 (S)	14 (N)	
1	Crop to bare soil	0.6	0.1	0.0	0.4	0.3	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.9	0.7	3.8
2	Forest to bare soil	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.8
3	Paddy field to bare soil	0.0	0.0	0.5	0.0	0.0	0.0	1.6	0.1	0.7	0.8	1.0	0.3	0.0	0.0	5.0
4	Shrub to bare soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	Water to bare soil	0.1	0.1	0.5	0.2	0.4	1.0	0.4	0.0	0.4	0.4	0.1	0.1	0.0	0.1	3.8
6	No change	1.7	1.0	0.7	1.0	1.9	1.0	0.0	0.7	0.0	0.0	0.0	0.7	1.0	0.0	9.7
	Total	**2.4**	**1.3**	**2.2**	**1.6**	**2.5**	**2.1**	**2.1**	**1.7**	**1.1**	**1.1**	**1.1**	**1.2**	**1.9**	**0.9**	23.2

4.1.2. Distance from Extraction Site to Road

In this research, it is assumed that the larger the distance from an extraction site to the main road, the more land cover change occurred, and this automatically resulted in higher physical impact on land cover change. In table 4-7, the distance from the extraction site to the road is presented. There is no extraction site which is located less than 100 meter from the road. The nearest distance from the extraction site to river is 120.3meter (site 6) and the largest distance is 408.9 meter (site 7).

Table 4-7 Distances to Road

No	Site	Distance to Road (meter)	No	Site	Distance to Road (meter)
1	Site 1	128.86	8	Site 8	290.89
2	Site 2	362.28	9	Site 9	265.05
3	Site 3	345.67	10	Site 10	272.62
4	Site 4	148.41	11	Site 11	294.17
5	Site 5	368.60	12	Site 12	132.63
6	Site 6	120.29	13	Site 13	218.95
7	Site 7	408.87	14	Site 14	181.36

4.2. Change in River Morphology

There are three criteria used to represent the change in river morphology. They are distance from extraction site to river, average slope in the extraction area, and change of river shape.

4.2.1. Distance from Extraction Site to River

Distance from extraction site to river is provided in Table 4-8. The nearest is site 3 (5.57 meter) and the furthest is site 7 (152.23 meter). Only 2 of the 14 sites are located more than 100 meter from river. Meanwhile, according to Presidential Decree 23/1990 about protected area management, 100 meter from big river to the land is a buffer zone, where the human activity should be limited. The nearer the distance from extraction sites to the river, the more physical impact on change in river morphology resulted.

Table 4-8 Distances to River

No	Site	Distance (meter)	No	Site	Distance (meter)
1	Site 1	132.68	8	Site 8	**49.21**
2	Site 2	**56.48**	9	Site 9	**99.51**
3	Site 3	**5.57**	10	Site 10	**68.62**
4	Site 4	**92.92**	11	Site 11	**36.77**
5	Site 5	**78.50**	12	Site 12	**43.12**
6	Site 6	**24.20**	13	Site 13	**78.10**
7	Site 7	152.23	14	Site 14	**92.57**

4.2.2. Average Slope in Extraction site

Table 4-9 Average Slope

No	Site	Average Slope (Degree)	No	Site	Average Slope (Degree)
1	Site 1	3.39	8	Site 8	3.29
2	Site 2	2.54	9	Site 9	4.43
3	Site 3	4.33	10	Site 10	5.03
4	Site 4	2.33	11	Site 11	7.72
5	Site 5	6.01	12	Site 12	7.05
6	Site 6	7.59	13	Site 13	2.98
7	Site 7	4.63	14	Site 14	5.71

Table 4-9 shows the average slope in each extraction area observed in this research. All extraction sites are located in the river bed area, so that the area is relatively flat and the average slope is between 2^0 and 8^0. Eight sites were located in area of less than 5^0 and six sites were located between 5^0 and 8^0.

4.2.3. Change in River Shape

4.2.3.1. Change in River Shape

The average change of river shape between 2005 and 2009 for each extraction site is shown in Table 4.10. The biggest change occurred at site 12 and 11, which is more than 32 meter. The smallest change occurred in site 8 and 13, with 11 meter change.

The proportion of river shape change is visualized in Figure 4-8. The size of dots represents the change of river shape. The bigger the dot, the bigger the changes of river shape at the corresponding extraction site.

Table 4-10 Average Change in River Shape

No	Site	Average Change (meter)	No	Site	Average Change (meter)
1	Site 1	17.03	8	Site 8	11.07
2	Site 2	13.20	9	Site 9	23.93
3	Site 3	**30.53**	10	Site 10	19.01
4	Site 4	14.12	11	Site 11	**32.18**
5	Site 5	26.74	12	Site 12	**32.39**
6	Site 6	20.60	13	Site 13	11.81
7	Site 7	13.83	14	Site 14	21.32

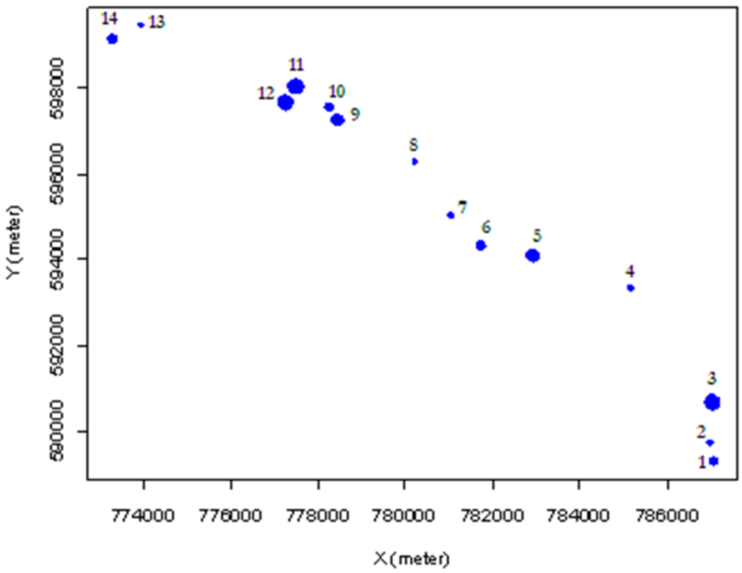


Figure 4-8 Change of River Shape per Extraction Site

Since the river flows from upstream (bottom-right corner) to downstream area (top-left corner), under natural conditions, the bigger changes are expected to take place in downstream compared to upstream. In this study area, there are no spatial patterns of river shape change that support that phenomenon. The big and small changes are distributed randomly along the river line. The reason behind this probably is human activity that influences the natural river flow. One of the human activities that may influence the river flow is gravel and sand extraction along Krueng Aceh River. Four variables (size of extraction site, volume of extraction site, distance to river and average slope of extraction site) that represent the gravel and sand extraction activities were chosen and analysed in the next section to examine the relationship between change in river shape and gravel and sand extraction.

