

Anthropogenic Disturbance of Mining Activities  
with Geomorphologic Change

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(地形変化を伴う資源採掘による人為的攪拌に関する研究)

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## Abstract

Anthropogenic material flows & stocks are expanding at ever-increasing rates across the world, and their environmental and economic impacts draw more and more attention from industry, academia, policy-makers, economic, and environmental bodies. Stocks such as buildings, consumer products, factories, and infrastructure are essential foundations of society thus support economic activities and provide services. As the knowledge base regarding anthropogenic material flows & stocks expansion, it is important to not only comprehend the societal side of material consumption and stock growth but also its counterpart to the material balance—the natural environment from which the materials come from and to go. The globally common environmental impact, anthropogenic disturbance caused by material extraction is destructive and irreversible effect on natural environment, while only few studies mentioned relationship between material flow and its direct impacts on natural environment. In addition, due to difficulties of data procurement, and muted interest in materials which are considered low-value high volume, the environmental burdens especially related to construction minerals have received less attention so far despite the huge amounts involved. In this study, top-down method; statistics and bottom-up method; geographic information systems (GIS) with digital elevation model (DEM) and landcover datasets were employed, to form a common method of monitoring and measuring of the anthropogenic disturbance at mining and fill sites. This geographically explicit method allowed to directly point out location and volume of anthropogenic disturbance.

In chapter 1, academic and politic background of sustainable development, especially, which is related to material flows and stocks were introduced. We focused on issues accompanying huge amount of material consumption and accumulation in the socio-economic sphere is anthropogenic disturbance. The state of art researches and remote sensing techniques were introduced in this chapter.

In chapter 2, two types of DEMs were applied to spatially quantify the impact of humans on natural environment by estimating Japanese domestic Hidden Flows (HF). We found not only potential volume of HF by comparing the respective results of bottom-up and top-down accountings, but also spatial distribution of anthropogenic disturbance. The results showed that from 1987 to 2005, DEM-based methodology may produce an overestimation of as much as 1.6%–6%, depending on the accuracy of the original DEM. In the bottom-up accounting, the total area of the anthropogenic disturbance, 170 million m<sup>2</sup> and volume of the anthropogenic disturbance, 5.8 billion m<sup>3</sup> which comprised the Domestic Extraction (DE) and HF. Top-down accounting, total volume of DE was 3.2 billion m<sup>3</sup>. By comparing two results, we estimated the potential volume of domestic HF, 2.6 billion m<sup>3</sup> of mining sector. A special feature of this study was the use of a direct analysis of anthropogenic landform change to calculate material extraction.

In chapter 3, a methodology of automatic detection and measurement of anthropogenic disturbance at material extraction sites was developed. Using Japan as a case study, ArcGIS's Weighted

Overlay Tool was used, a computational tool which can solve geographic multi criteria problems such as site selection and suitability model. The results suggested that ratio of unused extraction to used extraction may exceed 1:1 for construction minerals. We also found that the environmental effects of anthropogenic activity are bigger than natural soil disturbance by several orders of magnitude. The annual average volume of material removed by anthropogenic disturbance per area was thus about  $3.1 \text{ m}^3/\text{m}^2$  per year, while loss of surface soils by natural phenomena such as water flow or wind is  $0.00028 \text{ m}^3/\text{m}^2$  per year, four orders of magnitude less than anthropogenic disturbance. And the mining and quarrying sites spread all over Japan, because of the low-cost and that were not transported over long distance to shorten the supply; mining and demand; urban area.

In chapter 4, dynamic of anthropogenic disturbance and its relevance to material flows such as DE and waste flows of Germany were discovered. Total area and mass of mining is 570 million  $\text{m}^2$  and 15.3 billion tonnes, while total area and mass of filling is 390 million  $\text{m}^2$  and 7.76 billion tonnes. In addition, location information of them may be useful for policy making, green business strategy design for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management. We also mentioned the existence of HF, which is used for backfill. HF such as waste rocks and overburden were regarded as no-economical materials, however, they have been used effectively to fill voids in material extraction site. We found mass of effective use of unused materials achieves 14.1 billion tonnes.

In chapter 5, Japanese and German anthropogenic disturbances were compared. The gap of annual volume per area of anthropogenic disturbance between Germany ( $0.85 \text{ m}^3/\text{m}^2$ ) and Japan ( $3.41 \text{ m}^3/\text{m}^2$ ) is  $2.56 \text{ m}^3/\text{m}^2$ , this would be caused by the difference of original national geography, type of mining, and sense of conservation of nature. The analysis of geographical features can contribute to assess the environmental impact of anthropogenic disturbance in a common framework.

In chapter 6, a summary of this study, findings and future works of anthropogenic disturbance were described. We also showed benefits for academics, industry, and policy-maker with possibility of developing common framework of monitoring anthropogenic disturbances. The DEM used methodology can be available in countries with poor statistics to develop of used and unused materials databases. Additionally, we mentioned necessity of another reliable and efficient methodology for global scale analysis in addition to three different methods (visual interpretation, automatic detection, and landcover), which were presented in previous chapters.

**Keywords:** anthropogenic disturbance, digital elevation model, hidden flows, domestic extraction, landfill, geographical information system

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# 1 Introduction

## 1.1 Movement toward sustainable society

More than 50% of the world population is living in urban area and this number is expected to be increased up to 70% by 2050. In next four decades, great number of people will be added in urban area; 1.2 billion from Africa, 1.9-3.3 billion from Asia which include 341 million from China. (UN DESA 2011). The population growth would influences economic growth and put pressure against natural environment, public health, and water supply from their agricultural, industrial, and manufacturing process (Bringezu et al. 2004, Kennedy et al. 2007). In response of the urbanization and a rapid economic growth including environmental impacts, resource efficiency, and sustainable management of natural resources would become more important in the global political agenda. In the recent global political meeting, Transforming Our World: 2030 Agenda for Sustainable Development which is held by United Nations show various plans of actions for human, global society, planet, and prosperity were developed in order to achieve universal peace in larger freedom (United Nations General Assembly 2015). It is a replacement of Millennium Development Goals, and it is agreed by leaders of most countries and stakeholders in the world. The 2030 agenda is a declaration of universal peace by means of implementation and renewed global partnership, and a framework for review and follow up. They put up 17 Sustainable Development Goals and 169 targets that will stimulate actions with integration of the 3 pillars of sustainable development: environmental, economic, and social sustainability. Noteworthy goals from the perspective of resource efficiency and sustainable management of natural resources are Sustainable Development Goals 8 (promote of sustainable economic growth and productive employment) and 12 (ensure sustainable consumption and production). However, as DPSIR (Driving Forces, Pressure, States, Impacts, Response) frame work explains, economic activities would be a driver of stress of human activities place on the environment (environmental pressure) and trigger to huge effect of environmental degradation (environmental impact) such as ecosystem and health loss and resource scarcity. The society's economic system starting from raw material extraction and processing through manufacturing and use toward waste management would bring environmental impacts such as acidification, biodiversity loss, climate change, eutrophication, soil erosion, land pollution, and water pollution. It is trade-offs between drivers and environmental impacts.

These Sustainable Development Goals encourage need of decoupling natural resource use and environmental impacts from economic growth that is supported by effective strategies and policy frameworks (UNEP 2011; UNEP 2016). SDGs were built-up through a

political negotiation process between the member nations, and it's not based on a scientific consensus process; therefore, conceptual and methodological challenges arise in the measurement of progress. How do we monitor the progress of decoupling natural resource use and environmental impacts?

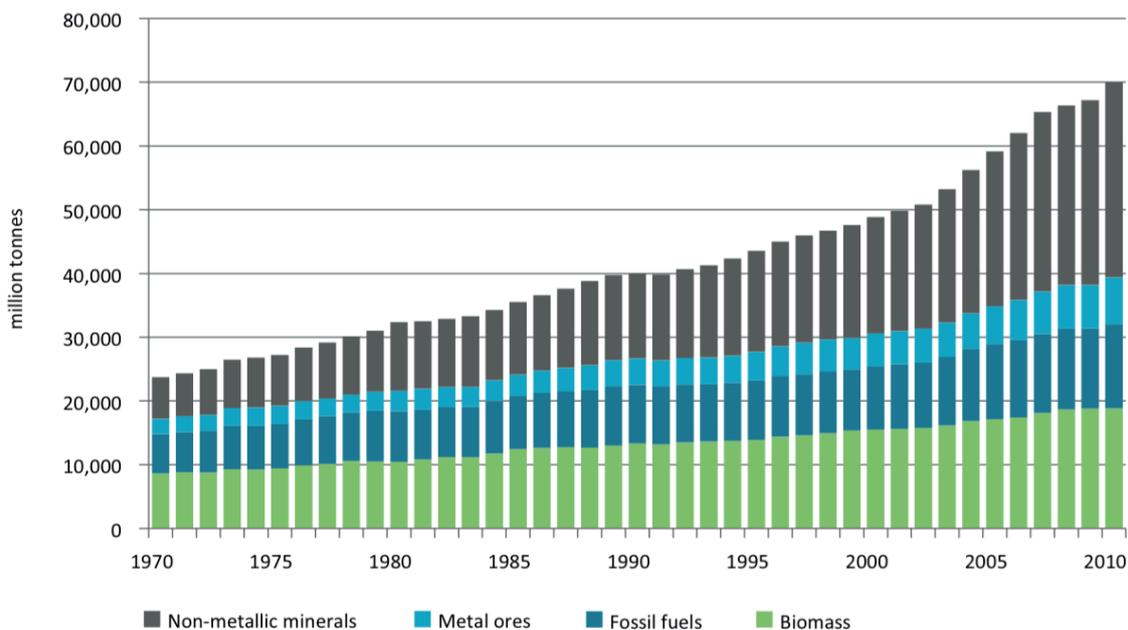


Fig.1.1 Global material extraction by 4 categories between 1970 to 2010 (adapted from UNEP 2016)

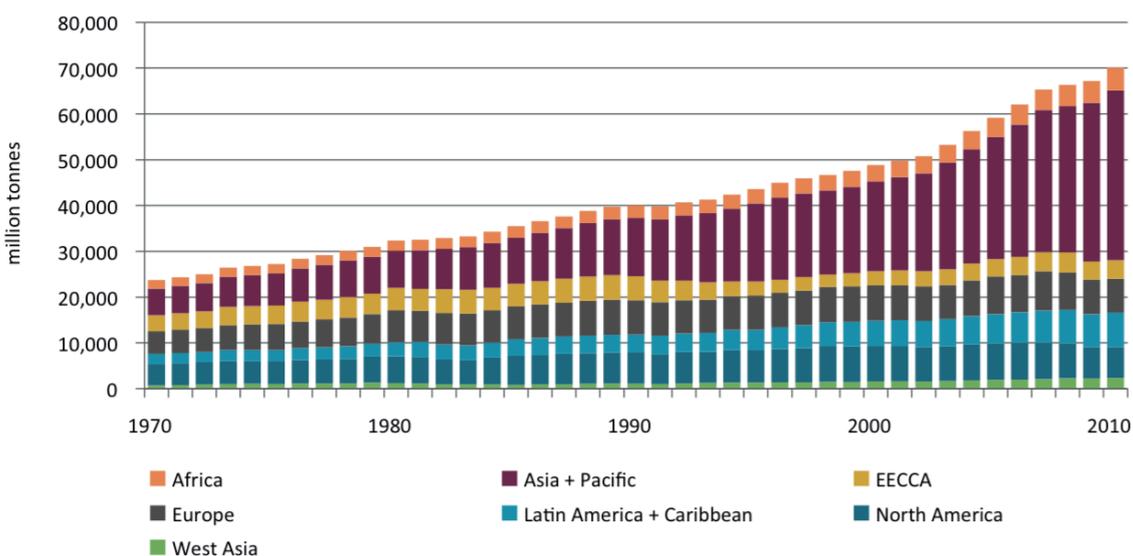


Fig.1.2 Global material extraction by 7 subregions between 1970 to 2010 (adapted from UNEP 2016)

Since the industrial revolution, human society requires great amount of natural resources to develop and maintain their socio-economical society. It is clear that is unavoidable for human society not to consume great amount of natural resources with global material extraction that has accelerated over the past four decades. From 1970 to 2010, it increased from 22 billion tonnes to 70 billion tonnes (UNEP 2016). Non-metallic minerals for construction use was the fastest growing materials. The material extraction growth is not even in the global economy, Asia and Pacific area had the large growth compared other area (Fig1.1 and 1.2). In recent years, the global amount of construction minerals entering the economy has reached about 35 billion tonnes per year, or around 5 t per person per year, although there are large discrepancies among countries: in China, the figure is over 13 t per year per person, while in Africa the per-capita average is only about 1.5 t per year (Miatto et al. 2017). Reducing the natural resource consumption and promoting economic growth with lower material input without environmental impacts are main mission of International Resource Panel (IRP), which is launched by UNEP in 2007. Scientists of IRP identify global issues which are related to sustainability and produce state of the art reports, advices and documents toward different audiences (IRP 2017). UNEP is in charge of the foundation of policy engagement with a lot of nations in the world by presenting new data and insights, raising awareness of issues, framing policy problems, developing open access database and verification through country data (IAEG-SDG 2016). Accurate and reliable database of resource consumption and indicators, which represent resource efficiency and environmental impact, are required in order to complete their works. Those database and indicators are supported by a lot of researches of economy-wide material flow analysis; qualitatively and quantitatively track material flows of natural resource extraction, consumption, production, recycling, and waste contribute to develop database and indicators making for sustainability (Adriaanse et al. 1997, Fischer-Kowalski et al. 2011, Matthews et al. 2000, UNEP 2016). In order to monitor Sustainable Development Goals 8 (promote of sustainable economic growth and productive employment) and 12 (ensure sustainable consumption and production), indicator of DMC/GDP, DMC/capita, planned indicator waste/capita and waste footprint /capita are applied for both developing and developed countries. DMC (Domestic Material Consumption) measures flow of natural resources used in enter socioeconomic sphere and is defined domestic material extraction plus imports minus exports (Eurostat, 2001). The resource efficiency is considered as not only environmental necessity but also as an economic, political and security opportunity with benefit for both industry and consumer (Behrens et al. 2015). That is how sustainable resources managements and decoupling are monitored. (Fig.1.3).

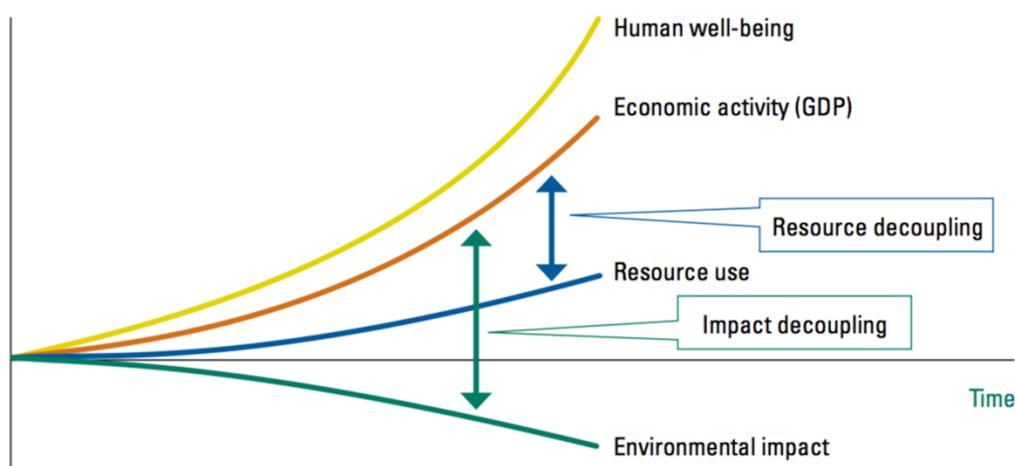


Fig.1.3 Concept of resource & impact decoupling by UNEP  
(adapted from UNEP 2011)

### 1.1.1 Close relevance of material stock & flow to anthropogenic disturbance

Industrial activity and rapid urban transformation require great amount of resources such as non-metallic minerals, metal ores, fossil fuels, and biomass. Especially, construction minerals including asphalt, gravel, sand and cement are accumulated in buildings, infrastructure, roads, and railways that bring great amount of HF (Hidden Flow). HF is a flow that does not enter the socioeconomic sphere such as loss of vegetation, overburden, and tailing flow caused by mining, construction and farming. When we focus on inflow and outflow materials at the socio-economical society, the construction minerals occupy the major part of them (Adriaanse et al. 1997, Matthews et al. 2000). Researches of Adriaanse et al. (1997) and Matthews et al. (2000) were some of the first conducted in the field of economy-wide MFA, and they set directions and foundations that continue to be relevant for the field of industrial ecology in the present time. The relationship between GDP, HF, DMI (Direct Material Input) and TMR (Total Material Requirement) of industrial countries such as Austria, Germany, Japan, Netherlands and the United States are analyzed for the purpose of enlarging our understandings of sustainable life, economics and development. DMI is a flow of natural resources that enter socioeconomic sphere for further processing. TMR is the sum of the total material input and HF. This is a total of materials which national economy required for their social activities. TMR would be a useful indicator that not only for showing eco-efficiency and resource productivity, but also for the potential environmental impact that is associated with natural resource extraction and use (Adriaanse et al. 1997, Eurostat 2001). The results show that they have similar trend of natural resource use instead of their different size of economics, population and land area. They also calculated volumes and percentages of construction

materials, which are related to all the domestic commodities in these countries were determined to be 1,730 million tonnes and 38%, 1,103 million tonnes and 77%, 749 million tonnes and 55%, and 59 million tonnes and 22%, respectively. As these data indicate, large amounts of construction minerals are transferred from the ecosphere to the socioeconomic sphere.

This material transfer causes geomorphological changes, mainly attributed to the effects of mining, soil excavation, infrastructural and land development, and cut and fill operations, among others. It causes large-scale disturbance of the biomass structure, induces unpredictable ecosystem changes, and alters often irreversibly the environment and topography (Bringezu et al. 2004, Hashimoto et al. 2006, Ross et al. 2016, Adriaanse et al. 1997) not only accounted for domestic commodities, but also for the HF of each commodity category. The total volumes and percentages of the HF relative to all the domestic commodities in the United States, Japan, Germany, and the Netherlands were determined to be 15,494 million tonnes and 338%, 1,143 million tonnes and 80%, 2,961 million tonnes and 217%, and 69 million tonnes and 25%, respectively. HF is usually not recorded in national statistics, thus each countries need to estimate HF by their own method. Each countries apply different methodology and there is not common procedures for accounting HF. Some research institute such as Vienna University of economics and business (WU), Eurostat, Resource Panel and research group applied each methodology to estimate global material flows. Table.1.1 represents overview and comparison of global material flow accounting dataset with coverage, source and estimation procedure (Fischer-Kowalski et al. 2011). Fischer-Kowalski et.al. (2011) also made a comparison of global used extraction between the five global data set (Table1.1) and explained the variation of estimation results of each categories (Table1.2). The main reason is coefficients, which are used in estimation of ores, industrial minerals and construction minerals. GDP is used by Krausmann and colleague (2008) in estimation of construction minerals, which is the most poorly covered by global statistics. The unreliability is not only founded in dataset, but also values of indicators, which are highly depended on dataset. Bringezu et al. (2004) illustrated differences of TMR (used and unused) by country and component, on the other hand, TMR and HF coefficient does not reflect the geographical characteristics. Still, there are issues of uncertainty for dataset and indicators that requires high reliability.

Table 1.1 Overview and comparison of global material flow accounting dataset with coverage, source and estimation procedure (adapted from Fischer-Kowalski et.al. 2011)

Reference	Schndl and Eisenmenger (2006)	Krausmann and colleagues (2008)	SERI (2009)	Krausmann and colleagues (2009)	Steinberger (2010)	Weisz and colleagues (2007)	Eurostat (2009)
Country coverage	173 countries	176 countries	203 countries	Global aggregate	176 countries	15 EU members	29 European countries
Time coverage	2000	2000	1980–2006	1900–2005	2000	1970–2004	2000–2005
Flow coverage	DE	DE, Im, Ex	DE	DE	DE, Im, Ex	ED, Im, Ex	DE, Im, Ex
Biomass data sources	FAO; e: global coeff.	FAO; e: country-specific coeff.	FAO; e: coeff. derived from Eurostat (2007)	FAO; e: global coeff. variable across time	FAO; e: country-specific coeff.	National statistics; FAO; e: European coeff.	National statistics; FAO; e: Eurostat (2007)
Ores and industrial minerals data sources	USGS; e: regional coeff.	USGS; UNICPS; e: national coeff.	BGS, USGS, UNICPS; WMD, national data; e: statistic national coeff.	USGS, e: global coefficients variable across time	USGS e: national coeff.	National statistics; UNICPS; e: European coeff.	National statistics; e: Eurostat (2007)
Fossil energy carriers data sources	IEA	IEA; UN statistics	IEA	IEA; UN statistics	IEA; UN statistics	National statistics; IEA	National statistics; IEA
Construction minerals data sources	e: development status; only for country groups	Combines information from statistical sources with a GDP-based estimate using PPPs	Combines information from statistical sources with a GDP-based estimate using const. prices	Physical estimate global aggregate only; no country data	Revised version of Krausmann and colleagues (2008). Physical estimate of construction minerals without using GDP	Reporting based on statistical sources; for some countries estimated on the basis of GDP	Reporting based on statistical sources; for some countries estimated on the basis of physical data

Note: DE = domestic extraction; Im = imports; Ex = exports; FAO = Food and Agricultural Organisation; USGS = U.S. Geological Survey; BGS = British Geological Survey; UNICPS = United Nations Industrial Commodity Production Statistics; IEA = International Energy Agency; WMD = World Mining Data; UN = United Nations; e = estimate based on; coeff. = coefficients; GDP = gross domestic product; const. = construction.

Table.1.2 Estimates of global used extraction in 2000 by main material groups (in billion tonnes) (adapted from Fischer-Kowalski et.al. 2011)

Reference	Biomass	Fossil energy carriers	Ores and industrial minerals	Construction minerals	Global material extraction
Schandl and Eisenmenger (2006)	16.9	9.6	3.5	19.0	48.8
Krausmann and colleagues (2008)	18.4	10.0	3.8	26.5	58.7
Krausmann and colleagues (2009)	17.7	10.0	4.5	17.5	49.6
SERI (2009)	18.2	9.7	7.1	15.3	50.3
Steinberger and colleagues (2010)	17.6	10.1	4.9	16.3	48.9
M	17.7	9.9	4.7	18.9	51.3
SD	0.6	0.2	1.4	4.5	4.2

Note: t = tonnes.

Table.1.3 Main material components of TMR by selected countries (adapted from Bringezu et.al. 2004)

Component	Finland	Germany	Italy <sup>a</sup>	Netherlands	UK	Poland	EU-15	USA	Japan	China
	1999	2000	1994	1993	1999	1997	1997	1994	1994	1996
Fossil fuels	10	29	5	15	14	13	15	31	13	8
Used	6	6	3	10	6	6	4	8	3	1.3
HF	4	23	2	4	8	7	11	23	9	7
Construction min.	18	11	8	4	6	4	9	8	8	(4.4)
Used	18	9	5	4	5	3	8	8	8	(0.4)
HF	0.03	2	3	0	1.5	1.0	2	0.1	0	(4.0)
Metals and industry minerals	33	17	6	7	10	6	13	12	11	2
Used	6	2.4	1.0	4	1.2	2	1.2	4	3	0.1
HF	27	15	5	3	9	5	12	8	8	2
Biomass	21	7	5	6	6	3	6	6	3	0.6
Used	15	4	4	6	4	3	6	4	2	0.6
HF	6	3	2	0	2	0	0.01	2	0.8	0
Erosion	3	4	3	17	1.2	3	4	13	1.3	4
Excavation	8	3	3	7	3	2	3	13	9	18
Other	5	1	1	11	0.4	0.1	0.3	1.4	0.6	0.5
Used	0.8	0.6	1	4	0.4	0.1	0.2	0.4	0.1	0.1
HF	4	0	0	8	0	0	0.1	0.9	0.4	0.4
TMR	98	72	32	67	41	32	51	85	45	(37)

Values in ( ) characterize uncertain or presumably insufficient data; HF=hidden flows.