4.2.3.2. Relationship between change in river shape and gravel and sand extraction

Change of river shape was chosen as the dependent variable, which is influenced by independent variables. Independent variables used are size of extraction site area (sq. m), volume of extraction (cu. m/day), distance from extraction site to river line (m) and average slope in the extraction site area (degree). The hypothesis in this analysis is that there is a significant relationship between the dependent variable and the independent variables.

Table 4-11 Correlation between dependent and independent variables

No	Independent Variables	Change of River Shape (m)
1	Size of extraction site area	0.42
2	Volume of Extraction	0.42
3	Distance to River	-0.47
4	Average Slope	0.73

Correlation between dependent variable and each independent variable was firstly obtained. Correlation ranges between 0 and 1, where 1 shows the biggest correlation between variables (see Table 4-11). All independent variables show a correlation with the dependent variables (change in river shape). Average slope has the biggest correlation (0.73). The other independent variables have more than -0.40 correlation. From all, only distance to river has a negative correlation. It means that the bigger the change of river shape, the nearer the distance to the river.

The relation between the change in river shape and each of the independent variables was also tested using univariate linear regression. The result is shown in Figure 4-9. The adjusted R^2 and p-value for (a), (b), (c), and (d) is provided in Table 4-12 below. Similar with the correlation results, the highest relationship was between change in river shape and average slope (d). The lowest p-value that showed the possibility to reject the hypothesis also occurred for slope (d).

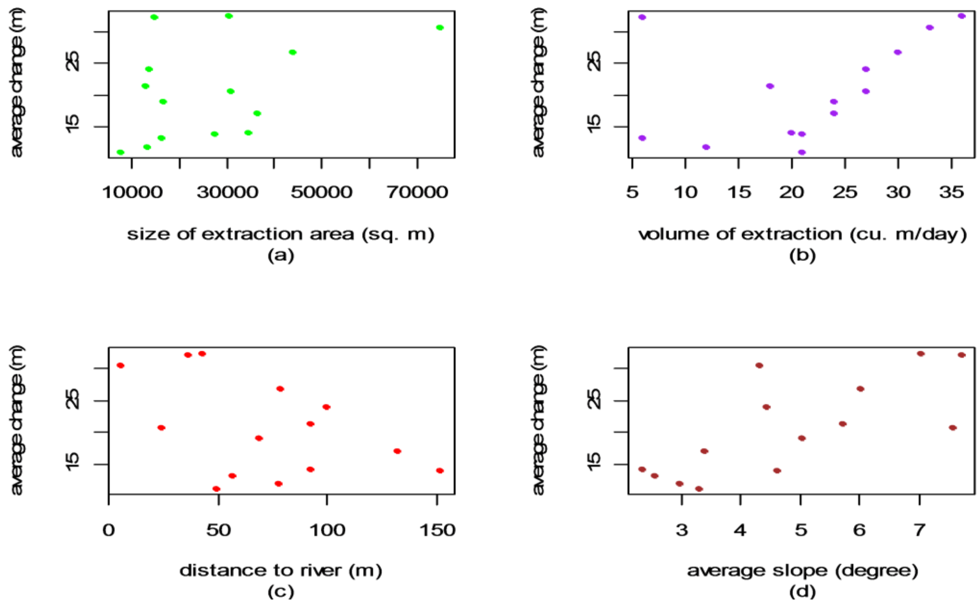


Figure 4-9 Relationships between Change of River Shape and Size of Extraction Site (a), Volume of Extraction (b), Distance to River (c), and Average Slope (d)

Table 4-12 Adjusted R^2 and p-value of uni-variate linear model

No	Relationship	R^2	p-value
1	(a)	0.111	0.42
2	(b)	0.109	0.134
3	(c)	0.155	0.091
4	(d)	0.501	0.003

If all independent variables are analyzed together using linear model in multivariate regression analysis, the result was there is a relationship between the variables. This model explains 58.3% (adjusted R^2) of the variability in the data and there is a chance of only 1.6% (p-value) of rejecting the hypothesis. Even though the relationship between the variables is not very strong, it is acceptable due to the dynamic of the river system. It might be possible that the change of river shape was influenced by other human activities beside of gravel and sand extraction or other natural processes in the river basin area. Based on this result, the hypothesis that 'There is a relationship between change of river shape and gravel and sand extraction activity, which is represented by volume of extraction, size of extraction area, distance to river line and average slope of extraction' is accepted.

4.3. Damage to Hydraulic Structures (Bridges)

4.3.1. Distance from Extraction Site to Bridge

Table 4-13 shows the distance from an extraction site to the nearest bridge. The distance considered was the distance from each extraction site to a downstream bridge. Since the river flow from upstream to downstream, the extraction of gravel and sand from river body will cause incision that accumulates downstream. Most of the extraction sites are located far from a bridge (>1000 meter) and only 4 sites (3, 4, 7 and 8) are located less than 1000 meter from a bridge.

Table 4-13 Distances to Bridge

No	Site	Distance (meter)	No	Site	Distance (meter)
1	Site 1	2724.17	8	Site 8	**723.10**
2	Site 2	2203.14	9	Site 9	4593.08
3	Site 3	**885.78**	10	Site 10	4106.22
4	Site 4	**506.49**	11	Site 11	2169.96
5	Site 5	1111.15	12	Site 12	1796.80
6	Site 6	2194.66	13	Site 13	4227.66
7	Site 7	**995.67**	14	Site 14	3058.83

4.4. Multi Criteria Analysis

Multi criteria analysis was conducted to assess the overall physical impact of gravel and sand extraction site in Krueng Aceh river basin area based on several criteria. The criteria used in this research were bare soil expansion (percent), change in river shape (meter), average slope (degree), and distance to river, bridges and roads (meter).

4.4.1. Effects table

The effects table showing criteria, measurement units and scores for 14 extraction site is presented in Table 4-14.

Table 4-14 Effects Table

	Unit	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Bare Soil Expansion	Percent	5.20	4.60	24.30	24.90	7.90	13.00	53.50	22.10	30.90	30.50	29.30	7.80	23.20	30.30
Distance to Road	Meter	128.86	362.28	345.67	148.41	368.60	120.29	408.87	290.89	265.05	272.62	294.17	132.63	218.95	181.36
Average Slope	Degree	3.39	2.54	4.33	2.33	6.01	7.59	4.63	3.29	4.43	5.03	7.72	7.05	2.98	5.71
Distance to River	Meter	132.68	56.48	5.57	92.92	78.50	24.20	152.23	49.21	99.51	68.62	36.77	43.19	78.10	92.59
Change of River Shape	Meter	17.03	13.20	30.53	14.18	26.74	20.60	13.83	11.07	23.93	19.01	32.18	32.39	11.81	21.32
Distance to Bridge	Meter	2724.17	2203.14	885.78	506.49	1111.15	2194.66	995.67	723.10	4593.08	4106.22	2169.96	1796.80	4227.66	3058.83

4.4.2. Standardization, Weighting and Ranking

All the scores were standardized using maximum standardization. Different weights were assigned to each criterion based on different visions (Equal weight, Mining and Energy Office vision, Environment Office vision, GTZ vision and researcher vision). The weight for each vision is provided in Table 4-15. The resulting ranking was described in the sub sections respectively. Each vision has different perception on the scale of importance for each criterion.