Stock analysis contributed to understand the state of natural environment and socio-economical society with material flow analysis. Stocks are an essential foundation of society by supporting economic activities and providing services such as buildings, consumer products, factories, and infrastructure. These in-use stock are recognized as important element of metabolism of city (Pauliuk & Müller 2014). The number of research into in-use stock of socio-economical is increasing and providing knowledge regarding the dynamics of stock growth and related material flows (Müller, 2006; Fishman et al., 2014, 2016; Wang et al., 2015), the material composition of stocks (Hu et al., 2010; Marcellus- Zamora et al., 2015; Ortlepp et al., 2015), the spatial distribution of stocks (Tanikawa and Hashimoto, 2009; Hsu et al., 2013; Rauch, 2009; Reyna and Chester, 2014; Tanikawa et al., 2015), the relations of material stocks with economics, energy, and CO<sub>2</sub> emissions (Allwood et al., 2012; Fishman et al., 2015; Müller et al., 2013; Pauliuk et al., 2015; Pauliuk and Müller, 2014), and the life cycles of stocked materials (Ciacci et al., 2015; Daigo et al., 2015; Kapur et al., 2008; Liu and Müller, 2013; Pauliuk et al., 2013). On the other hand, metabolism of cities threaten the sustainable development of cities, and each cities have different types of environmental pressures such as irregular accumulation of nutrients, heat islands, exhaustion of local resources are known as negative aspect of metabolism of cities (Kennedy et al. 2007). In the research field of economy-wide material flow, the Net addition to stock, the difference of inflow and outflow could be considered as future waste (Matthews et al. 2000, Eurostat 2001, Douglas et al. 2002). And nowadays, demolition of buildings is the main source of waste in industrialized societies. Therefore, researches of waste flows such as Hashimoto et.al. (2006) that focused on material flow and stock of construction minerals (aggregate, asphalt, cement, crushed stone, gravel and sand) to understand the mechanism of waste generation is essential for making sustainable waste management plan in both city and national scale. Demolition waste from buildings are often recycled as basement of road and seawall, while rest of them and organic waste are incinerated and dumped on farmland or filled into the sea. According to the increase of dumping from personal and industrial waste, the needs of waste disposal site are ever increasing around the urban area (Douglas et.al. 2002). And landfilling of waste materials, tailing and waste rock generate environmental impact with land use conflicts (Augiseau et al. 2016). The environmental damages by tailing and waste rock cannot be forgotten, and there is also public attention to the management of tailing pond and tailing dam. In the record of Eurostat (2003), mining and quarrying waste achieves over 300 million tonnes in the EU-15 by annual. They cover 14 types of metals (aluminum, cadmium, chromium, copper, gold, iron, lead, manganese, mercury, nickel, silver, tin, tungsten, and zinc), coal (hard, rock, and black coal) and 10 types of industrial minerals (barytes, borate,

feldspar, fluorspar, kaolin, limestone, phosphate, potash, strontium, and talc). In order to reduce the hazardous substances influences the human health, landfilling mining also has an important role of reducing of negative influences in landfills and dump sites (Burlakovs et al. 2017). On the other hand, in some area, there is the practical use of methane gas from landfills in order to generate electricity for local grid (Douglas et al. 2002).

The material balance principle, which is the foundation of material flow and stock accounting states that as the anthropogenic in-use material stocks increase, natural stocks decrease at an equivalent amount. We can find strong relationship between material flow and landscape, new construction and maintenance of buildings and infrastructure stock demand for metals and construction minerals that alter landscape by mining and promote anthropogenic disturbance (Douglas and Lawson 2001). Global HF associated with anthropogenic disturbance is increasing besides the construction material extraction which are used in construction sector. However, as Bringezu et.al. (2004) shows there is not a standard common framework to account global HF systematically. Therefore, developing methodology for estimating HF through monitoring domestic extraction under common methodological framework with reliable accuracy is important for understanding the dynamics of anthropogenic disturbance. Additionally, TMR can show potential environmental impact that is associated with natural resource extraction and use, yet it cannot indicate specific environmental pressure such as anthropogenic disturbance that causes destructive and irreversible effect of the natural environment (Bringezu and Schutz 2001). The practical geomorphological information is also required in the study of anthropogenic disturbances.

### **1.1.2 Digital elevation model: effective dataset for monitoring variety of different scale of anthropogenic disturbance**

We can investigate the dynamics of anthropogenic disturbance by measuring area, depth and volume of material extraction and fill site. The categories can be measured by using DEM in monitoring ground surface change. By comparing DEMs for different time frames, it is possible to observe geomorphological change. DEMs also enable association of anthropogenic disturbance with spatial information, thereby allowing observation of the environmental pressure and its evolution over time.

The recent development of remote sensing technology has enabled to obtain global and local DEM. DEM are raster datasets: digitized grids of cells of fixed spatial resolution, with each cell having a value that represents a particular type of information such as temperature, land-use, elevation, etc. (Esri 2015). In the case of a DEM, the raster is a grid map of the

elevation of terrain, in which the value of each cell in the grid represents the elevation from sea level of the terrain in that cell. There are two types of DEMs: Digital Terrain Model (DTM) and Digital Surface Model (DSM). The first type represents the bare ground elevation, stripped of all the objects that cover or lie on it (e.g. trees, buildings). The latter includes all objects that lie on the ground surface.

Variety types of DEMs are now public available in global scale. Table.1.4 and 1.5 indicate current satellites of NASA and JAXA, and global DEMs in public. Each country's national DEM are usually produced by own national mapping agency. They create national DEM from their national counter map and it regarded to have high vertical and horizontal accuracy. Recent technological development also contributes to create national scale elevation map, LiDAR (light detection and ranging) is well known of its utility. Satellite remote sensing also produced global DEM with large covering area of the world. ASTER GDEM (advanced space-borne thermal emission and reflection radiometer, global digital elevation model), SRTM (shuttle radar topography mission) DEM and AW3D are now available at online download service. They are created from stereo pairs or triplets of optical images or data from synthetic aperture radar. Nowadays, we can access high resolution global DEMs and can observe world topographic changes, by effort of improving the accuracy of satellite data and calculation process.

Table.1.4 The earth observing mission of NASA and JAXA (selected)

Institute	Name	Launch date	Principal function
NASA	SORCE	2003	Track solar radiation
	AQUA	2002	Mesures land, ocean, and atmosphere interactions
	TERRA	1999	Mesure land, ocean, and atmosphere interactions
	OSTM	2008	Mesures sealevel change
	LANDSAT8	2013	Monitor lans use
	GRACE	2002	Twin satelites measure the gravity field for
	SMAP	2015	Mesures soil moisture
	GPM CORE	2014	Mesures rain and snow
	OCO-2	2014	Measures carbon dioxide
	AURA	2004	Measures the ozon layer
JAXA	ALOS-2	2014	Mesures land and ocean
	GPM/DPR	2014	Mesures rain and snow
	GCOM-W	2012	Measures atomosphere interactions, soil moisture
	WINDS	2008	Satellite communication

Table.1.5 Global DEMs in public

Name	Observation period	Resolution [m]	Feature
SRTM	2000	30,90	11 days STS-99 mission in 2000 produced by NASA
ASTER	2008~	30,90	Joint operation of NASA and Japan which covers 80% of DSM generated by ALOS of JAXA
ALOS 3D	2006-2011	5, 30	Limited area with high resolution produced by variety
LiDAR	-	-	Elevation data for Mars produced by NASA
MOLA	1999, 2001	200, 463	DEM created by several dataset from different organizations
GTOPO30	1996~	1000	

Remote sensing techniques have been used for analysis and modeling of ecological and hydrological phenomenon to monitor natural environment. DEM which represents basic information of the earth's surface is applied for flood simulation, soil mapping, soil erosion analysis, PH modeling and material transfer calculation (Mcbratney et al 2003, Rueda et al. 2013, Baltensweiler et al. 2017, Taniakwa and Imura 2001). DEMs have been used in varieties of research fields such as geography, geology, and geomorphology to estimate the soil and earth movements, which are caused by natural phenomena such as landslides, slope failures, and mountain stream debris outflows (Iwasaki et al. 2008; Miura and Midorikawa 2007; Shimizu et al. 2008; Shiraishi et al. 2008). The non-residential buildings (e.g. factories and others) in a city also focused on and applied remote sensing techniques for estimating demolition waste from buildings in city scale (Kleemann et al. 2017). In the field of civil engineering, Tanikawa and Imura (2001) calculated the cut and fill volume of earth and soil on a residential development site by creating triangular irregular networks (Esri 2015), which are a form of vector-based digital geographical data contained in an area constructed by triangulating a set of points using a DEM. They also estimated HMF and total material requirement at a residential construction site. Sugimoto and colleagues (2015) estimated the material excavation at a site where fill for the construction of the Kansai International Airport was mined and compared the result with the statistically determined volume published by the local government (Osaka Prefectural Government 2011). Sugimoto and colleagues (2015), who applied three types of DEMs (10-m-mesh, 50-m-mesh, and a mesh based on aerial photos, respectively) to the pre-mining data set and two types of DEMs (5-m-mesh and ASTER global digital elevation model, respectively) to the post-mining data set. They presented six types of results for DEM-based accounting. Kawahara and Tanaka (2010) focused on the

mining of lime- stone and calculated the total volume of material excavated per unit mining area.

Since March (1864) mentioned human impact on nature, nature conservations are discussed with industrial activities. Geographers also joined this research stream, alternation of landscape and disturbance of biosphere are well getting known as consequence of human activities (William et al. 1956 and Turner et al. 1994). Anthropocene represents epoch dating of human societies began to alter earth's ecosystems including atmosphere, landscapes, and oceans. The subject of anthropogenic geomorphology is based on artificial landforms that modify natural environment. Table 1.6 represents geographical impact of human activities, direct anthropogenic processes; constructive, excavational, and hydrological and indirect anthropogenic processes; acceleration of erosion and sedimentation, subsidence, slope failure, and triggering earthquakes (Szabo et al. 2006). Landform types are divided into 3 types; excavation processes (E), planation processes (P), and accumulation processes (A). From the perspective of natural environmental protection and nature conservation, study of anthropogenic geomorphology, not only man-made landforms, but also man-induced landform is required to avoid harmful impacts (Szabo et al. 2006).

Special characteristic of this study will be future availability of introducing this methodology to countries with poor statistics. It is difficult to have accurate and reliable database regarded to material flows in developing countries, while DEM used methodology for accounting DE, HF, and fill is available throughout the world. This characteristic might be a good example to answer question that is raised by Bringezu et al. (2004), there is not a standard common framework to account global HF systematically. Therefore, developing and improving a method for estimating HF under common methodological framework with reliable accuracy is important. Additionally, TMR can show potential environmental impact that is associated with natural resource extraction and use, yet it cannot indicate specific environmental pressure (Bringezu and Schutz 2001). Applying the DEM based methodology to both material extraction and fill site is not only quiet unique approach to understand the environmental impacts by mining, but also contribute to make dynamics of HF clear.

Table.1.6 Geographical impact of human activity (adapted from Szabo and David 2006)

Type of intervention	Land-form type	Direct		Indirect	
		Primary	Secondary	Qualitative	Quantitative
Montanogenic	E	-	Open-cast pits	Subsidence	Fluvial landforms caused by mine water inflow
	P	-	Waste-filled valleys	Accumulation in pits	
	A	-	Waste tips	Bulges around tips	
Industrogenic	E	Cooling lake basins	Quarries for planation	Mass movements on industrial raw material deposition sites	Accelerated erosion by sewage inflow
	P	'Industrial estates'	Slurry reservoirs		
	A	Sockles for windmills	Slag deposition sites		
Urbanogenic	E	Cave dwellings	Loam pits	Cellar collapses	Erosion by runoff from sealed surfaces
	P	P for construction	Garbage disposal sites		
	A	Tells, burial hills	Debris hills		
Traffic	E	Road cuts	Hollow roads	Slumps on embankments	Increased piping
	P	Airfields	Mounds removed		
	A	Embankment	Roadside A		
Water management	E	Artificial channels	Navy pits	Abrasion due to impoundment	A in culverts Rapid incision
	P	Polders	Cutoffs		
	A	Levees	A by dredging channels		
Agrogenic	E	Waterholes	Excavation pits	Rapid gullying	A behind dams Deflation forms
	P	Terraces	Pseudoterraces	Sheetflow	
	A	Lynchets	Stone ridges	Alluvial fans	
Warfare	E	Moats	Bomb craters	Avalanches caused by explosions	Erosion modified water-courses for defence purposes
	P	Airfields	Destroying settlements		
	A	Earthworks	'Trümmelberge'		
Tourism, sports	E	Recreation lake basins	Field sports (moto-cross)	Abrasion along recreation lake shores	Accelerated erosion along hiking paths
	P	Sports tracks	landscapes		
	A	Ski-jumping ramps			

E = excavation processes/landforms; P = planation processes/planated landforms; A = accumulation processes/landforms

## 1.2 Objective of this research

This study aims to clarify dynamics of anthropogenic disturbances by presenting a new methodology which uses remote sensing techniques to account Domestic Extraction and related HF. We employ GIS and DEM that enable us to monitor anthropogenic disturbance and HF in material excavation from local, regional, national and global scale. This methodology has high potential for quantifying anthropogenic disturbances with spatial distribution. As the first step to standard procedure, we took case study and examine the performance of several types of DEMs for the research of anthropogenic disturbance. This study provide insight into the relationship of material flow and anthropogenic disturbances by taking case study on two industrialized countries, Japan and Germany. Both countries are highly industrialized and have many researches related to material consumption, sound material use and material stock & flow analysis. However, they have different geographical characteristics, economic structure, and historical changes. It is an interesting comparison of material extraction and HF in national scale. This study aims to:

- 1) develop a novel methodology for accounting used and unused material extraction. This can be achieved through landform change observation by using GIS and DEM. The methodology can be applied in both local and global scale with high calculation accuracy.
- 2) build database of national scale used and unused material extraction. This can contribute to enrich the database of global material extraction and related HF especially in countries with poor statistics.
- 3) understand the environmental impact caused by mining and filling activity, to estimate HF that does not enter the socioeconomic sphere and not accounted in statistics.
- 4) investigate dynamics of anthropogenic disturbance by focusing on mining and filling site where is the start and end points of material flows. It makes possible to depict practical relationship between material flow and anthropogenic disturbance in a land rocked country like Germany.

## 1.3 Research structure

In chapter 1 we introduce academic and politic background of sustainable development, especially that are related to material flows and stocks. We focus on the issues accompanying huge amount of material consumption and accumulation in the socio-economic sphere is anthropogenic disturbance. The state of art researches and remote sensing techniques are introduced in this chapter.

In chapter 2 we employ two methods to quantify domestic extraction and potential HF, using bottom-up method: DEM and GIS, and top-down method: statistics. We spatially

quantify the impact of humans on the natural environment by estimating the anthropogenic disturbance of mining and quarrying, and contribute to the knowledge of HF by examining the phenomenon using relatively unexplored methodology of assessing the relationship between anthropogenic disturbance and material transfer by means of DEM and GIS. We find that not only potential volume of HF by comparing the respective results of bottom-up and top-down accountings, but also their destructive effect on the environment and the spatial distribution of anthropogenic disturbance.

In chapter 3 we developed a methodology of automatic detection and measurement of anthropogenic disturbance of soil and earth at excavation and mining sites which accounts not only for the material extracted for usage in the anthroposphere, but also its related unused extraction. This geographically explicit method allows to directly point out the location and volume of anthropogenic disturbance. Using Japan as a case study, ArcGIS's Weighted Overlay Tool is used, a computational tool which can solve geographic multi-criteria problems such as site selection and suitability model. The changes in the three attributes of elevation, slope, and aspect between the two examined periods were used as input criteria. In calibration phase, different weights of influence were assigned to elevation, slope, and aspect in 6:2:2 relative relations based on the experimental and practical researches conducted.

In chapter 4 we employed two global DEMs, ASTER GDEM (advanced space-borne thermal emission and reflection radiometer, global digital elevation model) and SRTM (shuttle radar topography mission), and two landcovers, Non-Forest map (Global 25m resolutions PALSAR-2/PALSAR/JERS-1 Mosaic and Forest/Non-Forest map), CORINE (coordination of information on the environment) focusing on Germany as a case study for estimation of DE and HF. We aim to measure anthropogenic disturbance extraction and filling sites, which accounts not only for the material extracted for usage, but also its related unused extraction.

In chapter 5, we made comparison between Japanese and German anthropogenic disturbances. The gap of annual volume per area of anthropogenic disturbance between Germany ( $0.85 \text{ m}^3/\text{m}^2$ ) and Japan ( $3.41 \text{ m}^3/\text{m}^2$ ) is  $2.56 \text{ m}^3/\text{m}^2$ , this would be caused by the difference of original national geography, type of mining, and sense of conservation of nature. The analysis of geographical features can contribute to assess the environmental impact of anthropogenic disturbance in a common framework.

In chapter 6 we give a summary of our study findings and future works of anthropogenic disturbance. We also illustrate benefits for academics, industry and policymaker. They can apply developed methodology for used and unused material database build in statistically poor countries, and it is available for environmental indicators which are created by accurate and reliable used and unused material database. Additionally, we

mentioned necessarily of another reliable and efficient methodology for global scale anthropogenic disturbance analysis in addition to three different methods (visual interpretation, automatic detection and land cover) which are presented in previous chapters.

#### **1.4 Main findings**

Firstly, we found that the methodology of using GIS and DEM is effective for measuring used and unused material extraction as environmental pressure by comparing statistics data. It contributes to build common framework to monitor anthropogenic disturbance with spatial distribution so that we can compare HF and DE by country by country. We also examine performance of different types of DEMs such as resolution, height accuracy and coverage for quantifying DE with HF.

Material balance of used and unused material extraction throughout Japan with mining and quarrying spatial distribution was discovered. We focused on the DE of construction minerals in Japan and estimated the DE and HMF by bottom-up and top-down accounting procedures. In this research, DEM-based methodology may produce an overestimation of as much as 8%–17%, depending on the accuracy of the original DEM. In the bottom-up accounting, GIS and DEM were used to determine the total volume of the anthropogenic disturbance (5.8 billion m<sup>3</sup>), which comprised the DE and HF. Top-down accounting using statistical data was also used to determine the total volume of the DE (3.2 billion m<sup>3</sup>). By comparing the two results, we estimated the potential volume of domestic HF (2.6 billion m<sup>3</sup>) of the mining sector. A special feature of this study was the use of a direct analysis of the anthropogenic landform change to calculate the material extraction.

The results suggest that the ratio of unused extraction to used extraction may exceed 1:1 for construction minerals in Japan. We also find that the environmental effects of anthropogenic activity are bigger than natural soil disturbance by several orders of magnitude. The annual average volume of material removed by AD per area is thus about 3.1 m<sup>3</sup>/m<sup>2</sup> per year, while loss of surface soils by natural phenomena such as water flow or wind is 0.00028 m<sup>3</sup>/m<sup>2</sup> per year, four orders of magnitude less than AD. This shows the strength of artificial landform change and clarifies the scale of pressures to the natural environment. Highlighting the need to reduce raw material extraction and increase the efficient use of the existing material stock.

We discovered the dynamic of anthropogenic disturbance and its relevance to material flows such as DE and waste flows of Germany. Total area and mass of mining is 570 million m<sup>2</sup> and 15.3 billion tonnes, while total area and mass of filing is 390 million m<sup>2</sup> and 7.76 billion tonnes. In addition, location information of them may be useful for policy

making, green business strategy building for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management. We also mentioned the existence of HF, which is used for backfill. HF such as waste rocks and overburden are regarded as no-economical materials, however, they have been used effectively to fill voids in material extraction site. We found the mass of effective use of unused materials by comparing the results of top-down accounting and bottom-up accounting.

### **1.5 Relevance of the research**

From the main findings, the achievements of our study relevant to manufacturing industry, mining industry, variety of science fields, global society, and local society of today and the future.

Manufacturing and mining industry can get profit of quantifying environmental impacts related to material extraction. The database of material and unused material extraction can be used as an estimation for environmental impact. Understanding the dynamics of HF following to anthropogenic disturbance is quite important in building indicators related environmental impacts of manufacturing and mining industry. In addition to this, in local and global area, the location information of mining sites is useful for pollution researches of mining and filling activities.

Research field of industrial ecology have benefit of introducing unexplored methodology of assessing the relationship between anthropogenic disturbance and material transfer by means of DEM and GIS. Statistical data are used in previous researches of developing material stock and flow database; hence introducing new methodology of remote sensing has big meaning. In order to build database, it can apply in areas with poor statistics of material extraction and environmental impact. This is not only because of technology development of remote sensing covering whole over the world, but also our methodology development of anthropogenic disturbance with spatial information.

Society and policymakers can profit of this research for city scale sustainable policy making such as waste management and countermeasure against pollution, and for global scale the database of unused material extraction can be used developing indicator of measuring decoupling natural resource use and environmental impacts from economic growth. Our research not only estimate HF as environmental impact, but also visualize spatial distribution of mining and filling site. Accurate and reliable database of HF and geospatial information would be useful for many policymakers.

## **2 Anthropogenic disturbance by domestic extraction of construction minerals in Japan**

### **2.1 Introduction**

Human society requires substantial resources, the supply of which involves the transfer of large amounts of materials from the ecosphere to the socio-economic sphere. Material flow analysis (MFA) is broadly employed in related studies owing to its ability to represent the relationship between the ecosphere and the socio-economic sphere by qualifying and quantifying the amounts of materials transferred between the two ambiances. The MFA also indicate resource productivity, and material resource use are related to economic growth (Bringezu et al. 2004). The databases thus obtained are used in the development of environmental policy, both regionally and globally. Douglas and Lawson (2001) noted that material transfer from the ecosphere to the socio-economic sphere impacts the landscape in two ways: (1) the generation of geomorphological change, which involves the removal of materials from the Earth's surface, and (2) the accumulation of concrete and other material structures in cities and industrial areas. Some excavated construction materials such as timber, iron, cement ingredients, gravel, and sand remain on the surface for a long period in the form of buildings and other infrastructure (Tanikawa and Hashimoto 2009). The excavation and refining of these materials not only causes geomorphological change, but also water and atmospheric pollution, soil erosion, and significant overburdened and wastelands, which significantly affect the local ecosystem (Hashimoto et al. 2006). Several studies have been conducted on material consumption and accumulation in the socio-economic sphere (Douglas and Lawson 2001). The advent of digital elevation models (DEMs) and geographical information systems (GISs) has enabled the quantification of material excavation by analysis of the geomorphological changes (Shimizu et al. 2008, Ross et al. 2016). A few studies have also considered geomorphological change as the starting point of hidden material flow from the ecosphere (e.g., Tanikawa and Imura 2001).

In the use of MFA, there are some problems with regard to the hidden material flow (HMF), which is a flow that does not enter the socio-economic sphere. Loss of vegetation, overburden, and tailing flow caused by mining, construction, and farming are typical known HMFs. Adriannse et al. (1997) and Matthews et al. (2000) do not only accounted for domestic commodities, but also estimated the detailed components of the domestic HMFs in Austria, Germany, Japan, the Netherlands and the USA. More recently, Wang et al. (2013) revisited these figures as part of a comparison with the case of China. Bringezu et al. (2004) The volume of the domestic HMFs relative to all the domestic commodities in Finland (1999),

Germany (2000), Italy (1997), Netherlands (1993), UK (1999), Poland (1997), Czech Republic (2000), EU-15 (1997), USA (1994), Japan (1994) and China (1996) were determined to be 17 tons per capita, 28 tons per capita, 7 tons per capita, 7 tons per capita, 11 tons per capita, 12 tons per capita, 31 tons per capita, 15 tons per capita, 57 tons per capita, 10 tons per capita, and 35 tons per capita, respectively (Bringezu et al. 2004). As these data indicate, large amounts of fossil fuels, construction minerals, and metals and industry minerals are transferred from the ecosphere to the socio-economic sphere. This movement generates geomorphological changes, mainly due to the effects of mining, soil excavation, infrastructural and land development, and cut and fill operations, among others.

The above mentioned studies were some of the first conducted in the field of EW-MFA (Economy Wide-Material Flow Analysis), and they set directions and foundations that continue to be relevant for the field of industrial ecology in the present time. However, these studies only estimated and compared the HMFs of different countries; they did not distinguish the spatial information and geographical features, although material transfer is strongly correlated to anthropogenic landform change. The same applies to several other studies that employed the same methodology, with the obtained statistical data also being ineffective for spatial determination of the HMF. Moriguchi and Hashimoto (2006) applied MFA to material transfer in Japan, and estimated the national HMF. They employed statistical data, therefore the spatial information and geographical features could not be determined. Tamura (2012) focused on anthropogenic landforms, and man-induced landforms and estimated the transferred earth volume [ $\text{m}^3$ ] per area [ $\text{m}^2$ ] due to large-scale residential development. The results were categorized according to low mountain ranges (10 m), hillocks (8 m), plateaus (3 m), and low grounds (1 m). The anthropogenic landform change was statistically quantified without distinction between spatial information and HMF. In the application of MFA, there is no standard approach to calculating the HMF using spatial information owing to the associated difficulties, especially in countries with poor and inconsistent statistical data.

To address this methodological gap, the analysis of anthropogenic disturbance using spatial information may be effectively used to observe, examine, and quantify environmental impacts, thereby affording policy makers useful and practical information for making decisions regarding sustainable resource usage. Anthropogenic disturbance entails artificial landform transformation due to processes such as mining, soil excavation, construction, and land development (Tamura 2012). It causes large-scale disturbance of the biomass structure, induces unpredictable ecosystem changes, and alters—often irreversibly—the environment and topography (Bringezu et al. 2004, Hashimoto et al. 2006, Ross et al. 2016). Moreover, the waste rocks produced by mining might contain toxic metals that pollute water and reduce soil

productivity (Hashimoto et al. 2006). A significant part of anthropogenic disturbance occurs in the form of HMF and an analysis of the disturbance promises to enhance the understanding of the dynamics and structure of HMF.

The recent introduction of remote sensing technology has enabled the development of global and local DEMs (Table.10.1, *SuppInfo.*). A DEM is the general form of a digital terrain model (DTM) and is used to represent the ground surface elevation without objects such as plants and buildings. Conversely, a digital surface model (DSM) depicts the surface elevation with any object present. By comparing DEMs for different timeframes, it is possible to observe the geomorphological change. DEMs also enable the association of anthropogenic disturbance with spatial information, thereby allowing the observation of the environmental pressure and its evolution over time. DEMs have been employed in different studies in the fields of geography, geology, and geomorphology to estimate the soil and earth movements caused by natural phenomena such as landslides, slope failures, and mountain stream debris outflows (Iwasaki et al. 2008, Miura and Midorikawa 2007, Shimizu et al. 2008, Shiraishi et al. 2008). In the field of civil engineering, Tanikawa and Imura (2001) calculated the cut and fill volume of earth and soil on a residential development site by creating triangular irregular networks (Esri 2015b), which is a form of vector-based digital geographic data contained in an area constructed by triangulating a set of points using a DEM. They also estimated the HMF and total material requirement at a residential construction site. Sugimoto et al. (2015) estimated the material excavation at a site where fill for the construction of the Kansai International Airport was mined, and compared the result with the statistically determined volume published by the local government (Osaka Prefectural Government 2011b). Worthy of special mention is Sugimoto et al. (2015), who applied three types of DEMs (10-m-mesh, 50-m-mesh, and a mesh based on aerial photos, respectively) to the pre-mining dataset, and two types of DEMs (5-m-mesh and ASTER GDEM (global digital elevation model), respectively) to the post-mining dataset. They presented six types of results for DEM-based accounting. Kawahara and Tanaka (2010) focused on the mining of limestone and calculated the total volume of material excavated per unit mining area ( $\text{m}^3/\text{m}^2$ ) (table.2.1). In addition to accounting for material excavation, these previous studies also estimated the HMF over a small area. However, anthropogenic disturbance and the accompanying HMF are global phenomena and not restricted to a small region. Moreover, only few studies have considered anthropogenic landform changes, and the investigations were also limited to small localized regions. An investigation of anthropogenic disturbance of soil and the earth by domestic extraction over a large area has not been previously undertaken in the context considered in the present study. Towards contributing to available knowledge on HMF, the present study

utilized a relatively unexplored methodology, whereby anthropogenic disturbance was estimated by spatial analysis, and the relationship between the disturbance and material transfer was investigated using a GIS and DEM. We particularly focused on the domestic extraction (DE) of construction minerals in Japan because of the high proportion (87 %) of such minerals (e.g., rock, gravel, and limestone) in the domestic material input (Material Flow in Japan 2006).

Table.2.1 Studies of anthropogenic disturbance with DEM

References	Ross et al. (2016)	Sugimoto et al. (2015)	Kawahara and Tanaka (2010)	Tanikawa and Imura (2001)
Target	Coal mining	Soil Mining	Limestone mining	Land development
Coverage	Mountaintop mining	A mining site	A mining site	Residential area
Data	10-m DEM from topogrid and LiDAR	Japanese domestic DEMs, ASTER GDEM, DEM from aerial photos	DEM from contour map	DEM from contour map
Contents	Quantification of mining volume and impacts analysis	Quantification and verification of the DEM used estimation method	Quantification of mining volume	Quantification of HMF
Features	Finding relationship between mining and acidity, selenium concentration	Verifying the methodological accuracy by comparing with statistical data	Estimating the mining trend by calculating mining volume [m <sup>3</sup> ] per area [m <sup>2</sup> ]	Estimating TMR of residential development by estimating HMF
Issues	The research target area is small area, and the relationship of material excavation to HMF is not discussed enough.			

## 2.2 Method and data

In this study, bottom-up and top-down accounting procedures were used to estimate the anthropogenic disturbance and HMF (Fig.2.1). In the bottom-up accounting using Japanese domestic DEMs, a 10-m basic map information mesh and 50-m digital map information mesh were used to account for the anthropogenic disturbance, including the DE and mining HMF. The top-down accounting of the DE was done using national statistical data and the Crushed Stone, etc. Statistical Yearbook and Fiscal Gravel Business Status Report Summary Table (Table.2.2). We compared the results of the bottom-up and top-down accountings and estimated the potential volume of the HMF.

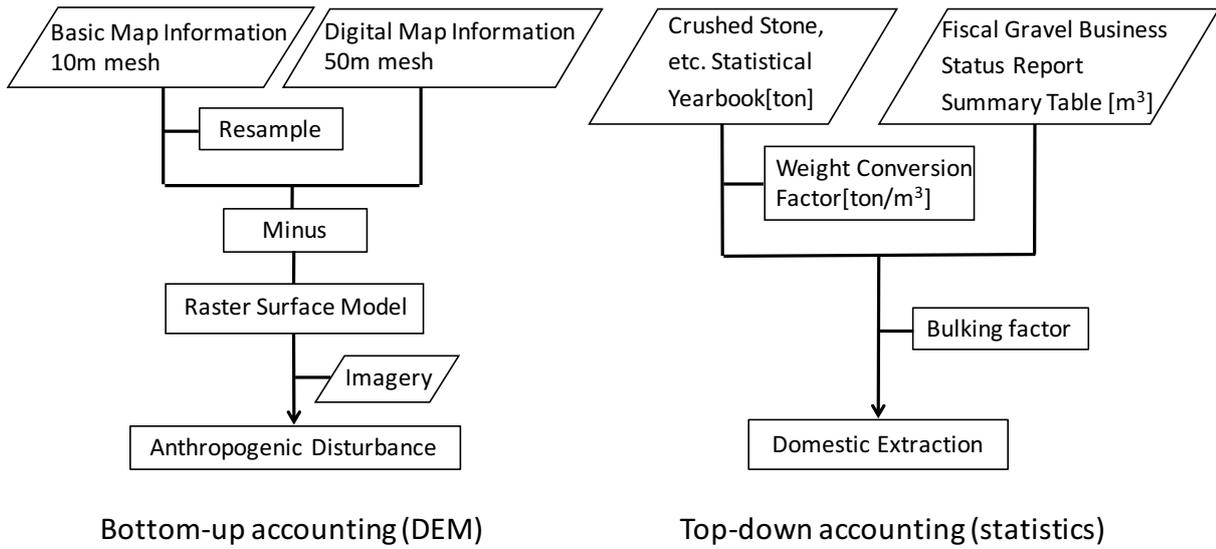


Fig.2.1 Flow charts of bottom-up and top-down accountings

Table.2.2 Details of the domestic DEM and statistics data

Type	Institutes	Objects	Accuracy [m]
Digital map information 50m	Geospatial Information Authority of Japan	1/25000 topographic map	7.2
Basic map information 10m	Geospatial Information Authority of Japan	1/25000 topographic map	5
Type	Institutes	Objects	Accuracy [m]
Fiscal gravel business status report summary table	Ministry of Economy, Trade and Industry	Gravel, sand and boulder	1987-2005
Crushed stone, etc. statistical yearbook	Ministry of Economy, Trade and Industry	Crushed stone and crushed sand	1987-2005

### 2.2.1 Bottom-up method: digital elevation model

The 10-m basic map information mesh and 50-m digital map information mesh were both produced using a 1/25000 counter map developed by the Geospatial Information Authority of Japan (Table.2.2). The elevations indicated in the map, which covers the entire territory of Japan, do not include plants and buildings. The employed domestic DEMs were of high resolution and height accuracy compared to global DEMs, and the 10-m and 50-m meshes were thus used for national estimation. In addition, owing to the need for both DEMs to have the same resolution, the 10-m basic map information mesh was converted into a 50-m mesh and a 50-m raster surface model was developed. A raster is one of the simplest types of datasets and consists of a matrix of cells organized into a grid, with each cell having a value that represents a particular type of information such as temperature, land use, or slope (Esri 2015a). The developed raster model represented the geomorphological change all over Japan. ArcGIS World Imagery was further used for visual interpretation of the mining site. The system generates satellite and aerial images with a resolution of 1 m or higher in many parts of the world (Esri 2015c). Visual interpretation is often used in remote sensing and requires high-resolution imagery (Nagai et al. 2012, Fukumoto et al. 2012).

The bottom-up accounting method can be expressed by the following equation:

$$MF(\text{gravel, stone}) = \Sigma(V_{t,i} - V_{t2,i}) \quad [1]$$

where  $MF(\text{gravel, stone})$  denotes the total mass of the anthropogenic disturbance,  $V_{t,i}$  is the volume in year  $t$  at place  $i$ , and  $V_{t2,i}$  is the volume in year  $t2$  at place  $i$ .

### 2.2.2 Top-down method: Statistics

The top-down accounting of the DE was done using the Crushed Stone, etc. Statistical Yearbook of Japan and Fiscal Gravel Business Status Report Summary Table issued by the Ministry of Economy, Trade and Industry (Table.2.2). The Crushed Stone, etc. Statistical Yearbook is a statistical report that mainly accounts for the aggregate supply and demand of construction minerals. It includes records of crushed stone and sand used for road construction and as concrete ingredients at the prefecture level. The Fiscal Gravel Business Status Report Summary Table is another statistical report that accounts for gravel, sand, and boulder excavations at the prefecture level.

In top-down accounting, the total volume indicated in the Crushed Stone, etc. Statistical Yearbook of Japan and Fiscal Gravel Business Status Report Summary Table is the amount of DE. The unit used in the yearbook is ton, while that employed in the Fiscal Gravel

Business Status Report Summary Table is cubic meters. We therefore used the weight conversion factor of 1.8 t/m<sup>3</sup> to convert the data in the yearbook to cubic meters, which is the unit of DEM-based accounting (Ministry of Land, Infrastructure, Transport and Tourism 2012 and Association of Japanese Gravel 2016). Moreover, to compare the results of the DEM-based accounting with that of statistical-based accounting, the latter was converted from loose volume (the volume after excavation) to bank volume (the volume before excavation). Owing to natural compression, the loose volume is greater than the bank volume and the former is usually employed during transportation of the material. In accordance with the recommendation of the Civil Engineering Work Standard Multiplication Workbook of Japan, an evenly bulking factor of 1.25 was used to convert the loose volume to bank volume in this study.

The top-down accounting method can be expressed by the following equation:

$$MF(\text{gravel, stone}) = \frac{(F+C/W)}{B} \quad [2]$$

where MF (gravel, stone) denotes the total mass of the DE,  $F$  is the amount of the material (e.g., gravel, sand, or boulder) determined from the Fiscal Gravel Business Status Report Summary Table [m<sup>3</sup>],  $C$  is the amount of the material determined from the Crushed Stone, etc. Statistical Yearbook [t],  $W$  is the mass-to-volume conversion factor [1.8 t/m<sup>3</sup>], and  $B$  is the bulking factor [1.25].

## 2.3 Results and discussion

### 2.3.1 Case study area: Material extraction related to construction of Kansai International Airport

Hannan in Osaka prefecture was chosen as the case study area for verification of the accuracy of the methodology adopted in this study. The mining and transportation of fill for the construction of the Kansai International Airport was considered. Fig.2.2 shows the locations of the airport and the mining site, while Fig.2.3 shows the pre- (1985) and post- (2008) excavation conditions. The large-scale landform transformation by the exaction is apparent. After the mining, beginning specifically in 1996, the mining site was developed into the Hannan sky town, which included 2,500 residential apartments (Osaka Prefecture 1996a).

Following are the reasons for considering the Hannan mining site as the case study area:

- 1) The mining information is recorded by both a private company and the local government. The total amount of material excavation was approximately 55 million m<sup>3</sup>. The excavation was done between 1987 and 1993.
- 2) The 50-m digital map information mesh and 10-m basic map information mesh respectively represent the 1987 and 1998 ground surface conditions (Fig.2.3), and the pre- (1987) and post- (1993) excavation landforms could thus be observed using a DEM.
- 3) All the excavated materials were used as fill and the mining thus did not have a HMF. It was therefore possible to simply compare the bottom-up and top-down accounting results to verify the methodological accuracy.

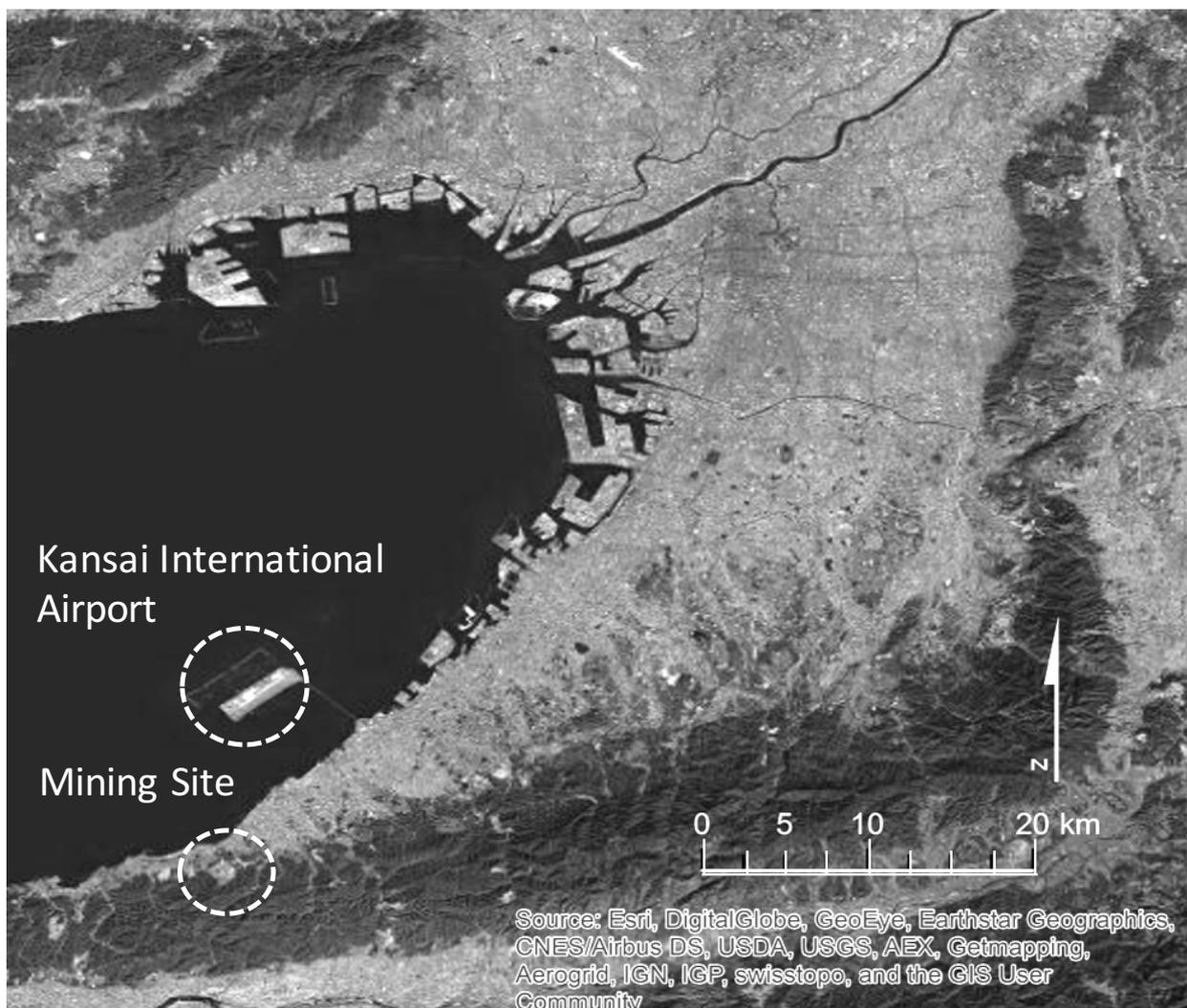


Fig.2.2 Case study area in Hannan, Osaka prefecture

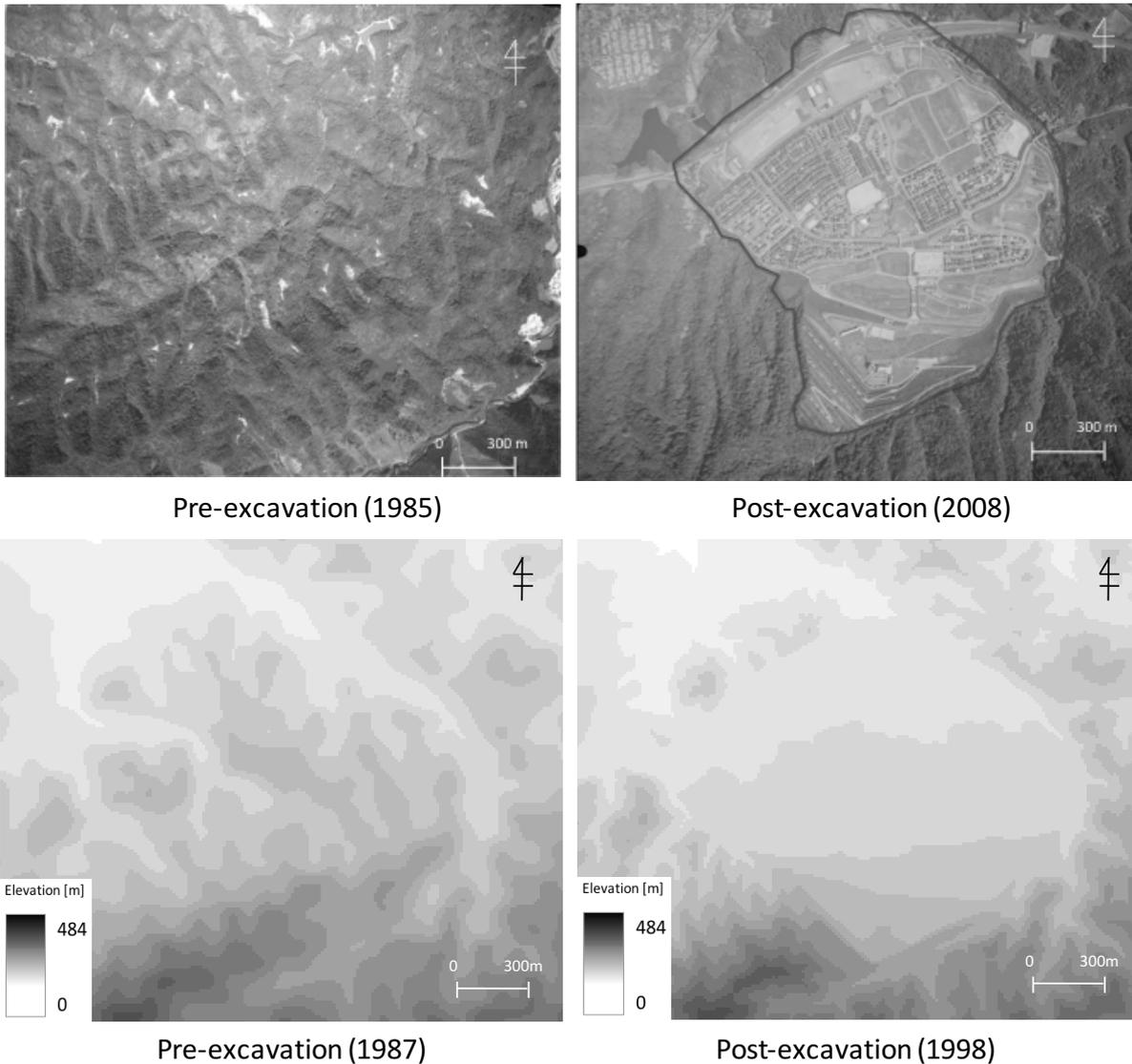


Fig.2.3 Pre- and post-excitation Ortho photographs and DEM of the mining site

Fig.2.4 shows the raster surface model, which depicts the elevation changes between 1987 and 1998. The white meshes indicate areas with dramatically decreased elevation, which implies significant material excavation. A total of 299 meshes were detected on the mining site. Fig.2.5, *Table 10.2 (SupplInfo.)* and *Fig. 10.1-2 (SupplInfo.)* present the details of the geomorphological changes, and the pre- and post-excitation histograms of the elevation, slope, and aspect, which facilitate an understanding of how the landform was transformed by mining. The average decrease in elevation is approximately 40 m, and impressive changes in the distribution and shape of the histograms can be observed. The pre-excitation histograms are gently spread and have a normal distribution, whereas the post-excitation histograms lean towards a low elevation, low slope, and north aspect, and have a

heavy-tailed distribution. For residential use after the mining, the site was artificially transformed into a flat land. An analysis of the histograms reveals the characteristic geographical changes at the mining site. The change in the distribution of the histograms from normal distribution to heavy-tailed distribution is considered to be a feature of the anthropogenic disturbance.