Table 4-15 Weight assigned by different visions

No	Criteria	Weight				
		Equal	Mining Office	Environment Office	GTZ Derived	Researcher
1	Bare soil expansion	0.167	0.062	0.131	0.168	0.044
2	Distance to road	0.167	0.028	0.028	0.168	0.044
3	Distance to river	0.167	0.200	0.325	0.408	0.168
4	Average Slope	0.167	0.062	0.131	0.168	0.168
5	Change in river shape	0.167	0.200	0.325	0.044	0.168
6	Distance to bridge	0.167	0.408	0.061	0.044	0.408

a. Equal Weight

In this vision, equal weight (0.1667) was assigned to all criteria. It means that there is no criterion which is more important than the others. The ranking result is shown in the Figure 4-10 below.

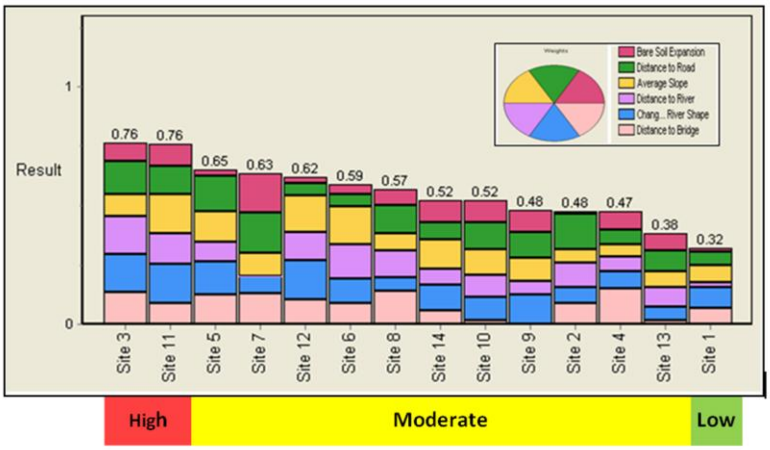


Figure 4-10 Ranking Result in Equal Weight

Site 3 and 11 show the highest impact with appraisal score of 0.76. The following site (site 5 to site 13) show the moderate impact and there is only one, site which is site 1, which is classified as having lowest impact among all extraction site with appraisal score of 0.32.

b. Mining and Energy Office

The respondent from the Mining and Energy Office assigned the highest weight on distance to bridge. The second highest was distance to river and change of river shape, followed by bare soil expansion, average slope and distance to road. The ranking result is shown in Figure 4-11.

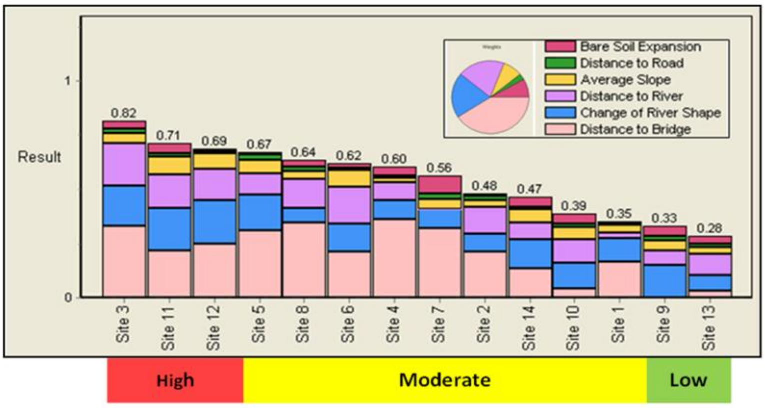


Figure 4-11 Ranking Result in Mining and Energy Office Vision

There are three extraction sites categorized as having high physical impact, which are site 3, 11 and 12 with appraisal score of 0.82, 0.71 and 0.69 respectively. Sites 9 and 13 with appraisal score of 0.33 and 0.26 show the low impact, and the remaining extraction sites are categorized as having moderate impact.

c. Environment Office

According to the Environment Office vision, distance to river and change in river shape are the most important criteria, therefore, the are assigned the highest weight, followed by average slope and bare soil expansion (same rank), and distance from extraction sites to bridge and road (same rank). The ranking result is presented in Figure 4-12.

Site 3, 11, 12 and 6 categorized as high impact, due to their appraisal score which is more than 0.67. Site 1 has the lowest appraisal score and classified as low impact, while the rest of the extraction sites show the moderate impact of gravel and sand extraction with the appraisal score ranging from 0.40 to 0.62

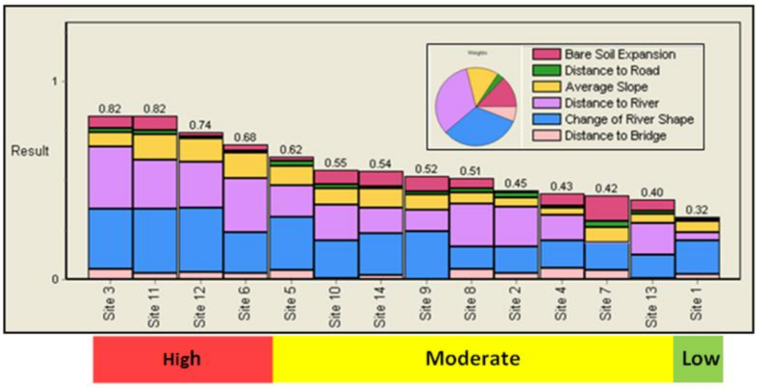


Figure 4-12 Ranking Result in Environment Office Vision

d. GTZ

In the GTZ research (Hendratno, 2006), distance from quarry to river and erosion level were two of indicators used to value the environmental damage because of gravel and sand extraction within Krueng Aceh river basin area. Assigned weight for distance from quarry to river was bigger than weight for erosion level. In this research, distance from river derived as distance from extraction site to river. Erosion level was translated as average slope, bare soil expansion and distance to road; because these criteria influence the vulnerability of soil erosion. Based on these, distance to river was given the highest weight, average slope, bare soil expansion, and distance to road was given the second highest weight, and the rest are given the lowest height. The result can be seen in Figure 4-13.