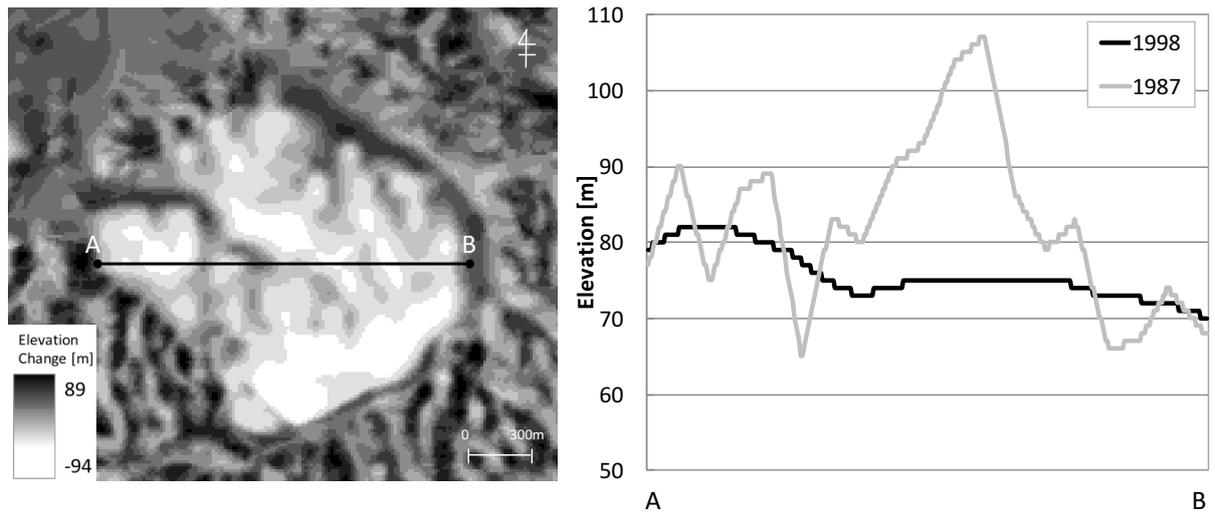


Fig.2.4 Raster surface model of the elevation changes between 1987 and 1998

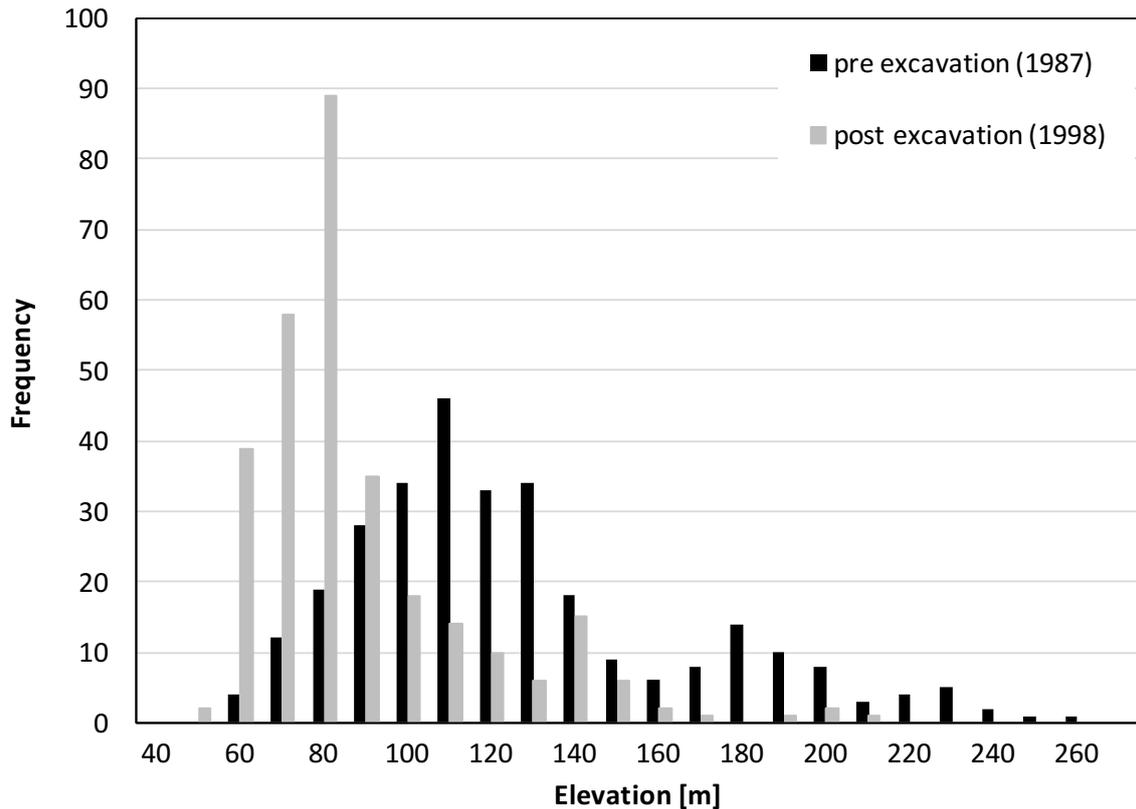


Fig.2.5 Histograms of the elevations in 1987 and 1998

Both bottom-up accounting (equation [1]) and top-down accounting (equation [2]) were applied to the case study. The results of the former were as high as 44.7 million m<sup>3</sup>, while those of the latter reached 44.0 million m<sup>3</sup>. This indicates that bottom-up accounting produced an overestimation of approximately 1.6 % compared to top-down accounting. According to Sugimoto et al. (2015), DEM-based accounting produced an overestimation of 8–17%. In the study, they applied 5 types of DEM for comparison of calculation results hence the accuracy varied widely. The comparative accuracy of the methodology adopted in the present study can be attributed to the accuracy of the original DEM and the employed bulking factor. There are minimal differences between bottom-up and top-down accountings. However, a methodological error (1.6% overestimation) was observed in the application of bottom-up accounting in the present case study. In addition, we examined the reproducibility of Sugimoto et al.'s (2015) application of DEM-based accounting to the Misaki area, with a focus on their quantitative investigation. We applied a 50-m digital map information mesh to the pre-mining dataset and an ALOS 30-m mesh to the post-mining dataset. We determined a total material excavation of 74.3 million m<sup>3</sup>, compared to the 70 million m<sup>3</sup> indicated in the

statistical record of the local government. This constitutes approximately 6% overestimation by the DEM method, indicating good reproduction of the results of Sugimoto et al. (2015), who observed an overestimation of 8%–17%. The gap between our results (6%) and Sugimoto et al. (2015) (8-17%) is based on DEMs that are used in researches. Depends on DEMs dataset, spatial resolution and vertical accuracy is different that directly affect the calculation results.

### 2.3.2 All over Japan

The accuracy of the adopted methodology was verified. Table.2.3 gives the revised results of the top-down and bottom-up accountings for the region of the case study and the entire territory of Japan. In addition, the mining area ( $m^2$ ), number of mining, and total mass of excavated material per unit mining area ( $m^3/m^2$ ) were calculated to examine the features and relationship between the anthropogenic disturbance and the HMF. Furthermore, to verify the why the volume of HMF in Japan is lower than in other countries—something that has been attributed to the higher rate of recycling of construction minerals in the country (MLIT 2005)—we conducted a spatial analysis of the anthropogenic disturbance to examine the geomorphological features of material extraction in Japan.

Table.2.3 Results of bottom-up and top-down accountings for 1987–2005

Area	Statistics		DEM	
	Volume [ $m^3$ ]	Volume [ $m^3$ ]	Quarry area [ $m^2$ ]	Quantified quarries
Hokkaido	234	412	12.3	76
Tohoku	419	893	32	181
Kanto	806	1002	27.7	196
Chubu	527	962	33.62	235
Kinki	390	886	20.2	153
Chugoku	223	623	21.2	89
Shikoku	135	271	8.6	37
Kyusyu	429	780	21.5	196
Japan	3163	5829	177	1163

The total volume of the anthropogenic disturbance in Japan as determined by bottom-up accounting in this study is 5.8 billion m<sup>3</sup>, while the total volume of DE determined by top-down accounting is 3.2 billion m<sup>3</sup>. The difference between the two accounting results is 2.6 billion m<sup>3</sup>, which represents the potential volume of HMF. This shows that 1 m<sup>3</sup> of DE is accompanied by 0.8 m<sup>3</sup> of HMF, implying a stripping ratio of 0.8:1. Wang et al. (2013) compared the values of the ratio of the HMF to the DE of construction materials of eight countries and observed significant variation. They cited a value of 0.72:1 (8 tons per capita of HMF to 11 tons per capita of DE) for Japan, which is very close to the 0.8:1 determined in the present study. The stripping ratio is the ratio of the total mass of overburden required to excavate a material to the total mass of the excavated material, and it represents the productivity and profitability of the mining. The stripping rate for the excavated fill material considered in this study is extremely lower than those for other minerals. DE in Japan mainly comprises construction minerals such as rock, gravel, and limestone, which usually exist on the Earth's surface and their extraction does not generate waste rock. A low stripping ratio is directly associated with a low HMF in Japan.

A total of 1163 mining processes were identified in the entire mining area, which measured 177 million m<sup>2</sup>. The total material excavation per mining area was 33 m<sup>3</sup>/m<sup>2</sup>, which is strongly related to the stripping rate. According to previous studies (Kawahara and Tanaka 2010, Sugimoto, et.al. 2015), the material excavation per mining area for large-scale mining of gravel, stone, and limestone in Japan is approximately 56.6–61 m<sup>3</sup>/m<sup>2</sup>. However, the present study indicated a value of 33 m<sup>3</sup>/m<sup>2</sup> for the entire country. This could be explained by the inclusion of small-scale mining. This low material excavation per mining area, which is due to a low stripping rate, is another characteristic feature of Japanese mining.

The use of a DEM enabled the detection of mining locations all over Japan (Fig.2.6). In particular, the authors noticed that there were several mining locations around urban areas compared to rural areas. This configures that most of the excavated construction materials such as sand, gravel, and stone were transferred to the urban areas and used as aggregates for the construction of buildings and infrastructure (Tanikawa and Hashimoto 2009). The low-cost materials were not transported over very long distances; that is, the distance between the supply (mining) and demand (urban) areas was short. Moreover, not only did the material transfer result in geomorphological changes and stock accumulation (Douglas and Lawson 2001), but these were also spatially related.

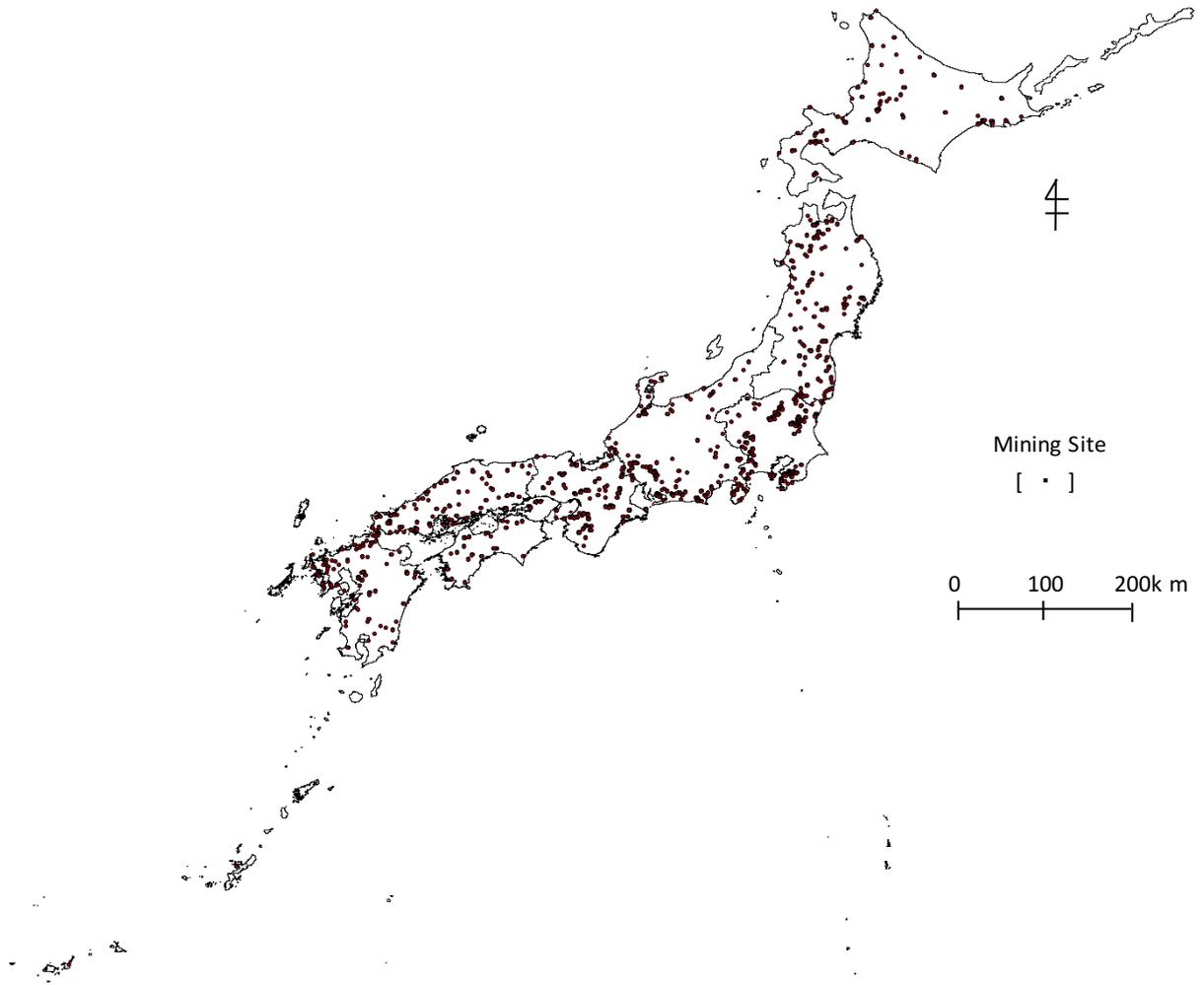


Fig.2.6 Spatial distribution of domestic extractions in Japan

## 2.4 Conclusions

As a first step in breaking new grounds, the present authors utilized a relatively unexplored methodology for estimating anthropogenic disturbance and HMF in Japan. The use of GIS and DEM for the geographical analysis of anthropogenic disturbance allows the estimation of the HMF and the acquisition of related spatial information.

Special features of this study were 1. no data restriction like the top-down method even in countries with poor and inconsistent statistical data, 2. including spatial information of anthropogenic disturbance which contribute to estimate human-induced landscape consumption and environmental changes, and 3. country scale coverage area which includes all over Japan. These features made it possible to approach HMF estimation with spatial information. This methodology can be applied to open-pit mining, land development, soil

excavation during construction, and the development of infrastructure. Although the present study focused on the extraction of construction materials, it should be noted that anthropogenic disturbance in the country also includes the DE of fossil fuels, ores, and industrial minerals, as well as land development, soil excavation during construction, and infrastructural development.

There is a strong correlation between stock accumulation and anthropogenic disturbance of soil and the earth, with the demand for construction materials promoting the anthropogenic disturbance (Douglas and Lawson 2001). For example, with regard to stock accumulation, Tanikawa et al. (2015) accounted for the in-use stock of construction materials in Japan, together with their spatial distribution, and attempted to establish the socioeconomic metabolism. As the starting point of material transfer and material accumulation in the socio-economic sphere, this study attempted to investigate it quantitatively, qualitatively, and spatially.

Further study with an expanded scope is thus necessary for the development of a database of anthropogenic disturbance, material extraction, and HMF. The employment of an automatic method for detecting anthropogenic disturbance would also be preferable to the use of visual interpretation in expanding the scope of study to the global arena. The geomorphological features of mining discernible from Fig.2.5 and Fig.2.1-2 (*SuppInfo*) can be used as indicators for detecting anthropogenic disturbance.

## 2.5 Acknowledgements

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## **3 Material stock's overburden: automatic spatial detection and estimation of domestic extraction and hidden flows**

### **3.1 Introduction**

Research into societal in-use material stocks has been on the rise in recent years. There is an ever-increasing base of knowledge regarding the dynamics of stock growth and related flows (Müller 2006; Fishman et al. 2014; Fishman et al. 2016; Wang et al. 2015), the material composition of stocks (Hu et al. 2010; Marcellus-Zamora et al. 2015; Ortlepp et al. 2015), the spatial distribution of stocks (Tanikawa & Hashimoto 2009; Hsu et al. 2013; Rauch 2009; Reyna & Chester 2014; Tanikawa et al. 2015), the relations of material stocks with economics, energy, and CO<sub>2</sub> emissions (Allwood et al. 2012; Fishman et al. 2015; Müller et al. 2013; Pauliuk et al. 2015; Pauliuk & Müller 2014), and the life cycles of stocked materials (Ciacci et al. 2015; Daigo et al. 2015; Kapur et al. 2008; Liu & Müller 2013; Pauliuk et al. 2013). Studies of the material flows of nations uncover that in terms of mass large shares – in many cases more than 50% – of the materials consumed yearly by human society are materials that become part of the anthropogenic material stock (Adriaanse et al. 1997b; Schandl & Schulz 2002; Weisz et al. 2006; Schandl & West 2010; Schandl & West 2012; West & Schandl 2013; Singh et al. 2012; Krausmann et al. 2009; Krausmann et al. 2014; Krausmann et al. 2016; Gierlinger & Krausmann 2012), including metals, timber, and plastics, and most predominantly minerals for construction such as aggregate, sand, bitumen, and cement. In recent years the global amount of construction minerals entering the economy has reached about 35 billion tonnes per year, or around 5 tonnes per person per year, although there are large discrepancies among countries: in China the figure is over 13 tonnes per year per person, while in Africa the per-capita average is only about 1.5 tonnes per year (Miatto et al. 2017).

The material balance principle at the foundation of material flow and stock accounting states that as the anthropogenic in-use material stocks increase, natural stocks decrease at an equivalent amount. However, for every unit of material that enters the economy, there is a certain amount of material which was mined, quarried, excavated, moved, or otherwise disturbed during the procurement of the wanted material but has no economic function and remains in nature, albeit in an altered state. This material, termed overburden, hidden material flow (HMF) (Adriaanse et al. 1997b), or unused extraction (2001) has long been recognized to be of the same order of magnitude as the used extraction (Matthews, Amann, Bringezu, et al. 2000). It acts as an indicator of the ecological stresses

associated with material extraction, which include alterations to the landscape, changes in land cover and the water system, as well as impacts on biodiversity and animal habitats. Specifically in the case of the construction industry, resource extraction, cut-and-fill for residential development and construction for buildings and social infrastructure generate large scales of geomorphological changes (Tamura 2012). This rapid anthropogenic disturbance causes destruction of the natural environment, and it is accelerated by technical innovations in industrial fields and ongoing demands for construction materials and mineral resources.

The indicator of total material requirement (TMR) was instituted to account for both used and unused material flows (Bringezu et al. 2004; 2001). Nevertheless, since the focus of recent advancements in the field material stocks, as cited above, have been on the socio-economic angle of material stock balance, the side of the natural environment has been somewhat neglected. This may be due to the ubiquity of construction minerals and their relatively small apparent ratios of used-to-unused materials as compared with materials such as metals and precious minerals, but the main reason for this is probably difficulties related to data procurement. While the materials consumed by society are commonly accounted for economic reasons, and the in-use stocks can be identified and counted through bottom-up, top-down, and other methods (Müller et al. 2014; Tanikawa et al. 2015), there is less data available for the unused material. Often indirect accounting methods are used, such as coefficients (Bringezu & Schuetz 2001) and ratios of overburden to useful material (Douglas & Lawson 2000) calculated from specific case studies, but these have very high variances both spatially and temporally – different locations have different mineral and chemical soil compositions, and mining and quarrying sites get depleted over time increasing their ratios, adding to the uncertainties of such indirect methods. While these issues are common to other material categories such as metals and industrial and precious minerals, the decentralization and ubiquity of the construction mineral excavation industry makes data collection even more difficult.

Although construction minerals are of low economic value and have relatively lower used-to-unused ratios compared to other materials, due to the sheer amounts of construction materials consumed the overall environmental effects are prominent and there is a growing need to accurately account and analyze the anthropogenic disturbance (AD) caused by the societal accumulation of stock of construction minerals. The extraction of materials leaves clear physical alterations of excavation and mining sites. Analysis of these geomorphological changes enables to directly measure the anthropogenic disturbances caused by ongoing demands for societal material stocks. In this study we introduce an

automated method to detect anthropogenic disturbances by identifying the unique characteristic geomorphological changes of excavation sites and open-pit mines in contrast to natural disturbances of soil. We employ this novel method on the entirety of Japan in order to gain a direct measurement of the anthropogenic disturbance in the country. Japan makes a good case study for this method, since the contemporary domestic extraction of materials in the country is almost entirely limited to construction minerals from excavation and quarrying. Active underground mines or wells, which would not be detectable through surface change methods, are virtually nonexistent. These anthropogenic disturbances (AD) include both the used extracted material (domestic extraction, DE in MFA parlance) and the unused extraction (HMF). Thus the anthropogenic disturbances detected and mapped with our method can be easily related to the official DE (used extraction) statistics, and the difference between the two can be assumed to account for Japan's hidden material flow. Throughout the study we refer to our estimations as anthropogenic disturbances related to construction and not as the TMR of construction materials in order to differentiate between the methods used to calculate each, and we discuss these differences in the discussion section.

## **3.2 Data and methods**

### **3.2.1 Research approach**

Disturbances and impacts to the ground surface are commonly studied using topographic maps, aerial photos and field surveys, and recently the development of remote sensing technology and Geographic information systems (GIS) promoted the use of three dimension models (Ross et al 2016). GIS and specifically elevation maps, referred to as Digital Elevation Models (DEM), facilitate direct measurements of geomorphological changes by comparisons of changes in elevation and other geomorphological attributes over time. DEMs are made from several data sources such as satellite data, aerial photos, and contour maps. The original data selection depends on the purpose of DEM usage. Aerial photos and contour maps are suitable for reproducing old geomorphology, but their coverage is limited compared to satellite data. For instance, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Global Digital Elevation Model and ALOS (Advanced Land Observing Satellite) World 3D – 30m are DEM datasets created from satellite data and their coverage is almost the entire planet. However, their resolution and elevation accuracy is lower than DEM created by aerial photos (Japan Space Systems 2012, Japan Aerospace Exploration Agency 2016).

Table.3.1 presents recent examples of DEM-based studies of geomorphological changes. DEMs have been used in various fields such as agricultural science, environmental science, geography and geology. Land slide and erosion are known as natural disturbances which cause geomorphological changes. in the field of disaster prevention and environmental science, not only the geomorphological information but also important information of landslides, such as their causes, dynamics and impacts are explored by using DEM (Shimizu et al 2008, Quan and Lee 2012, and Shahabi and Hashim 2015). Especially, visual interpretation and the analytic hierarchy process (a theory of measurement through pairwise comparisons in order to assess the relative weight of multiple criteria and to derive priority scales) are commonly used for locating the natural disturbance site and landslide susceptibility site (Saaty 2008, and Quan and Lee 2012). These methods have been employed successfully for identification of natural disturbances such as landslides and erosion in medium to large spatial scales of regions, yet for anthropogenic disturbances studies have been so far limited to measurements of small spatial regions such as single mining or excavation sites due to the time-consuming activity of identifying locations of AD (Tanikawa and Imura 2001, Kawahara and Tanaka 2010, Sugimoto et al 2015 and, Ross et al 2016). Worthy of special mention is that the analytic hierarchy process (AHP) which would be a suitable method for locating natural disturbances has not been applied to detect anthropogenic disturbances.

Table.3.1 Recent studies of geomorphological change using DEM data

References	Anthropogenic Disturbance					Natural Disturbance		
	Sugimoto et al. (2015)	Ross et al. (2016)	Kawahara and Tanaka (2010)	Tanikawa and Imura (2001)	Yoshida et al. (2017) (under review)	Shimizu et al. (2008)	Shahabi and Hashim (2015)	Quan and Lee (2012)
Target	Quarrying	Coal mining	Limestone mining	Land development	Domestic extraction	Landslide, erosion	Landslide	Landslide
Coverage	A mining site Digital	Mining at mountain	A mining at mountain	Residential area	All japan Digital	A mountain	Part of highland	Whole island
Data	Map 50m-mesh and 10m-mesh Basic Information Digital Elevation Model Map	10-m DEM from topogrid and LiDAR	DEM from contour map	DEM from contour map	Map 50m-mesh and 10m-mesh Basic Information Digital Elevation Model Map Quantification of domestic extraction and HMF	15-m ASTER GDEM	10-m AIRSAR DEM	20-m DEM
Contents	Quantification of quarrying	Quantification of mining and impacts analysis	Quantification of mining	Quantification of HMF	Quantification of domestic extraction and HMF	Quantification of landslide	Detection of landslide	Detection of landslide
Features	Verifying the methodological accuracy by comparing with statistical data	Finding relationship between mining and acidity, selenium concentration	Estimating the mining trend by calculating mining volume [m3] per area [m2]	Estimating TMR of residential development by calculating HMF	Estimating domestic extraction and HMF of all over the Japan Visual interpretation is not suitable for global scale estimation.	Estimating both landslide and erosion	Automatically detecting of natural disturbance, such as landslide and slope failure	
Issues	The research area is limited and narrow, and relationship between DE and HMF is not mentioned.						Anthropogenic disturbance is not considered	

Fundamentally, anthropogenic disturbance is calculated by a comparison between two periods of time of the changes in elevation in a site of mining or excavation, in effect measuring the volume of earth moved at the site. However, this method would also detect natural disturbances of soil. In previous studies (Yoshida et al. under review), a site of anthropogenic disturbance had to be known in advance or manually identified and then its geomorphological state compared over time, a time-consuming effort subject to subjective judgment. However, anthropogenic disturbance was found to be characterized by dramatic and distinct geomorphological changes: ground surface becomes flatter with a decrease in elevation and steepness of slopes, as well as changes in the direction of the slope (Yoshida et al. under review). In this study, we introduce an algorithm, using a series of GIS tools, to automatically detect anthropogenic disturbances by first identifying these unique geomorphological changes, then calibrating the algorithm on known sites, and finally allowing it to scan the terrain of the whole of Japan to detect, map, and measure the volume of anthropogenic disturbance on the national scale. Figure 3.1 shows the flow chart of the algorithm and the following sections detail the steps of this approach.

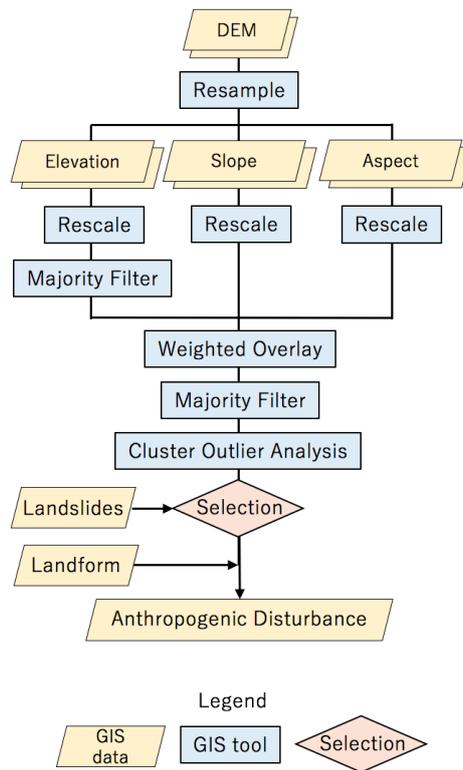


Fig.3.1 Flow chart of the automatic AD detection algorithm

### 3.2.2 Digital Elevation Models

The basic GIS datasets used in this study are Digital Elevation Models (DEMs). DEMs are raster datasets: digitized grids of cells of a fixed spatial resolution, with each cell having a value that represents a particular type of information such as temperature, land-use, elevation, etc. In the case of a DEM, the raster is a grid map of the elevation of terrain, in which the value of each cell in the grid represents the elevation from sea level of the terrain in that cell. There are two types of DEMs: Digital Terrain Model (DTM) and Digital Surface Model (DSM). The first type represents the bare ground elevation, stripped of all the objects that cover or lie on it (e.g. trees, buildings). The latter includes all objects that lie on the ground surface.

The sources that were used for this research are two DTM datasets published by the Geospatial Information Authority of Japan (Table3.2). Both of these sources were produced from 1:25000 contour maps which cover the entire

territory of Japan. The first source is a digital map with a resolution of 50 meters, representing the ground conditions in 1987, and the second is a 10m-resolution Basic Information Digital Elevation Model Map, which is a mosaic of regional updates from 1998 to 2005, therefore depending on the area it represents the ground conditions in any of the years 1998 to 2005. These DTMs not only have resolutions which are considered high (50m and 10m grid cells), but also have high elevation accuracy ( $\pm 3.6$  and  $\pm 2.5$ m, respectively), making them suitable for detecting and estimating anthropogenic disturbances in detail.

Since the resolutions of the two sources are different, we converted the 10m-resolution basic information digital elevation model map into a 50m-resolution grid by using the Resample Tool of the ArcGIS computer application which can change the spatial resolution of a raster dataset by cubic interpolation (Esri 2015), and regional 50m-resolution grids were merged to fully cover the whole area of Japan.

Table.3.2 Details of the DEM data sources used in this study

Data	Agency	Data sources	Coverage area	Coverage year	Published year	Cell Resolution [m]	Height accuracy [m]
Digital Map 50m-grid	Geospatial Information Authority of Japan	1:25,000 topographic maps	All Japan	1987	2001	50	$\pm 3.6$
10 m-grid Basic Information Digital Elevation Model Map				1998–2005	2006	10	$\pm 2.5$
Landslide GIS Data	National Research Institute for Earth Science and Disaster Prevention	1:40,000 monochrome aerial photos		1982–2013	2012	N/A	N/A
Landform GIS data	Ministry of Land, Infrastructure, Transportation and Tourism	Fundamental Land Classification Survey and Land Classification Survey		–1998	1998	N/A	N/A

### 3.2.3 Slope and Aspect

In addition to the elevation data necessary for the calculation of the volume of AD, two more geomorphological attributes of a cell are required for the identification of AD as opposed to natural causes: the slope and its aspect. Slope is defined as the steepest angle of inclination from the elevation of a cell to the elevation of its adjoining neighbors, from 0° (flat) to 90° (steep) (ESRI 2015a). Aspect is the compass direction of the slope measured in clockwise degrees from

0° (north) to 359.9° (ESRI 2015b). Figure 2 presents the concepts of elevation, slope, and aspect of a cell. By using not only the elevation, but also the slope and aspect, it becomes possible to observe geomorphological features more clearly, such as flat land on a mountain, slopes facing a certain direction on a hill, the average steepness of a mountain, and so on (Shahabi and Hashim 2015, Quan and Lee 2012). The DEM data sources contain just the elevation of the terrain in each cell. The slope and aspect of the cells of the two datasets were calculated using the tools available in the spatial analyst toolbox of the ArcGIS software.

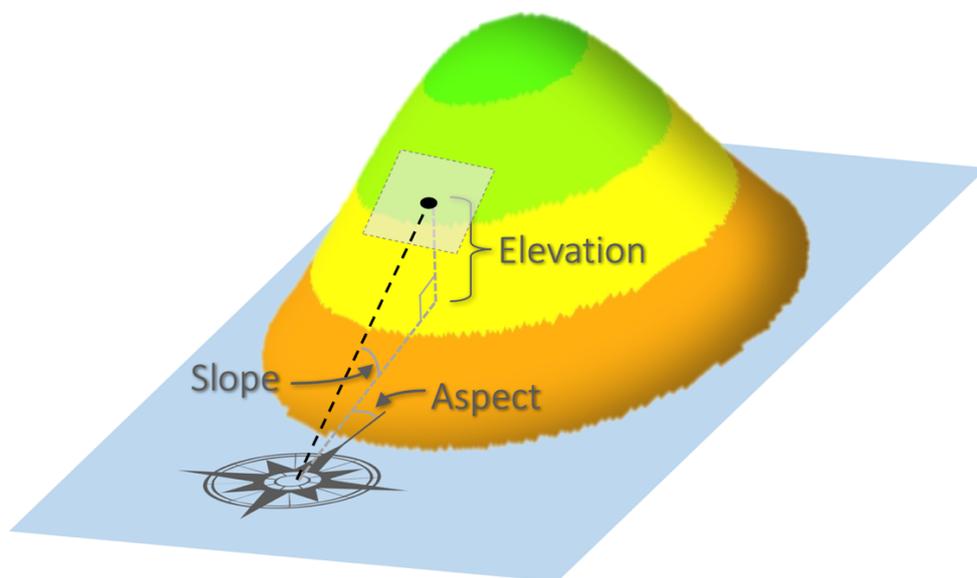


Fig 3.2 The concepts of elevation, slope, and aspect. Elevation is the height of a cell from sea level. Slope is the steepest angle of inclination from the elevation of a cell to the elevation of its adjoining neighbors, and aspect is the compass direction of the slope.

#### 3.2.4 Automated Detection and Estimation Model

In order to automatically identify anthropogenic disturbance, ArcGIS's Weighted Overlay Tool is used, a computational tool which can solve geographic multi-criteria problems such as site selection and suitability model (Esri 2015c, Malczewski 2000). In the field of geomorphology, this Weighted Overlay Tool has

been in use for landslide susceptibility mapping and the results show useful information for hazard mitigation purpose and regional planning (Shimizu et al. 2008), but it was not yet used for detection of anthropogenic disturbance.

The changes in the three attributes of elevation, slope, and aspect between the two examined periods were used as input criteria in the Weighted Overlay Tool. Since each of the three attributes has a different scale and unit of measurement, they had to be rescaled into a relative scale, enumerated from a minimum of 0 to a maximum with the value of 9 as required by this ArcGIS tool (Esri 2015). Elevation change was rescaled in ten steps (0-9), with the bigger elevation losses between the two periods receiving higher values and no change in elevation or positive change being assigned a 0. The same ten-step rescaling process was applied for slope change, in this case the more flat and less steep a cell became the higher the assigned value, because anthropogenic disturbance was previously found to generate flatter landforms (Yoshida et al. under review). In the case of aspect change, only two criteria were assigned: a change in direction (9) or no change (0). A change in direction means the aspect value changed more than 45 degrees, and no change is less than 45 degrees (Table.3.3).

Calibration of the model using four known mining sites as case studies recognized that change in elevation is more important than changes in slope and aspects in the detection of AD. Therefore, different weights of influence were assigned to elevation, slope, and aspect in 6:2:2 relative relations based on the experimental and practical researches conducted in the calibration phase, as described below. The final data grid used in automatic detection has for each cell a single number summing the percentage-weighted values of the three attributes.

Table.3.3 The weight values of each attribute

Attribute	attribute Weight	Classification	Rescaled value
Elevation Change	60%	-299 m to -100 m	9
		-100 m to -79 m	8
		-79 m to -64 m	7
		-64 m to -51 m	6
		-51 m to -39 m	5
		-39 m to -28 m	4
		-28 m to -17 m	3
		-17 m to -6 m	2
		-6 m to 0 m	1
		0 m -	0
Slope Change	20%	-59° to -29°	9
		-29° to -23°	8
		-23° to -19°	7
		-19° to -15°	6
		-15° to -12°	5
		-12° to -8°	4
		-8° to -5°	3
		-5° to -2°	2
		-2° to 0°	1
		0° -	0
Aspect Change	20%	360° to 45°	9
		45° to 0°	0

### 3.2.5 Post-detection processing and calculation of AD

Mining and excavation operations occur in scales larger than individual 50-meter cells, therefore anthropogenic disturbances are observed not only in one cell, but cover several cells. A filter (ArcGIS's Majority Filter Tool) was applied for remove single cells and small cell clusters which may be considered errors. The Majority Filter replaces cells based on the majority value in their contiguous neighborhoods for generalizing the edges of zones in the grid. Following this, the Cluster Outlier Analysis Tool was applied to unify cells with identified AD into clusters. Each cluster is treated as a single site of anthropogenic disturbance.

Following this, Landslide GIS Data was overlaid in order to exclude landslide area which was mistakenly detected and extract only the anthropogenic

disturbance. We used landslide distribution GIS Data which is published by the National Research Institute for Earth Science and Disaster Prevention (NIED 2014). The data was made by visual interpretation of aerial photos (1:40000 monochrome aerial photos published by the Japanese government's Ministry of Land, Infrastructure, Transport, and Tourism); a method which has the highest accuracy for landslide detection (NIED 2014). A total of approximately 373 thousand landslides that occurred between 1982 and 2013 through the whole of Japan are accounted and their location is recorded in this dataset, although this includes only landslides whose width was more than 150m. Minor landslides were not accounted for.

Finally, the remaining sites of geomorphological change can be determined to be sites of anthropogenic disturbance and their total volume was calculated from the change in elevation per cell using the following equation:

$$AD(\text{gravel, stone}) = \Sigma (V_{t2,i} - V_{t1,i})$$

where  $AD(\text{gravel, stone})$  denotes the total volume of the anthropogenic disturbance,  $V_{t2,i}$  is the volume in the period 1998-2005 at site  $i$ , and  $V_{t1,i}$  is the volume in 1987 at site  $i$ .

While conversion of the volume to mass is difficult due to the high variability in the material composition of soils at different locations, we were able to identify the type of land at each site using landform data. The landform data used in this research is published by the Ministry of Land, Infrastructure, Transportation, and Tourism (REFERENCE). This data was created based on two land classification surveys, the Fundamental Land Classification Survey by the national and prefectural (regional) governments, and the Land Classification Survey by municipalities. These comprehensive surveys aimed to improve the basic data of natural conditions of the land (geomorphology, subsurface geology, soil) of the whole country for more efficient land utilization. In this dataset,

landforms are broadly divided into 5 categories (mountain, hill, volcanic area, plateau and low ground) which we use in this study.

### **3.3 Results**

#### **3.3.1 Calibration of detection and estimation accuracy**

For construction of Kansai International Airport in the Osaka region, great amounts of soil and earth were extracted for landfill of an artificial island. The sites of excavation were Hannan, Kada, Sumoto and Tsuna in the same region (Obayashi 2011, Osaka Prefectural Government 1996, Yorigami 2011). Figure.3.3 shows the locations of Kansai International Airport and the excavation sites. These sites were chosen for the calibration and verification of the accuracy of the detection methodology adopted in this study because information related to the excavation (location, total volume excavated, and period of activity at the site) is reliable and accessible from the records of both the company and local government (Table3.4), and because sites were studied previously with DEM data by Sugimoto et al (2015) and Yoshida et al. (2017), offering comparisons with these previous studies' results.

The four sites were used for calibration, using their known locations and area to confirm that the automatic detection algorithm recognizes and accurately detects the sites. Of the four sites, only the Hannan site's excavation activity was fully contained between the years of our two DEM datasets. Activity at the other sites began in 1987, but ended after the final year of our latter dataset. Therefore, we were able to compare the official statistics of total excavation from Hannan with the results of our calculation method and confirm its accuracy. It is worth noting that all the excavated materials from the Hannan site were transported and used for landfill, thus officially no HMF remained on-site or elsewhere (Obayashi 2011, Osaka Prefectural Government 1996, Yorigami 2011).

Table.3.4 Details of mining for landfill at airport construction

Area	Excavation activity			DEM coverage	
	First year	End year	Volume [million m <sup>3</sup> ]	Digital Map 50m-mesh	10m-mesh Basic Information Digital Elevation Model Map
Hannan	1987	1993	55	1987	1998
Kada	2000	2007	85	1987	2005
Sumoto	1999	2007	50	1987	2005
Tsuna	1999	2007	35	1987	2005



Fig.3.3 Composite satellite imagery of the Osaka area, marking the location of Kansai International Airport and its excavation sites (background image source: Google Earth, 2016)

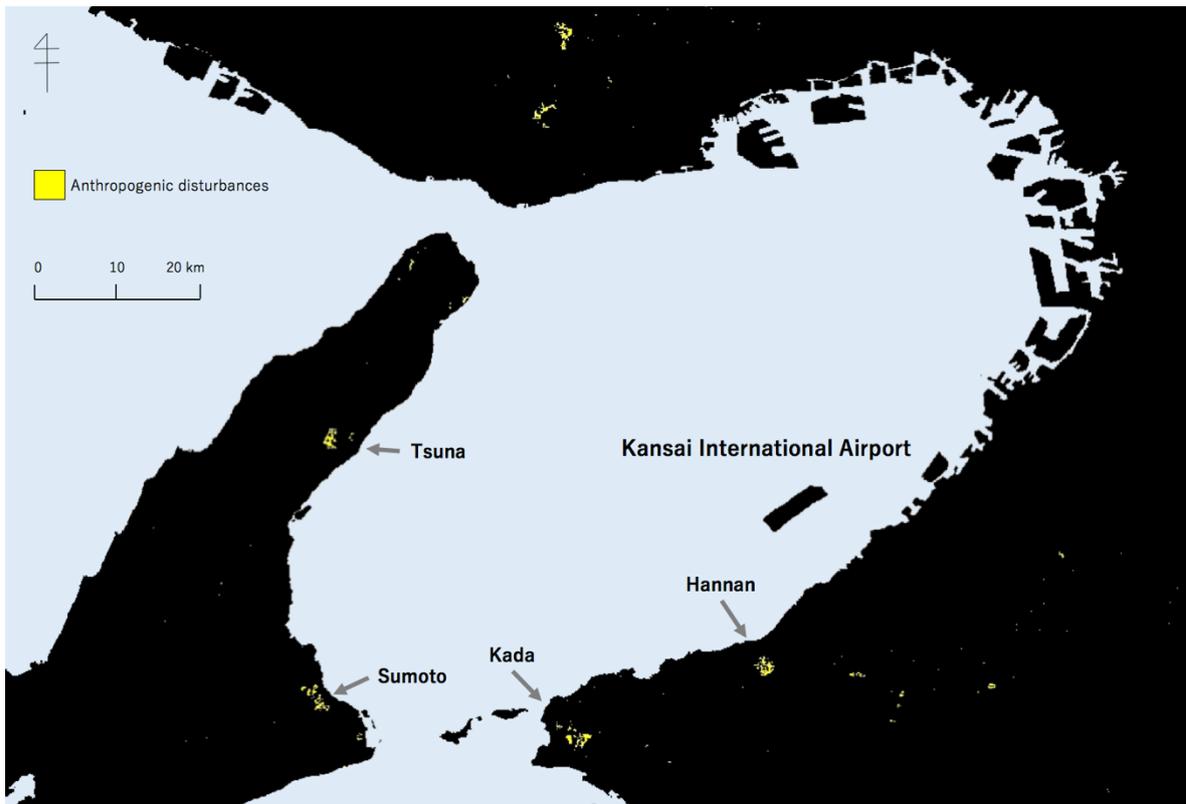


Fig.3.4 Surface map of AD using the automatic detection model. Colors indicate areas with AD changed by excavation and mining. Large scale excavation works for airport construction, such as Hannan, Kada, Sumoto and Tsuna are readily visible. Additionally, small mining, excavation, and residential developments around the Osaka region can be seen.

At the Hannan mining site, the total material extraction calculated in this study reached 55.9 million m<sup>3</sup>, while the officially recorded volume is 55 million m<sup>3</sup> (Obayashi 2011). This indicates that the DEM based estimation produced an estimation of approximately 1.6 % compared to the statistically recorded volume. According to Sugimoto et al (2015), DEM-based estimations may produce an overestimation of as much as 8% - 17%, depending on the accuracy of the original DEM. In addition to the case study of Hannan, we also focused on the Misaki area and checked the research reproducibility of Sugimoto et al (2015). According to the local governmental records, the total material excavation from Misaki was 70 million m<sup>3</sup>. We used Digital Map 50m-grid for

pre-mining, and ALOS 30m-grid for post mining and found that the total material extraction reached 74.3 million m<sup>3</sup>. Assuming that the government records are accurate, the result suggests that the DEM based estimation produced an overestimation of only 6%. Compared to the results of Sugimoto et al (2015) (8%-17%), our estimation results generate a lower overestimation (6%), and high research reproducibility was shown in the research of Misaki. Therefore, while there is a discrepancy between our results and the published statistics it is minimal and provides confidence in our procedure.

### **3.3.2 Anthropogenic disturbance in Japan**

The methodology was applied for accounting entire territory of Japan, and the results include the volume of anthropogenic disturbance (m<sup>3</sup>), anthropogenic disturbance area (m<sup>2</sup>), and total volume of anthropogenic disturbance per unit the area (m<sup>3</sup>/m<sup>2</sup>). Furthermore, to examine the geomorphological features of Japanese anthropogenic disturbance, spatial analysis of the anthropogenic disturbance was used.

The results show that the total volume of anthropogenic disturbance in Japan between 1987 to 1998-2005 was 7 billion m<sup>3</sup> or almost 0.5 billion m<sup>3</sup> per year. A total of 2517 anthropogenic disturbance processes (sites) were identified in the entire area, which together measured 149 million m<sup>2</sup>, and the total volume of anthropogenic disturbance per area was 47 m<sup>3</sup>/m<sup>2</sup>. There is an unequal distribution between the number of sites and the volumes of AD generated by them. Clustering the sites by the volume excavated using the Jenks natural breaks classification method, it can be seen that over 60% of the sites were found to be small, of only 1-3 million m<sup>3</sup> of AD each, but these account for only a quarter of the overall AD (Figure.3.6). In fact, nearly equal amounts of about a quarter of the total excavated volume occurred in these small sites as in medium sites (4-8 million m<sup>3</sup>, 28% of the volume but only 23% of the number of sites), larger sites (9-17 million m<sup>3</sup>, 25% of the volume but 10% of the number of sites), and very large sites (18-56 million m<sup>3</sup>, 22% of the volume but only 4% of the number of sites). We further differentiate the latter group to very large sites (18-33 million m<sup>3</sup>) and giant sites (34-56 million m<sup>3</sup>), to demonstrate the immense contribution of 7%

to the total AD by these mere 21 sites to the total material excavated. The calibration sites were found to be medium sized.