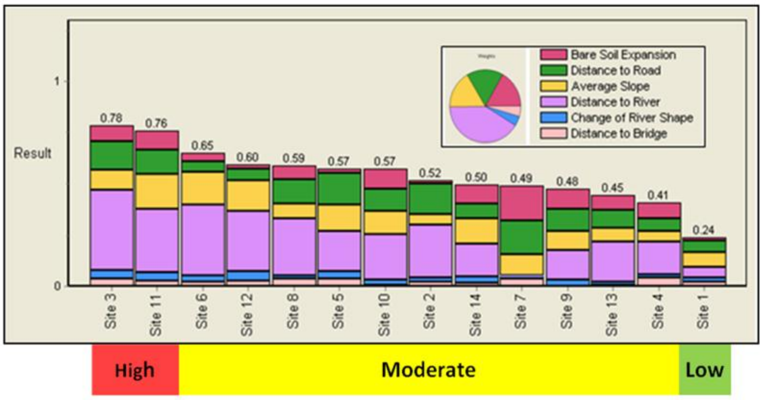


Figure 4-13 Ranking Result in GTZ Vision

Sites 13 and 11 were categorized as having high physical impact because of their highest appraisal score (0.78 and 0.76 respectively). Site 1 shows the lowest appraisal score (0.24) and therefore has the lowest physical impact. The remaining extraction sites are classified as having moderate impact.

e. Researcher

In researcher vision, distance to bridge was selected as the most important criteria, because the damage of bridge due to gravel and sand mining already occurred in Aceh Besar Regency. The next most important were change of river shape, average slope and distance to river. These criteria

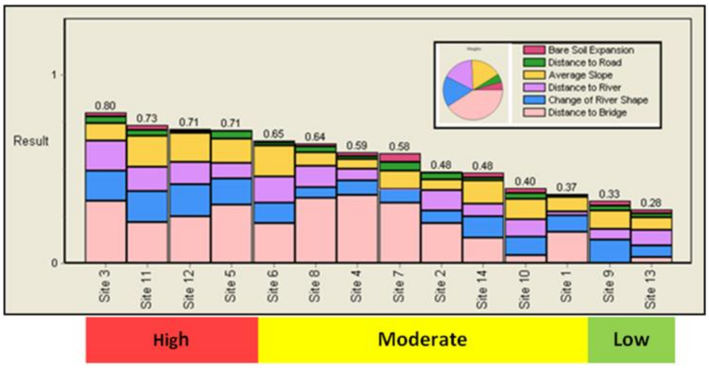


Figure 4-14 Ranking Result in Researcher Vision

influence the change of river morphology. In order to minimize the change of river morphology as part of river system in general, the local government stated in its spatial planning that the river buffer zone area, which is 100 meter from river to land on both riversides. The least important criteria selected were the bare soil expansion and distance to road that indicate the change in land cover, because change of land cover can be improved by doing reclamation in the extraction site. The result was shown in Figure 4-14. There are four sites which show the high physical impacts: site 3, 11, 12, and 5. Site 9 and 13 have low physical impact with appraisal score of 0.33 and 0.28. The remaining extraction sites are categorized as having moderate physical impact due to gravel and sand extraction.

Table 4-16 presents the summary of physical impact level resulted from different weights assigned by different stake holders and for the equal weight vision.

Table 4-16 Level of Physical Impact for each extraction site based on different visions

Site Number	Rank				
	Equal	Mining Office	Environment Office	GTZ Derived	Researcher
1	Low	Moderate	Low	Low	Moderate
2	Moderate	Moderate	Moderate	Moderate	Moderate
3	High	High	High	High	High
4	Moderate	Moderate	Moderate	Moderate	Moderate
5	Moderate	Moderate	Moderate	Moderate	High
6	Moderate	Moderate	High	Moderate	Moderate
7	Moderate	Moderate	Moderate	Moderate	Moderate
8	Moderate	Moderate	Moderate	Moderate	Moderate
9	Moderate	Low	Moderate	Moderate	Low
10	Moderate	Moderate	Moderate	Moderate	Moderate
11	High	High	High	High	High
12	Moderate	High	High	Moderate	High
13	Moderate	Low	Moderate	Moderate	Low
14	Moderate	Moderate	Moderate	Moderate	Moderate

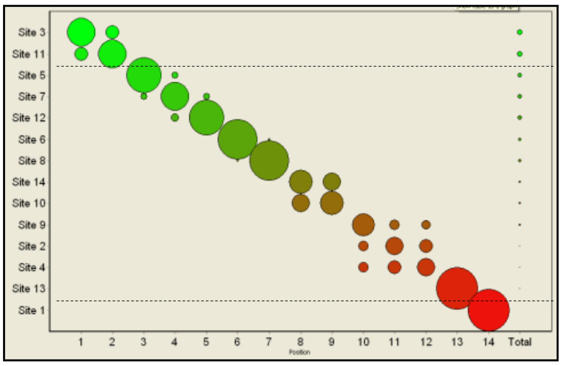
The table shows that site 3 and 11 have the highest overall impacts for all visions. The sites 2, 4, 7, 8, 10, and 14 always show as moderate impact for all visions. There is no certain site which always has low impacts in all visions. Site 1 has low impact in three visions (equal, Environment office and GTZ visions) and moderate impacts in other two visions. Site 5 and 6 has moderate impacts in four visions and high impact in one vision (researcher and Environment Office Respectively). Sites 9 and 13 have low impacts in Mining Office and researcher vision, but moderate impact in other three visions. Site 12 has moderate impact in equal and GTZ vision and high impacts in Mining office, Environment Office and researcher vision.

4.4.3. Sensitivity Analysis

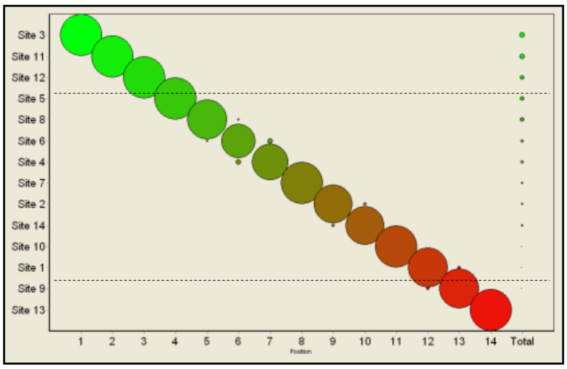
The sensitivity analysis was conducted to see the robustness of ranking result based on weight and score assigned. It consists of weight and score uncertainty and sensitivity to rank reversal.

4.4.3.1. Weight and Score Uncertainty

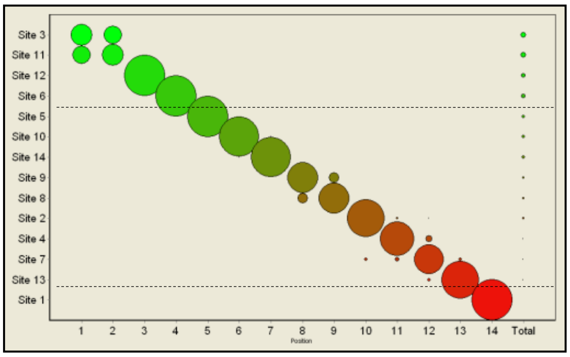
For weight uncertainty, all criteria were given the same value, which is 20% of uncertainty. This value was chosen because there is no specific literature found to assigned weight of these selected criteria. The result of sensitivity analysis in weight uncertainty was provided in Figure 4-15. The dashed line was the separator of class showing the level of impact. In equal weight (a) and Environment Office vision (c), there is possibility for site 3 and 11 to be reversed in ranking. Since those sites are in the same class (high impact), there is no change in the class of physical impact in general.