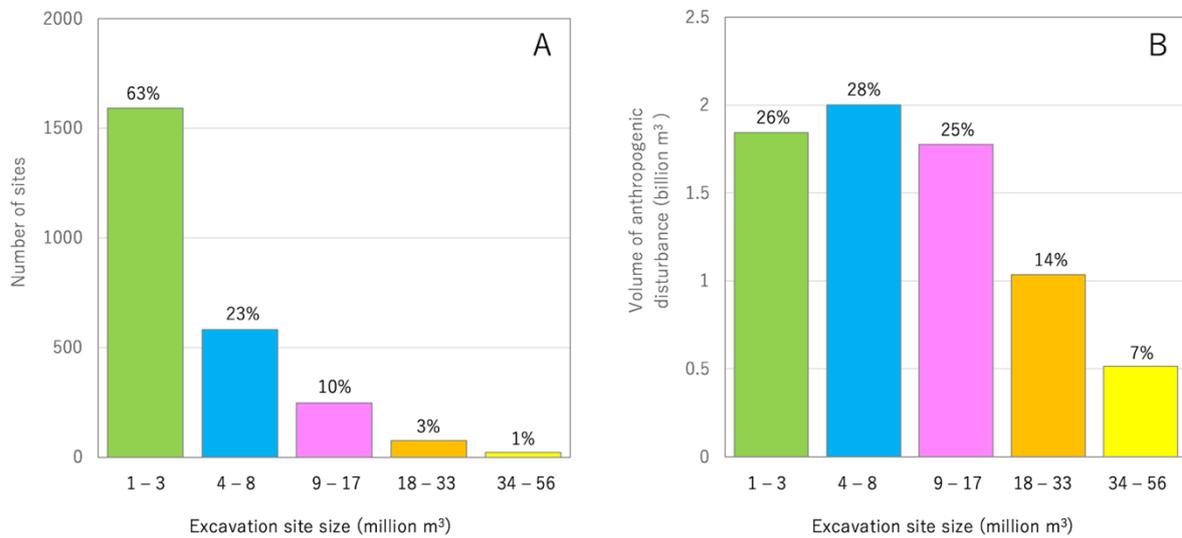


Fig.3.5 Number of excavation sites (A) and total volume of anthropogenic disturbance per excavation site size (B).

The unequal distribution of AD can also be seen on a spatial dimension (Figure.3.7) across Japan. Each point in the figure represents a site of anthropogenic disturbance. Although there are sites of AD all over Japan, including some of Japan's minor outlying islands, there are clear concentrations in a few regions. The biggest concentration is in a stretch of inland area roughly between the major urban centers of Tokyo and Nagoya which includes almost all of the giant AD sites, as well as two other heavily-disturbed areas around the Tokyo metropolitan area, one to its north and the second on the Izu peninsula. Further regions of concentrations of AD are in the center of the northernmost Hokkaido island, in the Niigata region, and the western part of the central Honshu island. On the other hand, a few regions are significantly clear of AD, including the Tokyo metropolitan area itself, which is a heavily urbanized flatland, and most of Hokkaido, large swathes of the Tohoku region on the north of Honshu island,

and the Kii peninsula, all of which are natural reserves, national parks, and world heritage sites.

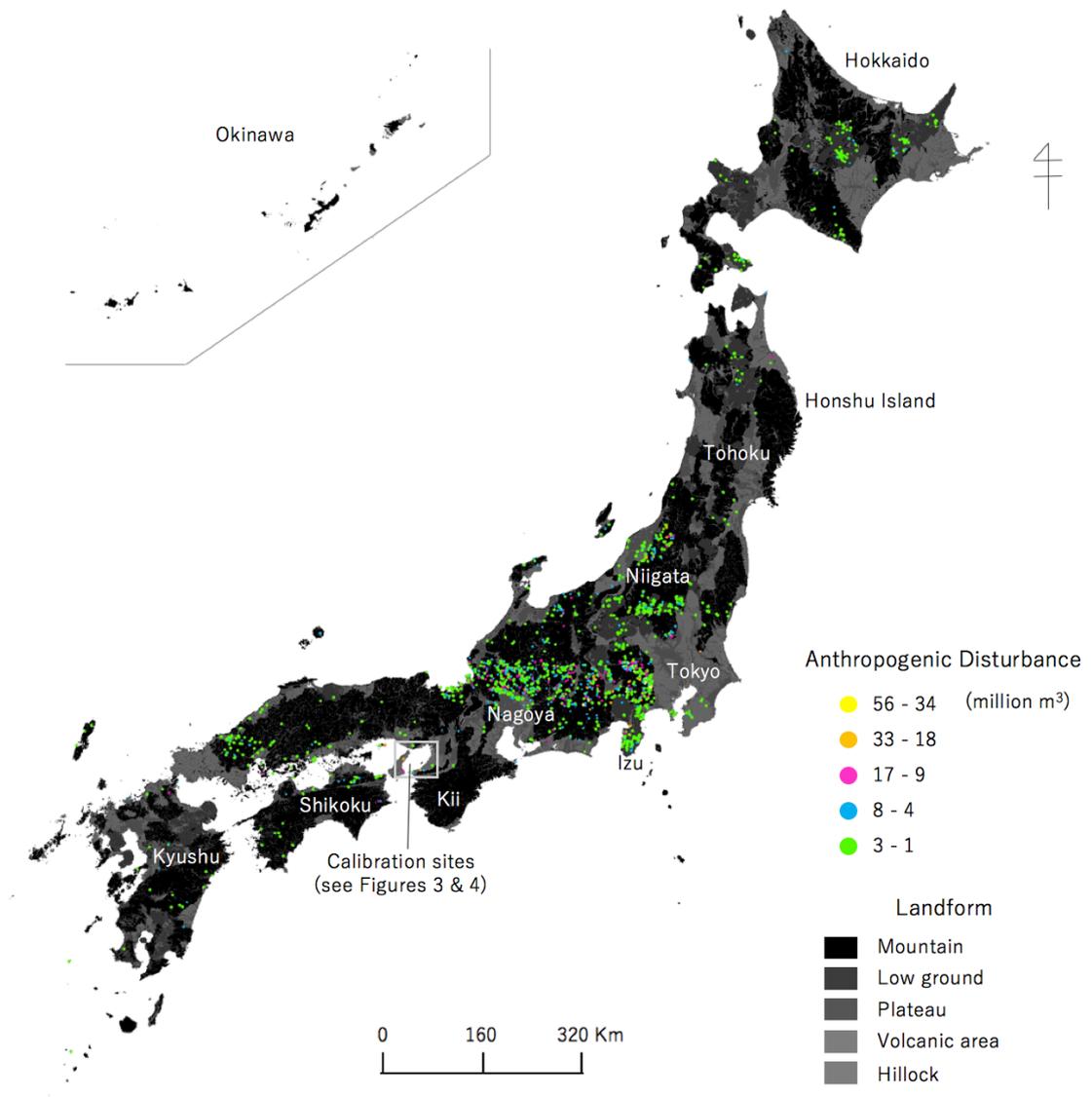


Fig.3.6 Spatial distribution of anthropogenic disturbances in Japan

The AD sites were overlaid on a landform map (Figure3.6), and the total area and volume of anthropogenic disturbances was accounted in each type

of landform (Figure.3.7). More than half of the volume (4.2 billion m<sup>3</sup>) of anthropogenic disturbances was found to be located in mountainous areas, which compose most of the landform of Japan and are the least populated. Volcanic areas, hillocks, plateaus, and low grounds each contain less than 1 billion m<sup>3</sup> of anthropogenic disturbances.

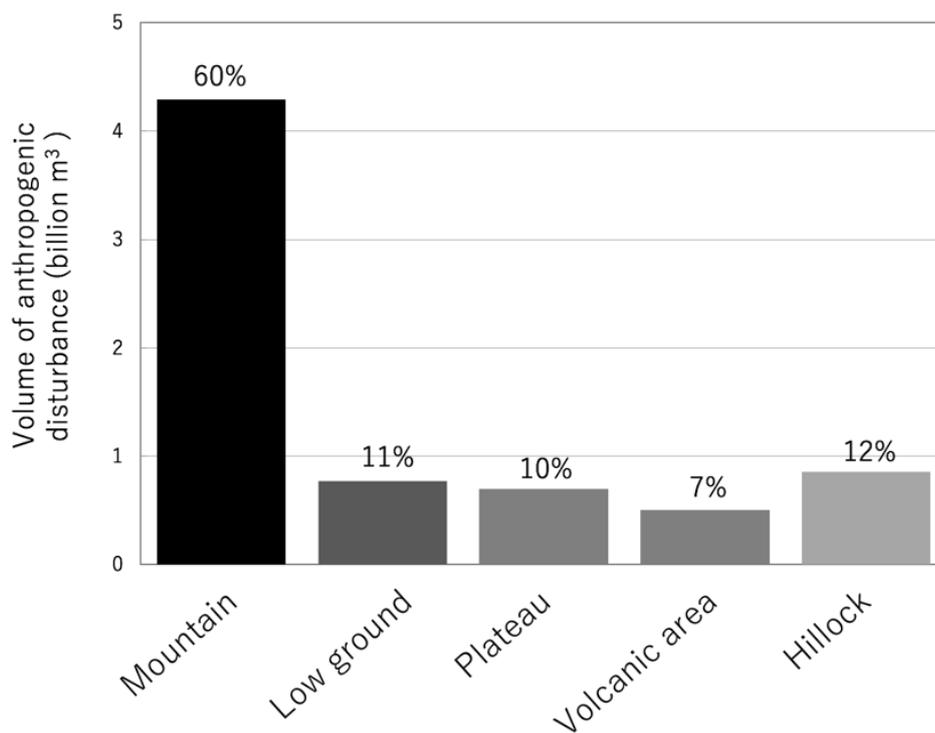


Fig.3.7 Volume of anthropogenic disturbance per landform type

### 3.4 Discussion

#### 3.4.1 Accounting for Anthropogenic disturbance

How much of the 7 billion m<sup>3</sup> of earth and soil disturbed by anthropogenic activities is actually used by the Japanese economy? The attributions of the 7 billion m<sup>3</sup> is presented in figure 8. Japan's domestic extraction (DE) is almost completely dominated by construction minerals, especially by sand and aggregate which require minimal processing and can be used almost as-is in their raw extracted form (2009), and so one could expect that the vast majority of

these 7 billion m<sup>3</sup> will end up as in-use material stocks of buildings and infrastructure. However, statistics of the total volume of DE, used extraction of construction minerals, in the same period as the one we analyze are only about 3.2 billion m<sup>3</sup> (Yoshida et al. under review, compiled from the Statistical Yearbook of Japan and Fiscal Gravel Business Status Report Summary Table, 1987-2000). Official statistics (Statistical Yearbook of Japan and Fiscal Gravel Business Status Report Summary Table, 1987-2000) seem to cover approximately 90% of mining and quarrying company, as material excavation by small companies and illegal mining activities are not recorded in the statistics (METI 2015). This would generate lower estimation of total volume of DE by statistics, or about 0.3-0.4 billion m<sup>3</sup> undocumented DE. However, even considering this uncertainty, this leaves almost 3.5 billion m<sup>3</sup> unaccounted for, 50% of our estimate. Non-anthropogenic disturbances, that is, natural disturbances such as landslides which were not detected as such with our method – could induce an error term in the algorithm. Even though the landslide GIS data that was used is known to not include minor landslides, it is highly unlikely that minor landslides would conjointly amount to more than a small percentage and so we reject them as major contributors to this figure.

On the contrary, this ratio is in line with previous TMR assessments of construction minerals in Japan (Adriaanse et al. 1997b; Matthews, Amann, Bringezu, et al. 2000) and other countries such as China and Finland (Wang et al. 2013), which include not only unused extraction and HMF related to domestic extraction, but also excavated materials for cut-and-fill and other infrastructure developments and their related unused extraction and hidden flows.

In a previous study (Yoshida et al. under review) we used a similar approach of estimating AD through comparisons of elevation changes in DEMs across Japan without the automated procedure but rather by manually identifying sites of excavation and mining activities. As only known sites were analyzed, the previous study's estimation of 2.6 billion m<sup>3</sup> HMF is directly related to domestic extraction. This leaves us with a difference of 0.9 billion m<sup>3</sup> in the current results, most of which can be attributed to excavation and not to natural processes since, On the other hand, excavation-related flows are likely. As a highly

mountainous country, cut-and-fill operations in land development and extensive grading and other terrain transformations are required commonly occurring activities (Moriguchi 2002; Adriaanse et al. 1997b).

Although this is the probable explanation for these 0.9 billion m<sup>3</sup>, it is unclear how much of this material was actually usable by society as excavations and how much was overburden related to excavations. The DEM based accounting include both DE and excavations of the ground for land development, and the related HMF of both activities. HMF consists of waste rocks and overburden of DE, and soils generated in construction sites. Some part of the overburden is left aside of the excavation or mining site, and is later used to refill the site, but most of the overburden and waste rocks are disposed in landfill as industrial waste (MLIT 2006, MLIT 2016). Soils generated in construction activities are also HMF, but 75% of them are used on-site or transferred to other construction sites. The remaining soils are disposed in landfills (MLIT 2016). As accurate country-wide figures for cut-and-fill activities and landfill of overburden cannot be obtained for the examined time period, it is difficult to attribute which portions of the remaining 0.9 billion are excavations, HMF related to excavation, and further HMF related to DE. Thus, while the ratio of about 1:1 used-to-unused materials is similar to previous TMR estimates of Japan, a full comparison of TMR and our AD estimates is still unobtainable, especially since TMR is reported in mass and our AD estimates are measured in volume. Conversion of the volume to mass would require the density and physical properties of the material at each site, which are highly variable.

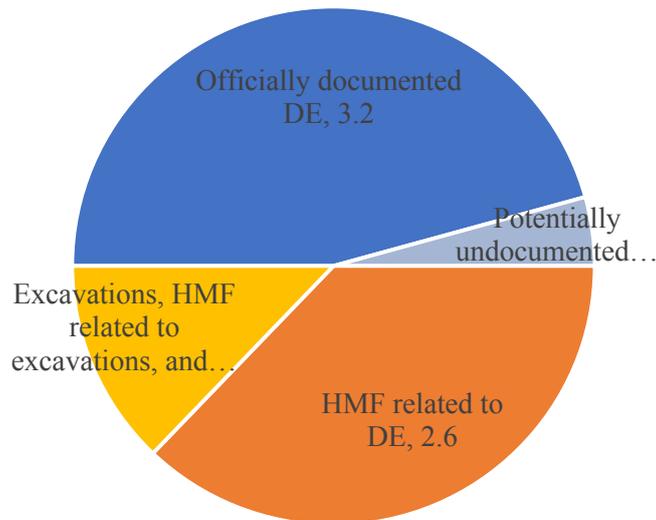


Fig.3.8 Breakdown of the anthropogenic disturbance in Japan, in billion m<sup>3</sup>. DE: Domestic Extraction. HMF: Hidden Material Flow.

### 3.4.2 Environmental and geographic implications of Anthropogenic disturbance

The total volume of AD per area was found to be 47 m<sup>3</sup>/m<sup>2</sup> for the entire examined period. This result conforms with previous findings, such as Kawahara and Tanaka (2010) (61 m<sup>3</sup>/m<sup>2</sup>), Sugimoto, et al. (2015) (54.6 - 58.8 m<sup>3</sup>/m<sup>2</sup>) and Yoshida, et al. (under review) (33 m<sup>3</sup>/m<sup>2</sup>). The yearly average volume of material removed by AD per area is thus about 3.1 m<sup>3</sup>/m<sup>2</sup> per year. This removal of material can be compared with natural soil erosion - loss of surface soils by natural phenomena such as water flow or wind, which is related to low yields and high production costs in agriculture, decreases in reef water quality, etc. Although soil erosion data for Japan was not available, Eurostat (2016) calculated the soil erosion in Europe to be about 0.00028 m<sup>3</sup>/m<sup>2</sup> per year - four orders of magnitude less than AD. This shows the strength of artificial landform change (Kawahara and Tanaka 2010, Sugimoto, et al. 2015) and clarifies the scale of pressures to the natural environment.

The use of graphically explicit data enabled to locate the anthropogenic disturbance sites (Fig.6), and more than half were found to occur in mountain areas (Fig.7). Approximately 67% of Japanese land is cover with forests

of which most are in the mountain areas (MFF 2015). Therefore, accompanying the anthropogenic disturbance of soil and the earth, forest vegetation and wildlife are also disturbed and put in risk. Each excavation site induces stresses on its surrounding natural environment and the fact that more than 60% of the sites were found to be of small volume hints that their contribution to the overall environmental impact may be bigger than their contribution to AD. Using the spatially-explicit method to account for AD, it may be possible to find an optimal size for excavation which minimizes the physical footprint and environmental adverse effects while maximizing the useful extracted volume. This, however, is beyond the scope of this study since to fully account for these parameters, such as changes in forest land cover due to AD, other data would be required. For further researches of detecting the impact of mining activity, Koarai (2015) show a high utility of DEM by creating a landscape ecological map for an evaluation of biodiversity. He applied overlay analysis of the vegetation classification and landform data. In addition to DEM based estimation, these types of analyses would be interesting for NGO and industrial sectors for accounting environmental impacts and adaptation the post-mining area, and could be extended to other countries and other types of material excavations.

### **3.5 Conclusions**

Society's material stocks require huge amounts of raw material from the environment. While the effects of the accumulation of stock on the anthroposphere are in the spotlight, so far research into the upstream environmental burdens of extraction of the necessary materials have been limited to economically high-value materials such as metals, and geographically explicit analysis even more uncommon. The use of GIS and DEM data for the geographical analysis makes it possible to detect anthropogenic disturbance and estimate its total volume including the HMF, and the spatial information of the destructive and sometimes irreversible effects of the natural environment also revealed.

In the present study, we focused on the large scale of anthropogenic disturbance, including excavation and mining in Japan, which are almost

completely limited to construction minerals that are consumed domestically. About 7 billion m<sup>3</sup> were accounted, of which 2.6 to 3.8 billion m<sup>3</sup> are unused extraction which never enters the economic sphere and therefore is considered to have no value, yet its sheer volume has serious adverse effects on the environment.

A special feature of this study is the automated detection and estimation of the anthropogenic landform change using a direct analysis method. This automated detection and estimation algorithm can be applied to many other subjects such as open-pit mining, land development, soil excavation during construction, and the development of infrastructure. This method requires only digital elevation models, whose availability is increasing globally and may be easier to procure than statistics, and which offer increased reliability compared to reported statistics and indirect HMF accounting methods. Expanding the usage of DEMs with automated methods would not only enrich the knowledge related to material stocks and flows in countries and regions with poor and inconsistent statistical data, but also contribute crucial spatial and quantitative information of human impacts to nature. This method thus sheds light on an otherwise hidden aspect of the material accumulation process in society. The findings point towards serious environmental disturbance by the ongoing extraction of materials from the environment. It can be expected that in other countries which are more natural resource-rich than Japan and whose extractive sectors are more dominant, the situation is even worse. These findings strengthen the call for serious reductions in the extraction of raw materials, and emphasize the need to improve the efficiency of usage of the materials already accumulated in society by improving the quality of the material stock to provide its services to society, lengthening the lifespans of stock, and re-using the stocked materials through recycling and urban mining.

### **3.6 Acknowledgements**

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## 4 Anthropogenic Disturbance of Germany

### 4.1 Introduction

More than 50% of people living in urban area in the world, and it is expected to be 70% by 2050 with rapid economic growth of developing countries (United Nations 2012). According to the growth of population in the urban area the demand for natural resources including non-metallic minerals, metal ores, fossil fuels, water, food and biomass are dramatically increase with enormous environmental impact such as acidification, biodiversity loss, climate change, eutrophication, soil erosion, land pollution and water pollution (UNEP). It is trade-offs between economic growth and environmental impacts. Material stock flow analysis/accounting plays important roles in order to monitor the decoupling of natural resource use and environmental impacts from economic growth (EUROSTAT 2009). Material extraction growth form 22 billion tonnes in 1970 to 70 billion tonnes in 2010 (UNEP 2016). This trend shows that non-metallic minerals for construction use was the fastest growing materials, and the material extraction grew is not even in the global economy, Asia and Pacific area had the large growth compared other area. In recent years the global amount of construction minerals entering the economy has reached about 35 billion tonnes per year (Miatto et al. 2016). Not only the natural resources, but also building stock is also known as a repository of natural resources from the perspective of urban mining.

Stock analysis contributed to understand the state of natural environment and socio-economical society with material flow analysis. Stocks are being essential foundation of society by supporting economic activities and providing services such as buildings, consumer products, factories, and infrastructure. Material stock of nations are accounted by top-down methodology and bottom-up methodology by a lot of researches, such as German material stock of non-domestic buildings achieves 6.8 billion tonnes (Ortlepp et.al 2015). the calculation model and uncertainties of material stock and flow are verified by Ortlepp et.al. (2016). According to technical development of building construction and revise of urban planning, building stock lifespan is dramatically

changing, in case of Zurich, Switzerland, average demolition age of buildings decreased from 200 years to 70 years (Aksözen et.al. 2017).

It is important issue for regional planners and politicians to quantify national and local waste flows (Kohler and Hassler 2002). In the regions of urban and sub-urban, regulation of water and soil is getting strict with limited capacity of waste materials mainly from new construction, refurbishing and demolition of building. And nowadays, demolition of buildings is the main stream of waste in industrialized societies. Therefore, researches of waste flows such as Hashimoto et.al. (2006) that focused on material flow and stock of construction minerals (aggregate, asphalt, cement, crushed stone, gravel and sand) to understand the mechanism of waste generation is essential for making sustainable waste management plan in both city and national scale. Demolition waste from buildings are often recycled as basement of road and seawall, while rest of them and organic waste are incinerated and dumped on farmland or filled into the sea. According to the increase of dumping from personal and industrial waste, the needs of waste disposal site are ever increasing around the urban area (Douglas et.al. 2002). And landfilling of waste materials, tailing and waste rock generate environmental impact with land use conflicts (Augiseau et al. 2016). The environmental damages by tailing and waste rock cannot be forgotten, and there is also public attention to the management of tailing pond and tailing dam. In the record of Eurostat (2003), mining and quarrying waste achieves over 300 million tonnes in the EU-15 by annual.

They cover 14 types of metals (aluminum, cadmium, chromium, copper, gold, iron, lead, manganese, mercury, nickel, silver, tin, tungsten, and zinc), coal (hard, rock, and black coal) and 10 types of industrial minerals (barytes, borate, feldspar, fluorspar, kaolin, limestone, phosphate, potash, strontium, and talc). In order to reduce of hazardous substances influences for human health, landfilling mining also has an important role of reducing of negative influences in landfills and dump sites (Burlakovs et al. 2017). On the other hand, in some area, there is the practical use of methane gas from landfills in order to generate electricity for local grid (Douglas et al. 2002).