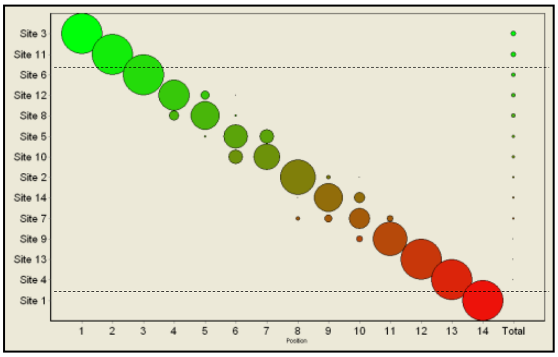
(a)



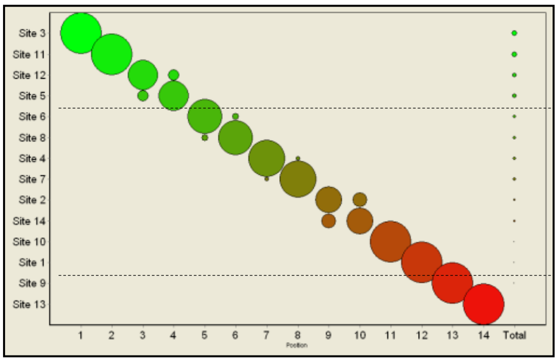
(b)



(c)



(d)

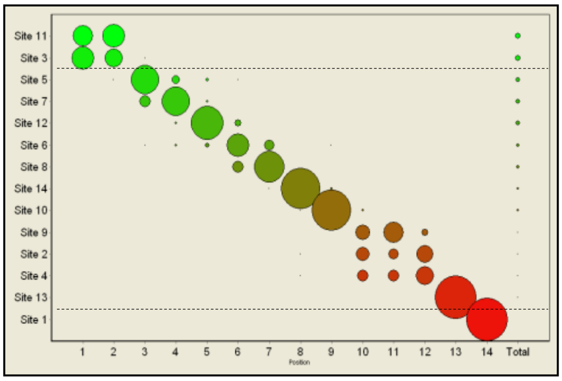


(a) : Equal Weight
(b) : Mining and Energy Office vision
(c) : Environment Office Vision
(d) : GTZ vision
(e) : researcher vision

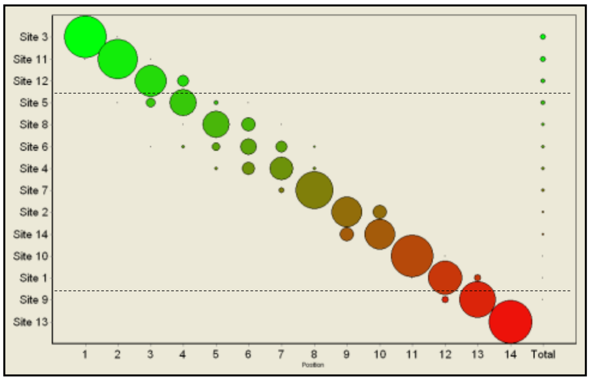
(e)

Figure 4-15 Site Rank in Weight Uncertainty

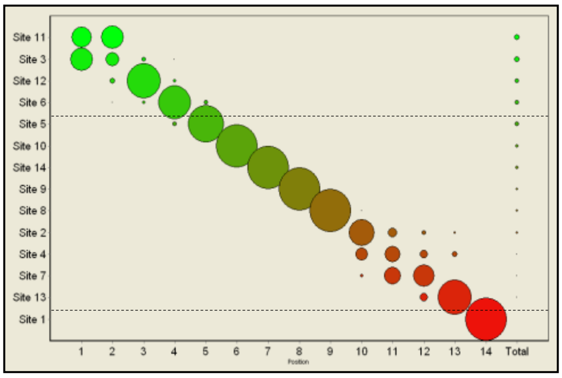
For score uncertainty, 20% uncertainty was assigned to bare soil expansion, change of river shape and distance to the river, while 10% uncertainty was assigned to average slope and distance to road and bridge. It is based on the source of data used to produce the score. For example, bare soil expansion was derived from remotely sensed image which was interpreted visually and digitized on screen. The uncertainty of score produced was higher than the criteria whose scores produced by remotely sensed image processed using reliable software, for example average slope which is derived from the ASTER GDEM. Uncertainty analysis was performed for each vision, and the result was provided in Figure 4-16. Similar to weight uncertainty analysis, there are several sites in certain visions that had probability to change in rank, for example sites 3 and 11 in visions (a), (c) and (d). Since they are in the same class, it does not change the class of physical impact.



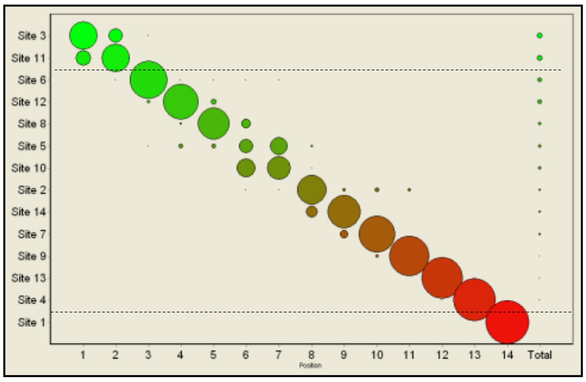
(a)



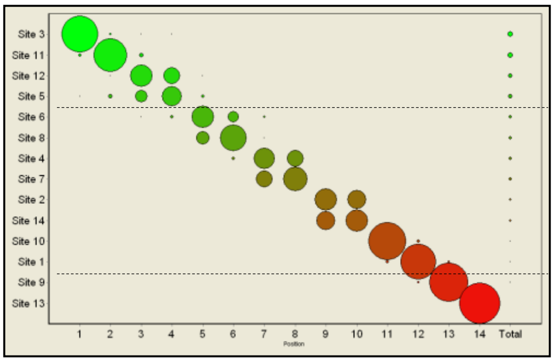
(b)



(c)



(d)



(e)

(a) : Equal Weight
(b) : Mining and Energy Office vision
(c) : Environment Office Vision
(d) : GTZ vision
(e) : Researcher vision

Figure 4-16 Site Rank in Score Uncertainty

4.4.3.2. Sensitivity Analysis and Rank Reversal

Sensitivity analysis was conducted for extraction sites which have similar appraisal score. In this condition, rank reversal that can result in class reversal was possible to occur. From all rankings and classes based on different visions, it is occurred in ranking based on weight assigned by Mining and Energy Office vision (see Figure 4-8). Site 12 considered as high (appraisal score: 0.69) and Site 5 considered as moderate (appraisal score: 0.67). In addition, site 1 is considered as moderate (appraisal score: 0.35) and Site 9 considered as low (appraisal score: 0.33). The result of sensitivity analysis is presented in Table 4-17.

For all criteria, the reversal value of sites 12 and site 5 was not within range of 10% from original value which means that there is no possibility of rank reversal. For sites 1 and 9, in one of criteria (distance to bridge), the reversal value was within 10% of original value meaning that there is small possibility that a rank reversal may occur.

Table 4-17 Sensitivity of Weight in Mining and Energy Office vision

No	Criteria	Reversal value		Original value	-10% from original value	+10% from original value
		site 12 and 5	site 1 and 9			
1	Bare soil expansion	0.8993	0.1192	0.0820	0.0738	0.0902
2	Distance to road	0.0527	0.0837	0.0280	0.0252	0.0308
3	Distance to river	0.0000	0.2022	0.0820	0.0738	0.0902
4	Average slope	0.1440	0.2682	0.2000	0.1800	0.2200
5	Change in river shape	0.1238	0.2696	0.2000	0.1800	0.2200
6	Distance to bridge	0.4629	0.3773	0.4080	0.3672	0.4488

For sensitivity analysis regarding the score, several scores was selected randomly and checked. The result is that there is no score which was within range of 10% from the original value, so that there is no rank reversal may be expected. Based on the uncertainty and sensitivity analysis, it can be concluded that the ranking results for five different visions as is shown in Table 4.16 is rather robust.

4.4.4. Legal and Illegal Extraction site

From 14 extraction sites studied in this research, only 6 of them (Site 2, 3, 4, 5, 11 and 13) have permit to do gravel and sand extraction issued by local government of Aceh Besar Regency. The remaining extraction sites are illegal. A summary of legacy status related to ranking result based on different visions is presented in Table 4-18.

None of the 8 illegal extraction sites show a high impact, except site 6 for 1 vision, six extraction sites (site 6, 7, 8, 10, 13, and 14) show a moderate impact and 2 sites (site 1 and 9) show a low impact. Legal extraction sites (site 2, 3, 4, 5, 13 and 14) have high to moderate physical impact according to different visions. Sites 3, 11 and 12 have high impact in almost all visions and sites 2, 3 and 5 have moderate impacts in almost all visions.

Table 4-18 Legacy Status and Ranking Result

Extraction Site	Legacy Status	Class of Physical Impact
Site 1	Illegal	Low in 3 visions; Moderate in 2 visions
Site 2	Legal	Moderate in all visions
Site 3	Legal	High in all visions
Site 4	Legal	Moderate in all visions
Site 5	Legal	Moderate in 4 visions; High in 1 vision
Site 6	Illegal	Moderate in 4 visions; High in 1 vision
Site 7	Illegal	Moderate in all visions
Site 8	Illegal	Moderate in all visions
Site 9	Illegal	Low in 3 visions, Moderate in 2 visions
Site 10	Illegal	Moderate in all visions
Site 11	Legal	High in all visions
Site 12	Legal	High in 3 visions; Moderate in 2 visions
Site 13	Illegal	Moderate in 3 visions; Low in 2 visions
Site 14	Illegal	Moderate in all visions

5. DISCUSSION

Land Cover Change and Bare Soil Expansion

In 2005, the total 0f 67.9 hectares of bare soil can be found around the 14 extraction sites used in this research (Table 4-1). This number should be less, considering that 2005 was the starting year of reconstruction process (right after the Tsunami on December 26, 2004). Several possible reasons can identified to explain the situation. First, the imagery used to make the land cover map was taken on October, 2005 while the reconstruction process lead to gravel and sand extraction started in the beginning of 2005. Between January and October, 2005, gravel and extraction site started to operate and it changes the existing land cover into bare soil. The second reason will be the type of river. Krueng Aceh River is a meandering river, where deposits of gravel and sand mostly come from its meander. The river meander was interpreted as bare soil, even though there is no extraction sites existed in that area. It is also the reason why bare soil expansion used as one indicator to indicate the gravel and sand extraction.

Bare soil expansion in the area where there is an extraction site was higher than in the area where there is no extraction site (table 4-5). Specifically in site 7, even though the bare soil expansion in the Northern part (without extraction site) is lower than the Southern part (with extraction site), the percentage of bare soil expansion in Northern part is quite high (20.5%) compare to bare soil expansion in other area without extraction site. It is because actually, there was also extraction site in the Northern part, but the time of operation is shorter than extraction site in the Southern part (Site 7). The extraction site in the Northern part was operated from 2007 to 2009 and therefore, it was not selected as one of extraction sites used in this research. The shorter the operation time of an extraction site, the less the bare soil expansion.
In other cases, the increase of bare soil (bare soil expansion) in the area without extraction site is not only lower, but also decreases (site 3 and 6). The reason might be still related to the operation time of the extraction site. There might be an extraction site in the Northern part of site 3 and 7, but they started in 2005 and ended several years after (not until 2009). From the year that the extraction site ended to 2009, the existing land cover type (bare soil) might have changed into another land cover type, like shrub or crops.

Change in River Shape

It was expected that the change of river shape will be bigger in downstream, because the change will be accumulated there (Roel, 1999). Based on the result (see section 4.2.3.1), there is no certain pattern in the change in river shape. The biggest change was showed at sites 3, 11 and 12 which are located in upstream (site 3) and downstream (sites 11 and 12). Site 14 which is located in the most downstream part shows a moderate change, and site 13 which is located between the big and moderate change show a small change. This condition can be caused by a slight difference in elevation between the most upstream and downstream in the study area. The distance from site 1 to 14 is 16.9 kilometres and the slope is about 14.9^{0}. Another reason is because of the differences in gravel and sand extraction characteristics, like size of extraction site, volume of extraction, and average slope.

The relationship between change in river shape and gravel and sand extraction (size of extraction area, volume of extraction, distance to river and average slope) was not very strong (see section 4.2.3.2), since the regression analysis explains 58.3% of the data variability. This result might be because of the small number of samples and the dynamic of river system.

Comparison this result with GTZ result

It can be inferred from the results that different weight assigned by five different visions results in a variety of ranking results and level/class of physical impact for each extraction site, as is shown in Table 4.16. The same class of physical impact in all visions occurred in sites 3, 11, 2, 4, 7, 8, 10, and 14, where sites 3 and 11 are considered as having high impact and the rests are considered as having moderate impact.

GTZ has conducted research related to impact assessment of gravel and sand extraction in Krueng Aceh river basin area, but that research focused more on the environmental damage due to gravel and sand extraction (Hendratno, 2006). The result of the GTZ research was that 5 extraction sites (site 5, 6, 7, 13, and 14) have high environmental damage and 9 extraction sites (site 1, 2, 3, 4, 8, 9, 10, 11, and 12) have moderate environmental damage. In GTZ result, more extraction sites are considered than in this research, including also the low environmental damage (see also section 2.2.4).