The material balance principle at the foundation of material flow and

stock accounting states that as the anthropogenic in-use material stocks increase, natural stocks decrease at an equivalent amount. We can find strong relationship between material flow and landscape, new construction and maintenance of buildings and infrastructure stock demand for metals and construction minerals that alter landscape by mining and promote anthropogenic disturbance (Douglas and Lawson 2001). Global HF associated with anthropogenic disturbance is increasing besides the construction material extraction which are used in construction sector. However, as Bringezu et.al. (2004) shows there is not a standard common framework to account global HF systematically. Therefore, developing methodology for estimating HF through monitoring domestic extraction under common methodological framework with reliable accuracy is important for understanding the dynamics of anthropogenic disturbance. Additionally, TMR can show potential environmental impact that is associated with natural resource extraction and use, yet it cannot indicate specific environmental pressure such as anthropogenic disturbance that causes destructive and irreversible effect of the natural environment (Bringezu and Schutz 2001). The practical geomorphological information is also required in the study of anthropogenic disturbances.

Remote sensing techniques have been used for analysis and modeling of ecological and hydrological phenomenon to monitor natural environment. DEM which represents basic information of the earth's surface is applied for flood simulation, soil mapping, soil erosion analysis, PH modeling and material transfer calculation (McBratney et.al 2003, Rueda et.al. 2013, Baltensweiler et.al. 2017, Taniakwa and Imura 2001). Additionally, there are lot of national and private survey of artificial landform change to quantify ground stability at human used area such as residential, commercial and industrial area. Recent research of material flow analysis is also applied DEM in quantification of material extraction, waste demolition prediction from urban area (Ross et.al, 2016, Kleemann et.al. 2016, Sugimoto et.al. 2015, Yoshida et.al.2017). Especially, the combination of DEM and statistics makes it possible to estimate HF and we can monitor anthropogenic disturbance of soil by mining activity (Yoshida et.al. 2016). Noteworthy that in case of landlocked countries, we can monitor the

material transfer from the begin (mining site) to the end (filling site) where directly get the negative environmental impact. Backfill and landfill sites are also focused as one of a huge anthropogenic disturbance, and the same methodology (Yoshida et.al. 2017) can be applied to measure mass of filled materials. It is expected to be able to monitor missing unused materials such as overburden and waste rocks from mining site that would be used as backfilling materials to fill abandoned and post mining site. However, the total mass of filled materials are not qualitatively and spatially discussed with national material flows.

This study quantitatively and spatially discusses the relationship between anthropogenic disturbance and material flows taking the Germany as a case study country. We focus on material extraction and filling site of entire Germany. We established a bottom-up method that employ GIS, DEM (ASTER, SRTM) and landcover (CORINE) for accounting mass of DE and filling. This methodology makes is possible to estimate HF by comparing results of bottom-up method and top-down method which uses statistics for DE. Additionally, monitoring landform change give us important insight of anthropogenic disturbance that is occurred by anthropogenic flow and environmental pressure/impact. We apply this material flow analysis that focusing on both the start point (material extraction) and filling (endpoint) to the Germany since 2000 to about 2010. The periods depend on observation period of ASTER and SRTM DEM.

This study aims to clarify dynamics of anthropogenic disturbances by presenting a novel methodology which uses remote sensing techniques to account DE and related HF. We employ GIS, DEM, and landcover that enable us to monitor anthropogenic disturbance and HF in material excavation from local, regional, national, and global scale. This methodology has high potential for quantifying anthropogenic disturbances with spatial distribution. As the first step to standard procedure, we took case study and examine the performance of several types of DEMs for the research of anthropogenic disturbance. This study provide insight into the relationship of material flow and anthropogenic disturbances by taking case study on Germany, a country of highly industrialized and have many researches related to material consumption, sound material uses

and material stock & flow analysis.

This study aims to:

1. develop a novel methodology for accounting used and unused material extraction. This can be achieved through landform change observation by using GIS, DEM and landcover.
2. build database of national scale used and unused material extraction.
3. investigate dynamics of anthropogenic disturbance and HF, focusing on mining and filling site by top-down and bottom-up methodology.

Investigating anthropogenic disturbance is important to understand practical relationship between anthropogenic flow and environmental pressure/impact. We know the existence of anthropogenic disturbance behind great amount of material inflow produced by constant demand for metals and construction minerals to develop and maintain urban functions (building, road, railway, dam, airport, pipeline and etc.) and outflow of their demolition waste. We relate the findings on material extraction and fill to anthropogenic disturbance to gain a new prospective of environmental pressure/impact.

## 4.2 Data and methods

### 4.2.1 Research approach

We employ geographic information systems (GIS) with DEM and, landcover datasets, to measure volume and detect location of anthropogenic disturbance of soil and earth at extraction sites and fill site (Table.4.1, Fig.4.1). DEMs contributes to investigate the dynamics of anthropogenic disturbance by measuring area, depth and volume, and landcover makes it possible to find out extraction and dump site. By comparing DEMs of different time frames, it is possible to monitor the geomorphological change by mining and filling (Yoshida et al. 2017, Ross et al. 2016). DEMs also enable the association of anthropogenic disturbance with spatial information, thereby allowing the observation of the environmental pressure and its evolution over time.

Table.4.1 DEMs and landcover dataset

Name	Data type	Observation		Feature
		period	Resolution [m]	
SRTM	DEM	2000	30,90	11 days STS-99 mission in 2000 produced by NASA
ASTER		2008~	30,90	Joint operation of NASA and Japan which covers 80% of the earth
CORINE	Landcover	1990, 2000, 2006, 2012	100	Combination of several satellite's data that covers most areas of Europe

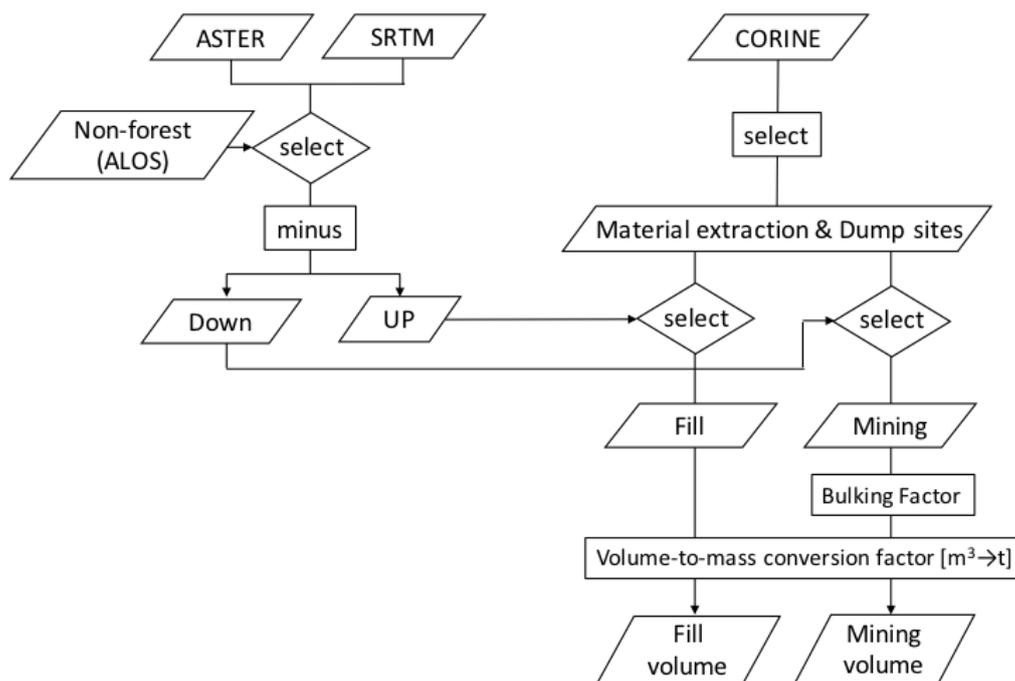


Fig.4.1 Flow chart of measurement and detection of anthropogenic disturbance

#### 4.2.2 Bottom-up method: digital elevation model and landcover

Variety types of DEMs are now public available in global scale. Each country's national DEM are usually produced by own national mapping agency. They create national DEM from their national counter map and it thought to have high vertical and horizontal accuracy. Recent technological development also contributes to create national scale elevation map, LiDAR (Light Detection and Ranging) is well known of its utility. Satellite remote sensing also produced global DEM with large covering area of the world. ASTER GDEM (Advanced Space-borne Thermal Emission and Reflection radiometer, Global Digital Elevation Model) (Fig.4.2), SRTM (shuttle radar topography mission) DEM are now available at online download service (USGS). They are created from stereo pairs or triplets of optical images or data from synthetic aperture radar. Global DEMs made it possible to observe world topographic changes, and with effort of improving the accuracy of satellite data and calculation process, now we can get DEMs with higher accuracy. In addition to DEM for a measuring volume, landcover data, CORINE (Coordination of Information on the Environment) and Non-Forest map (Global 25m resolutions PALSAR-2/PALSAR/JERS-1 Mosaic and Forest/Non-Forest map) are required to identify the location of mining and fill site (JAXA 2017, EEA 2017). CORINE covers

most of Europe areas in 44 classes with high accuracy and resolution. In order to produce CORINE, satellite data such as Landsat-5 (MSS/TM), Landsat-7 (ETM), Spot-4/5, IRS P6 LISS (III) and RapidEye, and high resolution satellite imagery data are used do visual interpretation. Few countries applied semi-automatic method to determine the landcover by using GIS integration and generalization (Copernicus 2017) (Fig. 4.3 and 4.4). Non-Forest map is produced by classification of backscattering intensity value in global 25m resolution PALSAR-2/PALSAR mosaic, determination of forest is according to FAO's definition that natural forest area larger than 0.5 ha with 90% occupation in a mesh (JAXA). Non-Forest map was used to exclude the forest area in the volume calculation of anthropogenic disturbance because of the ASTER GDEM include the surface objective height. And material extraction and dump site was selected according to CORINE landcover to specifically identify the mining and fill sites.

Following equation (1) is used in the bottom-up method.

$$MF(\text{gravel, stone}) = \Sigma(V_{t,i} - V_{t2,i}) \quad [1]$$

where  $MF(\text{gravel, stone})$  denotes the total mass of the anthropogenic disturbance,  $V_{t,i}$  is the volume in year  $t$  at place  $i$ , and  $V_{t2,i}$  is the volume in year  $t2$  at place  $i$ .

This mining volume by bottom-up method is calculated in natural condition which is compressed by own weight (Bank volume) in unit of  $\text{m}^3$ . Bank volume is need to be converted to "Loose volume" by using Bulking factor for comparison with statistics, hence we applied common banking volume (1.65). In addition to this, mining and filling unit also need to be converted from volume[ $\text{m}^3$ ] to mass[t]. According to conversion ratio of its components of DE and fill by statistics, Bulk density ( $\text{tonnes}/\text{m}^3$ ) were applied to the mining and fill volume in bottom-up method.

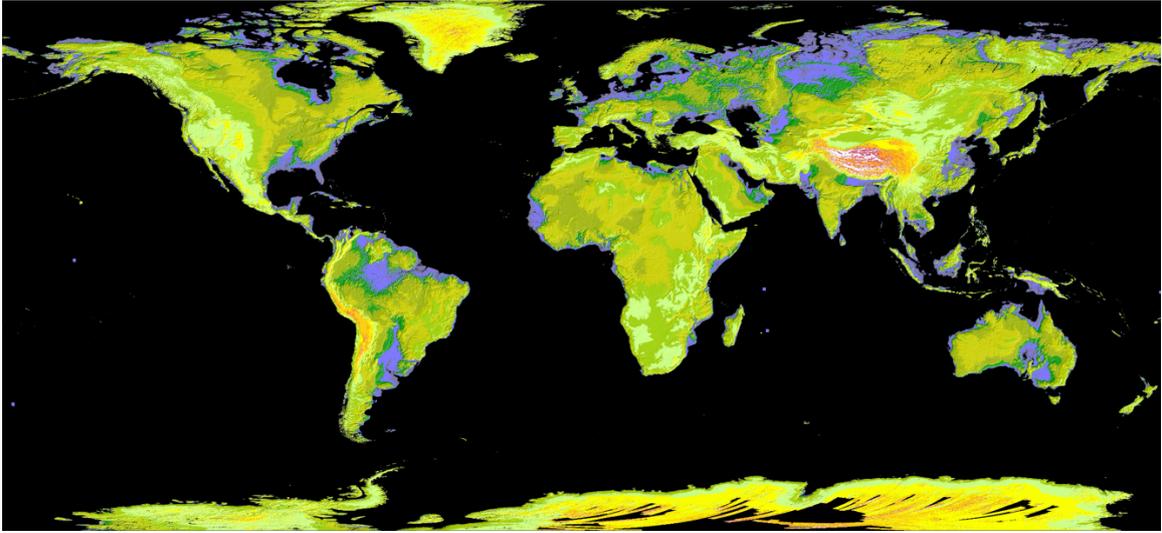


Fig.4.2 Coverage area of ASTER GDEM  
(adapted from NASA)

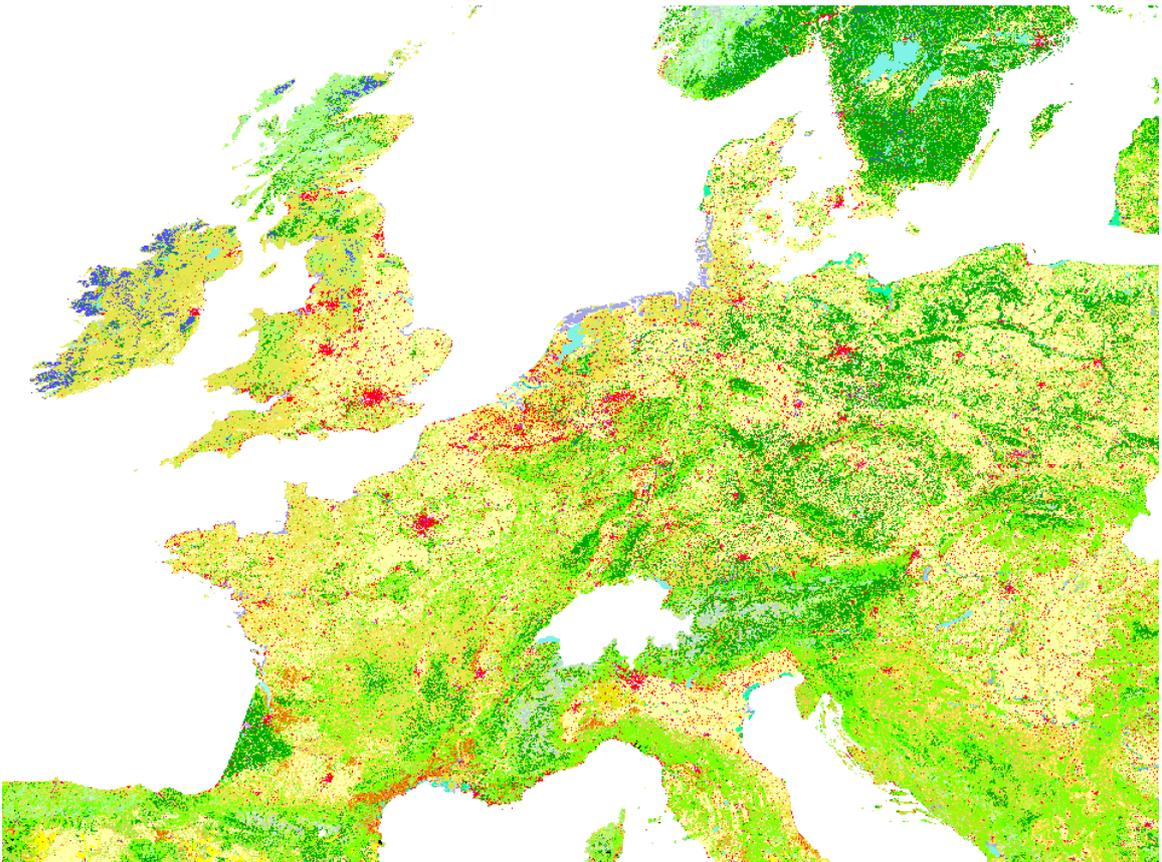


Fig.4.3 Coverage area of CORINE  
(adapted from European Environmental Agency)

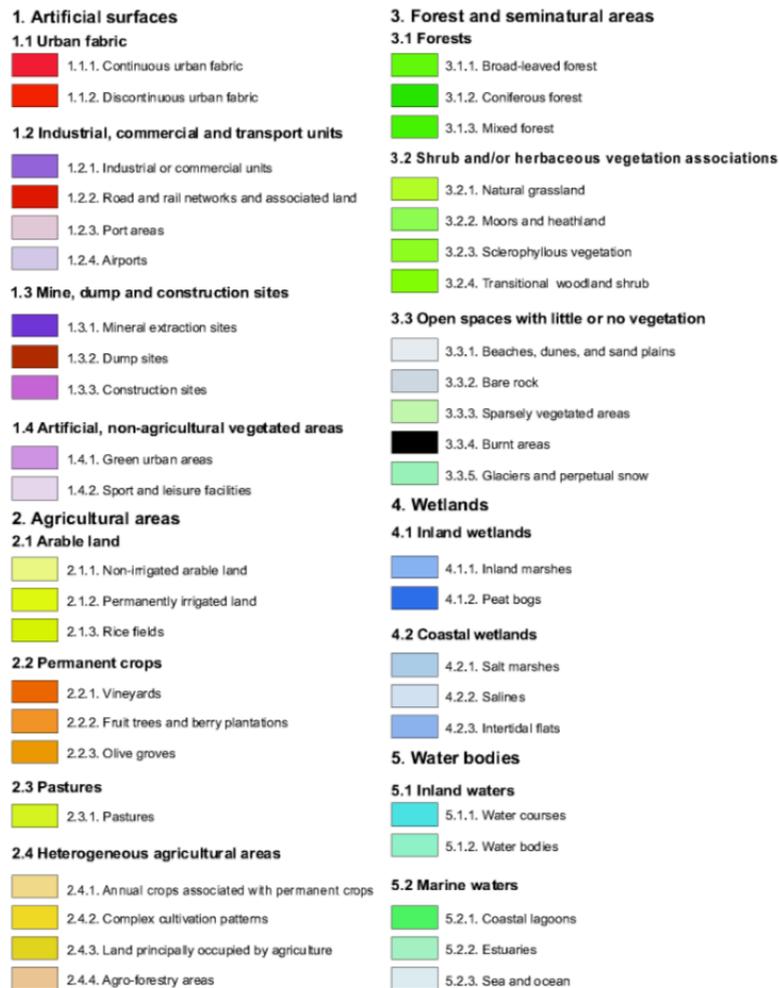


Fig.4.4 Landcover classes of CORINE  
(adapted from European Environmental Agency)

#### 4.2.3 Top-down method: national statistics and global material flows database

In parallel to the bottom-up accounting, national statistics data and global material flow database were used for account mass of used material extraction, unused material extraction, waste material and landfill (Table.4.2). Global material flow database was produced by Vienna University of Economics and Business (WU) that can be used for variety of policy-oriented analyses of economy and environmental interactions (Marina). In order to account DE of entire Germany, we selected only used and unused material (industrial minerals, ores, construction minerals, coal) from 2000 to 2010. Federal statistical office Germany (DSTATIS) is leading provider of high-quality statistical information of Germany and we select

environmental waste record for accounting total waste generation. We also used waste and recycling management record which is produced by German Environmental Agency.

Table. 4.2 Statistics data of used, unused, waste, and landfill materials

Type	Data sources	Agency	Period	Material
Extraction(used)	Global Material Flows Database	Vienna University of Economics and Business (WU)	2000-2010	Industrial minerals, ores, construction minerals, coal,
Extraction(unused)		Statistisches Bundesamt, Wiesbaden (DSTATIS)		
Waste Material	Environmental Waste(Umwelt Abfallentsorgung)	Environmental Agency (Umwelt Bundesamt)		All (Municipal waste, mining material, waste from production and trade, construction and demolition waste, waste from treatment plants.)
Landfill	Waste and recycling management			

## 4.3 Results

### 4.3.1 Top-down method: domestic used extraction and unused extraction

Our results show that the total DE of Germany was 12.1 billion tonnes, while DE of industrial minerals, ores, construction minerals, and coal achieved 9.32 billion tonnes from 2000 to 2010 (Fig4.5). The trend shows slow decrease of total DE from 1.2 billion tonnes in 2000 to 1.0 billion tonnes in 2010. The first largest extracted material; construction minerals constantly kept its share, approximately 60 % of total DE. The second largest extracted material was coal, which commonly extracted approximately 200 million tonnes in annual. The rest of DE was consisted of industrial minerals, ores, other fossil fuels, oil, gas, other biomass, biomass forestry, biomass food, biomass feed, and biomass animals.

We also accounted total domestic unused extraction (HF), which was 21.5 billion tonnes, while HF of industrial minerals, ores, construction minerals, and coal achieved 20.1 billion tonnes between 2000 to 2010. It is notable that 86% of HF was consisted by coal, which achieved 16.6 billion tonnes in a decade(Fig.4.6). The average ratio of German DE and HF was 1: 1.8, which represented that 1.8 tonnes of HF (overburden and waste rocks) required to extract 1 tonnes of used material.

Billion tonnes

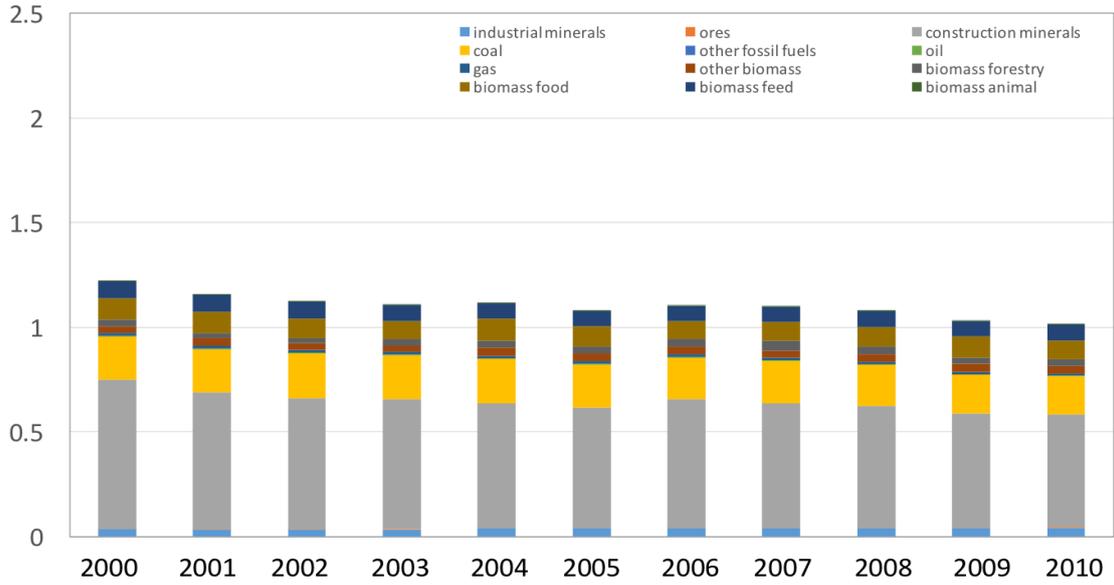


Fig.4.5 Domestic used extraction, 2000-2010

Billion tonnes

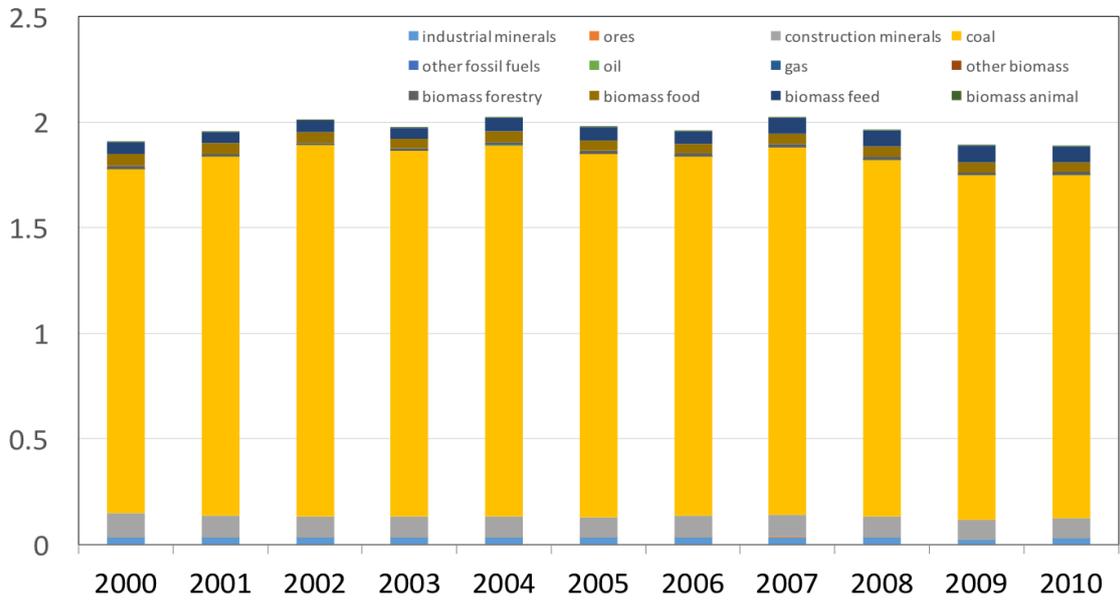


Fig.4.6 Domestic unused extraction (HF), 2000-2010

### 4.3.2 Top-down method: Waste generation and filling material

Fig 4.7 displays total waste materials and its components from 2000 to 2010. In total, 4.07 billion tonnes of waste materials were discharged from German society in a decade. The trend was characterized by the share construction minerals, which constantly had a share of over 50% of total waste materials throughout the study period. However, waste of construction minerals has decreased from 254 million tonnes in 2000 to 193 million tonnes in 2010. Fig 4.8 displays trend of gradual decrease of construction minerals by ingredients, soil and stone took a share of over 50% in every year. The final treatment of soil and stone of construction minerals and demolition waste are shown in Fig.4.9. The largest share of final disposal of soil and sand is backfilling material extraction site, which decade average is 73.6 million tonnes per year. From 2000 to 2010, total filled waste materials achieved 1.78 billion tonnes (Fig.4.9), while 2.85 billion tonnes of materials were recycled (Fig.4.11, 4.12).