None of the five visions used in this research has similar result to GTZ result, but in general, similarity and differences were occurred between GTZ result and five visions. Site 2, 4, 8, 9 and 10 are categorized as having moderate class in both results. The differences are occurred for the remaining extraction sites. For several sites, class resulted by GTZ is higher than class resulted in this research. For example, all extraction sites considered as high class in GTZ result (sites 5, 6, 7, 13 and 14) are mostly categorized as moderate class in this research. The opposite condition is also occurred, where the class resulted by GTZ is lower than class resulted in this research. Extraction sites 3, 11 and 12, which are categorized in moderate class in the GTZ result, have a high class in this research.

These differences may come from several reasons. Different indicator used to assess the impact is the main reason of the differences. GTZ used 9 indicators (see Table 2-2) include mining technique, volume of extraction, the depth, slope and size of the pit, rock characteristics, distance to river, erosion level and reclamation to assess the environmental damage. From those indicators, only distance to river and erosion level (translated into average slope, bare soil expansion and distance to road) used in this research, through certain adjustment with the data availability. Other indicators used in this research are distance to bridge and change in river shape as the indicator, which are not considered by GTZ.

Other possible reason is the different weight assigned for each indicator used. GTZ give more weight on indicators which can directly damage the environment. In this research, different weight was assigned based on 5 visions (1 equal weight and 4 stakeholder vision). In stakeholder vision, each stake holder has their own perception in deciding the scale of important for each indicator.

In addition, different time line when research was conducted may affect the different class resulted. GTZ research was conducted in mid of 2006, which is 1.5 year after the Tsunami of 2004. It means that the result explains only the impact due to gravel and sand extraction occurred within 1.5 years. Meanwhile, this research assesses the impact due to gravel and sand extraction between 2005 and 2009. Many changes are expected to occur between mid of 2006 to 2009. Since the reconstruction process still continues until 2009, there is possibility that the volume of extraction increase in several extraction site. This can result in the change of impact class from moderate to high, as it is occurred in site 3, 11 and 12. It is also related with the legacy status in each extraction site (Table 4-17). The increase of class happens in extraction sites which have permit to do extraction (legal), for example are site 3, 11 and 12. In most of illegal extraction sites, the class are relative stable (site 8, 9, and 10) or even decrease, from high to moderate (site 6, 7, 13 and 14) and moderate to low (site 1).

These two researches were conducted using different approaches in data collection. Data needed for indicators used in this research are mainly derived from remote sensing and existing spatial data, while the research conducted by GTZ used data which were mostly obtained from the field. The combination of the two approaches may result in the more comprehensive and accurate result in assess the impacts due to gravel and sand extraction within Krueng Aceh river basin area. For example, the size of extraction site area is rather difficult to measure in the field, but it can be measured easily using remote sensing data.

This research has some limitations as follows:

- The physical impact assessment only focuses on 14 extraction sites which are operated from 2005 to 2009, while from observations on land cover change, there are other extraction sites which have significant impacts on land cover change but they are not assessed in this research
- The 14 selected sites cannot well represent the real gravel and sand extraction activity within Krueng Aceh river basin area. Krueng Aceh river basin area covers a big area where there are more than 30 extraction sites within it. In addition, in executing statistical analysis, for example regression analysis, the more sample used will produce more representative results.
- SPOT image of 2005 and 2009 used to generate the land cover map did not have the original bands, so a supervised classification could not be carried out. The land cover map produced was therefore generated through visual interpretation and on screen digitizing.

6. CONCLUSION AND RECOMMENDATION

The conclusion of the research can be summarized as follows:

Key indicators

1. Bare soil expansion, distance from extraction site to main road, average slope within extraction area, distance from extraction site to river, change in river shape and distance from extraction site to downstream bridge are key indicators to assess the physical impact of gravel and sand extraction within Krueng Aceh river basin area.
2. The higher the value of bare soil expansion, distance to main road, average slope and change in river shape, the higher the physical impact from gravel and sand extraction. The higher the value of distance to river and downstream bridges, the less the physical impact.

Change in land cover

3. In 2005, 100 meter buffer zone was dominated by water (24.8%), forest (21.5%), paddy field (21.4%) and crop (18.33%) and 100-250 meter buffer zone was dominated by forest (37.6%), paddy field (31.6%) and crop (14.9%). Bare soil occupied only 8.6% in the 100 meter buffer zone and 1.85% in the 100-250 m buffer zone (Table 4-1).
4. In 2009, 100 m buffer zone was dominated by water (27.5%), forest (20.3%), and paddy field (18.6%) and 100-250 m buffer zone was dominated by forest (33.6%), paddy field (33.2%) and crop (14.1%). Bare soil increase to 12.5% in the 100 m buffer zone and 5.11% in the 100-250 m buffer zone (Table 4-2).
5. Between 2005 and 2009, there are decreases in forest, crop and shrub and an increase in bare soil and built up area. Paddy field decreased in the 100 m buffer zone and increased in the 100-250 m buffer zone (Table 4-4).
6. There is a significant difference in bare soil expansion between area with and without extraction site. In 100 m buffer zone, percentage of bare soil expansion in area with extraction site was ten times higher than in area without extraction site. In 100-250 m buffer zone, bare soil expansion was fifteen times higher than area without extraction sites (Table 4-4)
7. The highest bare soil expansion occurred in site 7 (53.5%), followed by site 9 (30.9%), site 10 (30.5%), and site 14 (30.3%). The remaining sites have less than 30% (site 11, 4, 3, 13 and 8), less than 20% (site 6) and less than 10% (site 5, 12, 1, 2) of bare soil expansion (Table 4-5).
8. All extraction sites are located more than 100 meter from the main road. The nearest distance from extraction site to main road is 120.3 m (site 6), and the largest distance in 408.9 meter (site 7); see Table 4-7.

Change in river morphology

9. There are 12 of 14 extraction sites located within 100 meter from the river. The nearest distance from the river is 5.57 meter (site 3) and the largest is 152.23 meter (site 7); see Table 4-8. Meanwhile, 100 meter from both side of river is protected area according to President Decree 23/1990.

10. Eight extraction sites (sites 7, 9, 3, 1, 8, 13, 4 and 2) have less than 5^0 on average slope in extraction area and six extraction sites (5, 6, 10, 11, 12 and 14) have 5^0 to 8^0 of average slope (Table 4-9)
11. The highest average change of river shape between 2005 and 2009 occurred in site 12 and 11 (32.9 and 32.18 meter). The smallest average change occurred in site 8 (11.07 meter); see Table 4-10.
12. The change of river shape was influenced by gravel and sand extraction, because the adjusted R^2 of multiple linear regression analysis between gravel and sand extraction (independent variables) and change of river shape (dependent variable) was 58.3%. The chance to reject the hypothesis (p-value) that stated 'the change of river shape was influenced by gravel and sand extraction was only 1.6%.

<u>Damage to hydraulic structures (bridges)</u>

13. There are four extraction sites (site 4, 8, 3, and 7) located less than 1000 meter to the downstream bridge, while other ten extraction sites located more than 1000 meter to downstream bridge. It is contradicted with Directorate General of irrigation's Decree 176/KPTS/1987 about the minimum distance from extraction site to bridge. It is stated that the minimum distance is 1000 meter downstream, to protect the river system.

<u>Overall physical impact of gravel and sand extraction within Krueng Aceh river basin area</u>

14. In all five visions considered in this research, site 3 and 11 show the highest overall physical impact, six extraction sites (site 2, 3, 7, 8, 10 and 14) show moderate impact, and site 1 shows for 3 visions a low impact (Table 4-16).
15. There are no illegal extraction sites which have high impact. Illegal extraction sites have moderate to low impact, while legal extraction sites (sites 2, 3, 4, 5, 11, and 12) considered as having moderate to high impact according to ranking result in different visions. Sites 3 and 11 always show as high impacts and sites 2 and 4 always show as moderate impact. Site 5 has moderate impact in 4 visions and site 12 has high impact in 3 visions.
16. Based on sensitivity analysis in uncertainty and possibility of rank reversal for weight and score assigned, the ranking result for all visions is rather robust.

<u>Comparison to GTZ result (class of environmental damage)</u>

17. According to GTZ result, 5 extraction sites (sites 5, 6, 7, 13, and 14) have high impact and the rest are considered as moderate impacts.
18. Only five extraction sites (2, 4, 8, 9 and 10) show a similar result, which has same class (moderate).
19. Sites 3, 11 and 12 were considered as moderate in GTZ result, but they were considered as high in almost all visions in this research. In contrary to this, Sites 5, 6, 7, and 14 are considered as high in GTZ result, but considered as moderate in almost all visions.
20. The differences between GTZ result and this research result might be because of the different criteria or indicators used. Only four criteria used in this research can be associated to indicators used in GTZ research. Another reason is that because of the different weight assigned for each indicator and the different of time interval.

Recommendation from this research:

1. Related to limitations of this research, the future research is expected using more extraction sites in more specific time interval, for example: every year, so that the physical impact can be assessed in more detail and statistical analysis will give more representative results. The use of more indicators derived from reliable source and combination of remote sensing with field observation data is expected to lead to a more comprehensive result.
2. Related to the results and discussion of this research, there is a need for the local government of Aceh Besar Regency, through its authorized institutions, to regularly monitor and evaluate each legal extraction site and seriously implement the law enforcement for the illegal extraction sites.

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ANNEX 1. LAND COVER TYPE OF 2005 AND 2009

No	Land Cover Type	Size (Ha)			
		2005		2009	
		100 m	100-250 m	100 m	100-250 m
Seulimuem sub district					
1	Water	69.88	3.85	74.91	1.03
2	Bare Soil	39.87	12.57	46.46	23.90
3	Shrub	14.65	39.13	8.81	32.51
4	Crop	64.23	88.08	65.61	87.21
5	Forest	58.39	138.62	52.20	123.97
6	Paddy Field	40.25	87.15	35.71	91.42
7	Built Up Area	6.42	32.65	10.00	42.01
Kota Cot Glie sub district					
1	Water	53.51	3.21	58.34	0.81
2	Bare Soil	3.15	2.68	21.80	16.38
3	Shrub	0.00	0.00	0.00	0.00
4	Crop	13.49	19.13	8.38	14.92
5	Forest	32.52	89.48	28.46	77.40
6	Paddy Field	85.97	143.19	72.75	149.63
7	Built Up Area	5.07	19.20	3.97	17.74
Indrapuri sub district					
1	Water	27.98	0.80	32.11	0.40
2	Bare Soil	4.81	1.12	9.16	1.25
3	Shrub	0.73	1.56	0.56	1.86
4	Crop	34.19	18.21	21.00	18.39
5	Forest	38.82	90.26	42.21	83.36
6	Paddy Field	4.64	37.79	3.75	40.49
7	Built Up Area	5.79	18.10	8.17	22.09

ANNEX 2. VALIDATION DATA FOR ACCURACY ASSESSMENT OF 2009 LAND COVER MAP

No	X	Y	Land Cover Type	No	X	Y	Land Cover Type
1	772571	599762	Water	46	786812	589846	Shrub
2	784066	594282	Water	47	785407	591422	Shrub
3	784940	593792	Water	48	786773	590558	Forest
4	786509	591197	Water	49	786773	590558	Forest
5	786922	589663	Water	50	786394	591079	Forest
6	787153	589203	Bare Soil	51	785524	591299	Forest
7	786933	590586	Bare Soil	52	779936	596064	Forest
8	784427	594399	Bare Soil	53	774772	598292	Forest
9	782854	593937	Bare Soil	54	773852	599865	Forest
10	781817	594367	Bare Soil	55	773437	599310	Forest
11	780966	594990	Bare Soil	56	785700	592166	Forest
12	779871	595775	Bare Soil	57	784988	593267	Forest
13	780047	596413	Bare Soil	58	786685	591626	Forest
14	778613	596851	Bare Soil	59	785584	592593	Forest
15	778250	597512	Bare Soil	60	772835	599963	Paddy Field
16	777320	597655	Bare Soil	61	773986	599722	Paddy Field
17	775064	598428	Bare Soil	62	776495	598179	Paddy Field
18	773330	599131	Bare Soil	63	778492	598341	Paddy Field
19	779190	596637	Bare Soil	64	779860	596883	Paddy Field
20	780183	596550	Bare Soil	65	783678	594480	Paddy Field
21	781679	594432	Bare Soil	66	786438	591805	Paddy Field
22	785432	592629	Bare Soil	67	786710	590498	Paddy Field
23	787399	590378	Bare Soil	68	786242	590874	Paddy Field
24	787188	589119	Crop	69	784752	593866	Paddy Field
25	785584	591238	Crop	70	784032	593978	Paddy Field
26	784422	594123	Crop	71	781801	594178	Paddy Field
27	782639	593907	Crop	72	777297	597421	Paddy Field
28	781257	594457	Crop	73	773667	598552	Paddy Field
29	779806	595944	Crop	74	782561	593882	Paddy Field
30	776095	597601	Crop	75	786691	589616	Paddy Field
31	775002	598418	Crop	76	786677	591529	Built Up Area
32	772828	599711	Crop	77	785691	592227	Built Up Area
33	775059	598583	Crop	78	785747	592786	Built Up Area
34	780135	596576	Crop	79	783918	594439	Built Up Area
35	783530	594282	Crop	80	780214	596721	Built Up Area
36	785018	593759	Crop	81	776140	597955	Built Up Area
37	785653	592610	Crop	82	773782	599814	Built Up Area
38	786553	591526	Crop	83	772743	599933	Built Up Area
39	786797	589517	Shrub	84	773756	598671	Built Up Area
40	787024	590001	Shrub	85	778521	596851	Built Up Area
41	785226	592355	Shrub	86	779801	596076	Built Up Area
42	774328	598092	Shrub	87	781188	594581	Built Up Area
43	775100	598791	Shrub	88	784111	594184	Built Up Area
44	783672	594413	Shrub	89	773425	599566	Built Up Area
45	787265	589489	Shrub				