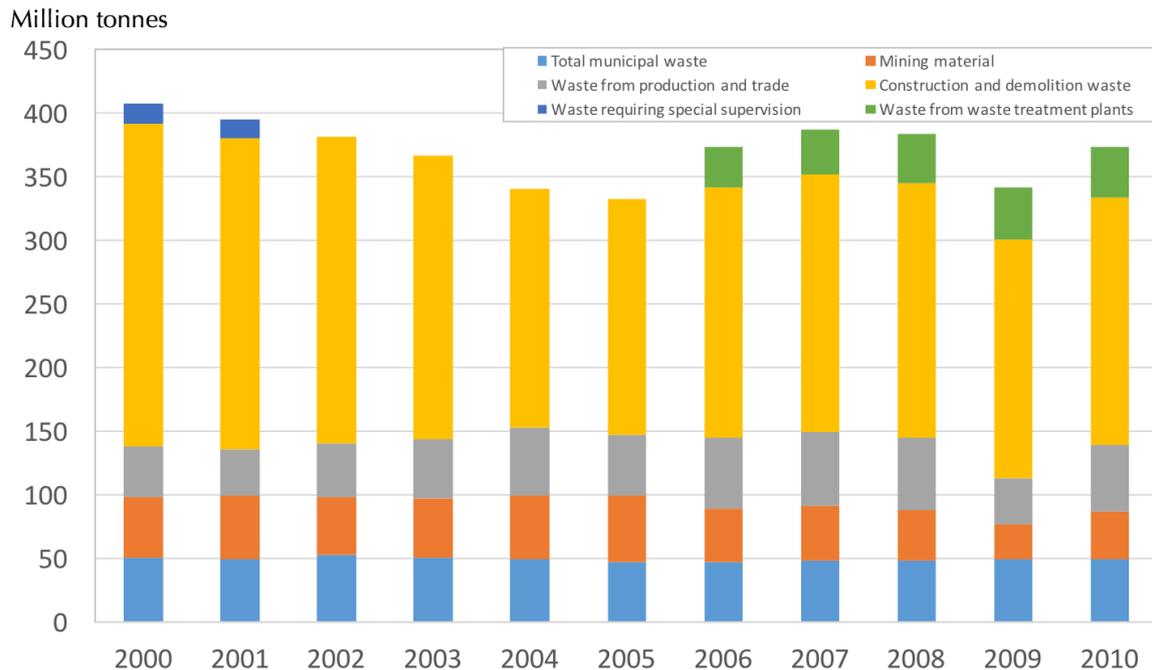


Fig.4.7 Total waste materials, 2000-2010

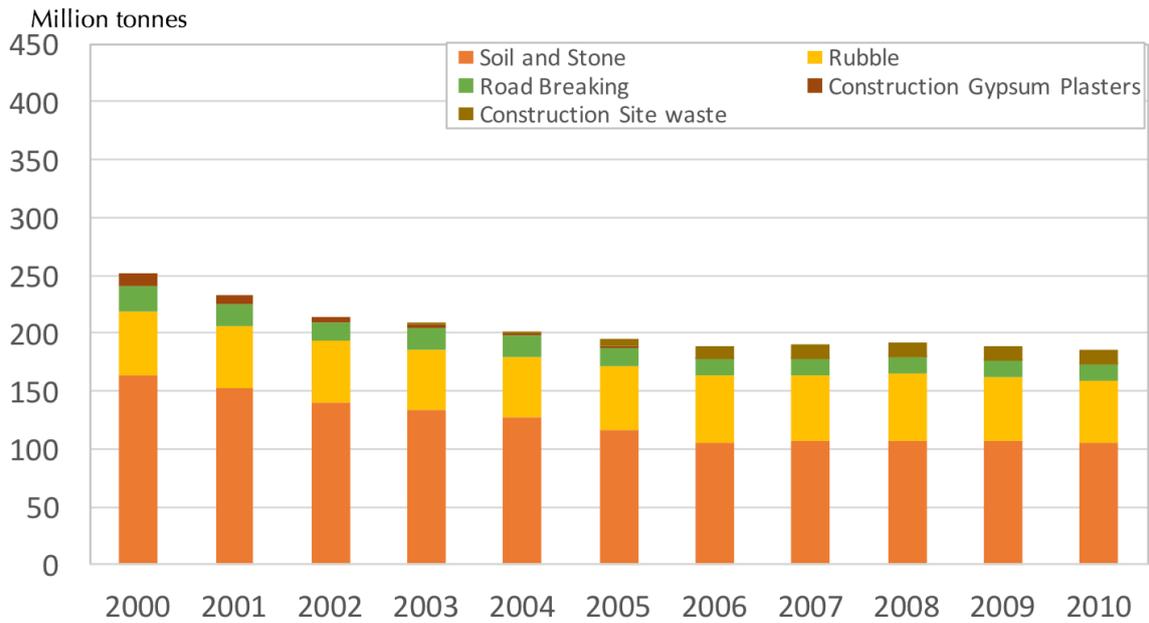


Fig.4.8 Components of construction and demolition waste, 2000-2010

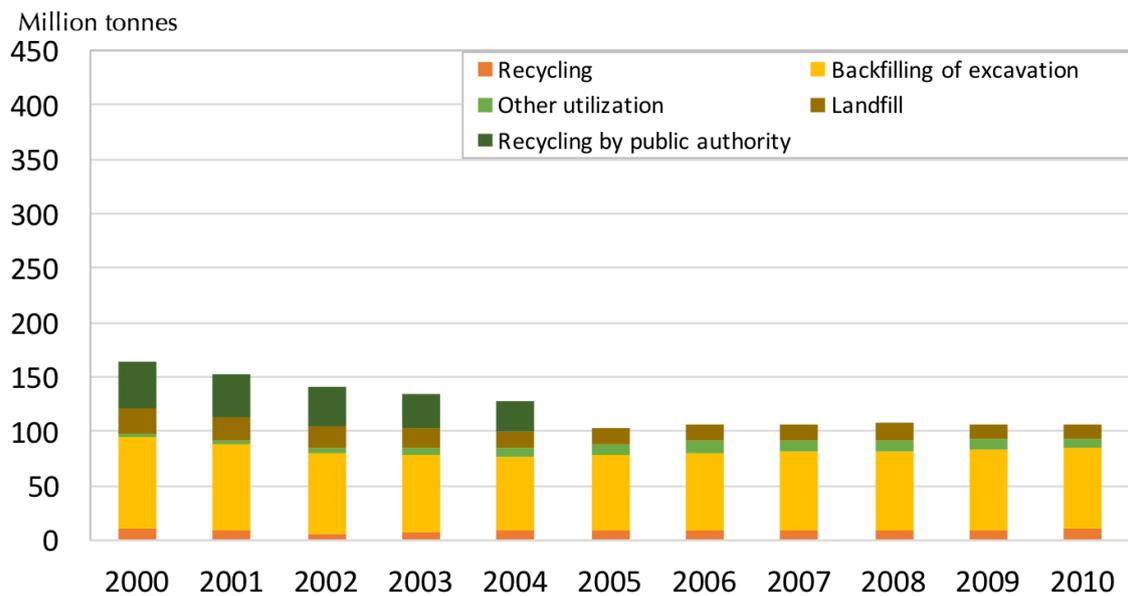


Fig.4.9 Final disposal and treatment of soil and stone of construction and demolition waste, 2000-2010

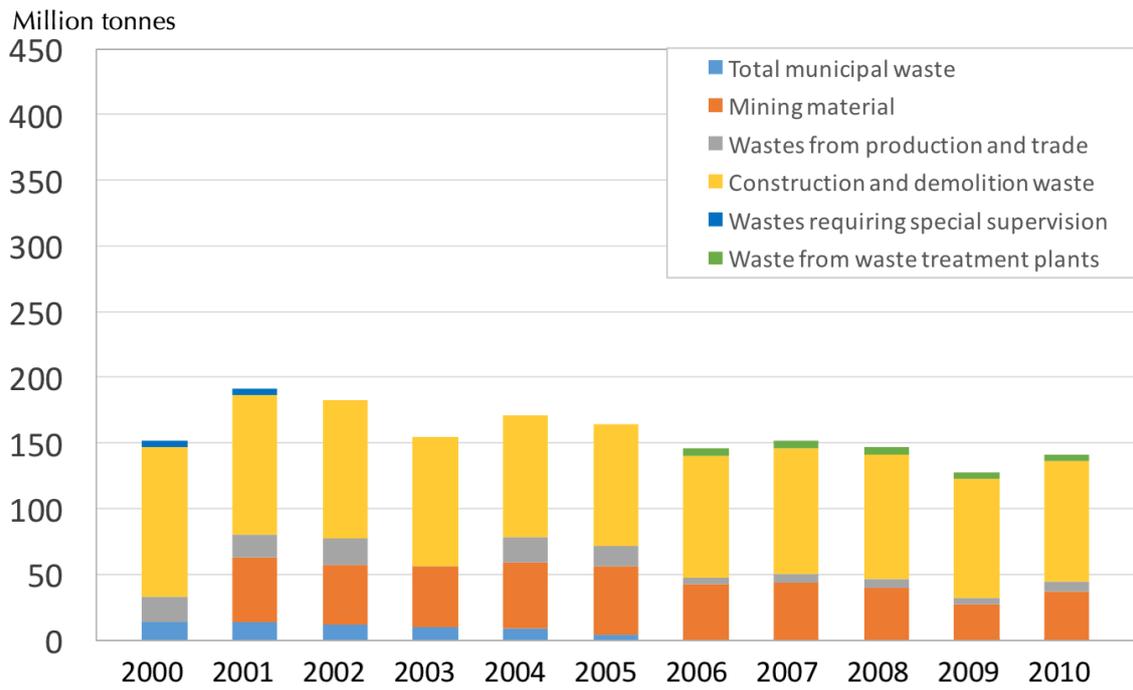


Fig.4.10 Total filled waste materials (backfill & landfill), 2000-2010

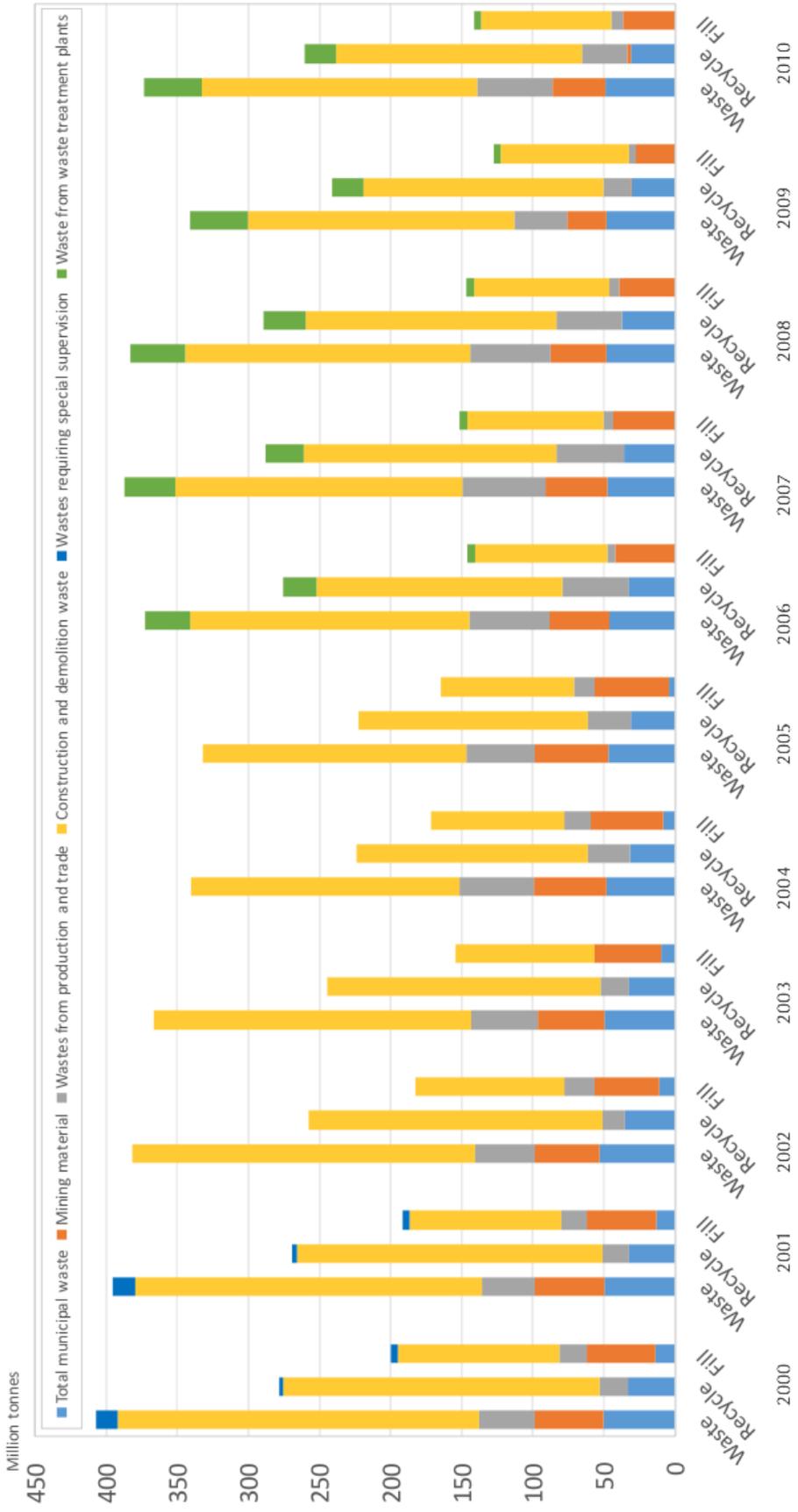


Fig.4.11 Total waste, recycled, and filled materials, 2000-2010

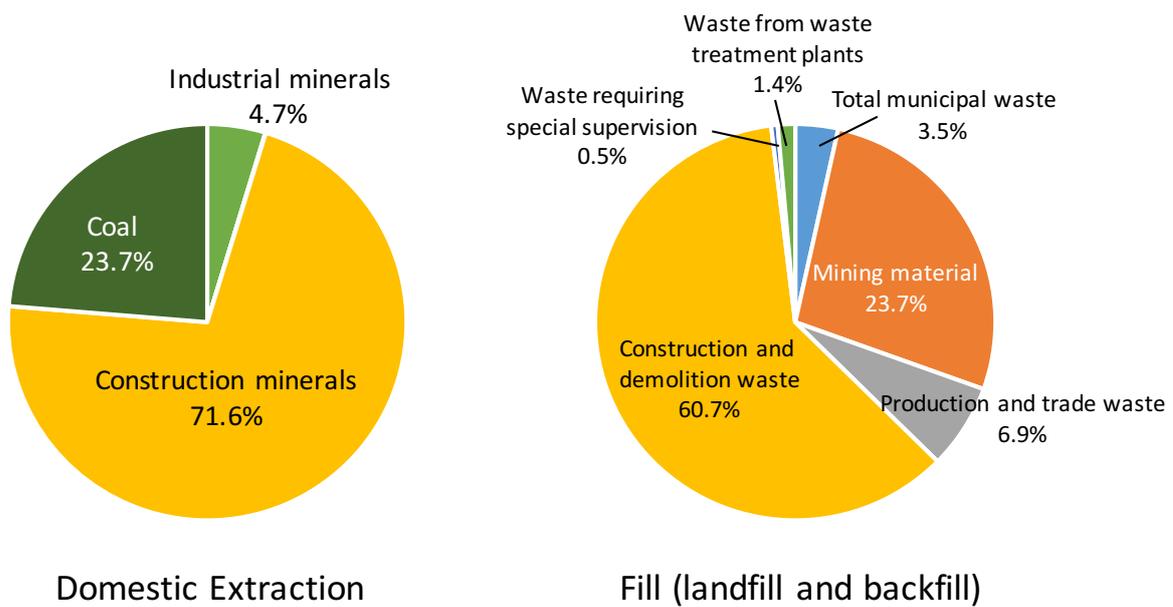


Fig.4.12 Components of DE and fill decade average

#### 4.3.3 Bottom-up method: material extraction and fill

Our bottom-up method results show, from 2000 to 2010, total DE of Germany is 4.86 billion m<sup>3</sup> and total fill volume is 4.85 billion m<sup>3</sup>, and material extraction and fill area achieves 570 million m<sup>2</sup> and 390 million m<sup>2</sup>. The volume of material extraction is named bank volume, which is in natural state that is compressed by own weight, while the fill volume is named loose volume. We applied bulking factor (1.65) to volume of material extraction, and bulk density 1.9 and 1.6 (tonnes/m<sup>3</sup>) for extraction and fill were multiplied to change of their unit from cubic meter to tonnes. The total DE and fill became 15.3 billion tonnes and 7.76 billion tonnes.

By using DEM and landcover dataset, we are able to measure volume, area, and depth and as well as location of material extraction and fill sites, Fig.4.13 and 4.14 represent their spatial distribution. Fig.4.13 shows that maximum depth and height of mining and fill sites, 104 m and 196m. This gap comes from volume change and waste dump. Waste dumps; mining waste materials that were put on upper ground beside the extraction site, hence the mining depth would be lower than height of fill. Most of filling sites were founded at close range of extraction sites, because material extraction and backfilling operation is running in parallel in open-pit and underground mining to improve

productivity and increase recovery rate of mining sites. Hence, backfilling sites located adjacent to material extraction sites. Not only backfill sites, but also landfill sites were also detected by using CORINE landcover dataset, dump site that represents fill site. However, it has no further explanation for dump operation, hence in this study, we cannot specifically divide landfill and backfill.

On the other hand, mining and filling sites were distributing throughout Germany (Fig.4.14). More than 70% of German DE is construction minerals such as gravel, soil, and rock that are low value and high deposits all over the world. In order to meet constant demand for construction activity(Fig.4.5), the low-cost materials were extracted from throughout Germany (Yoshida, et al 2017). In addition to material extraction of construction minerals, landfill sites of waste materials also would locate to urban or residential area to decrease its transportation cost. More than 60% of fill materials are coming from construction sector, demolition waste, hence, they are disposed as landfill throughout Germany (Fig.4.12).

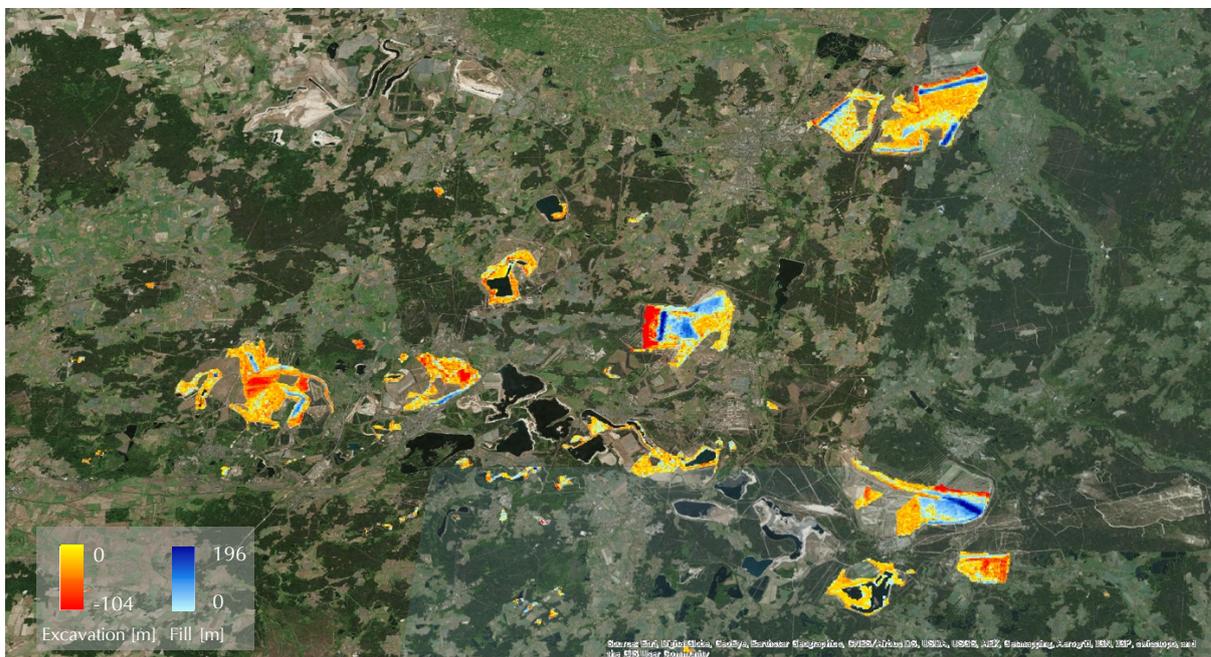


Fig.4.13 Ground image with dramatic elevation change by mining and filling, north of Dresden (red color: mining sites, blue color: filing sites)

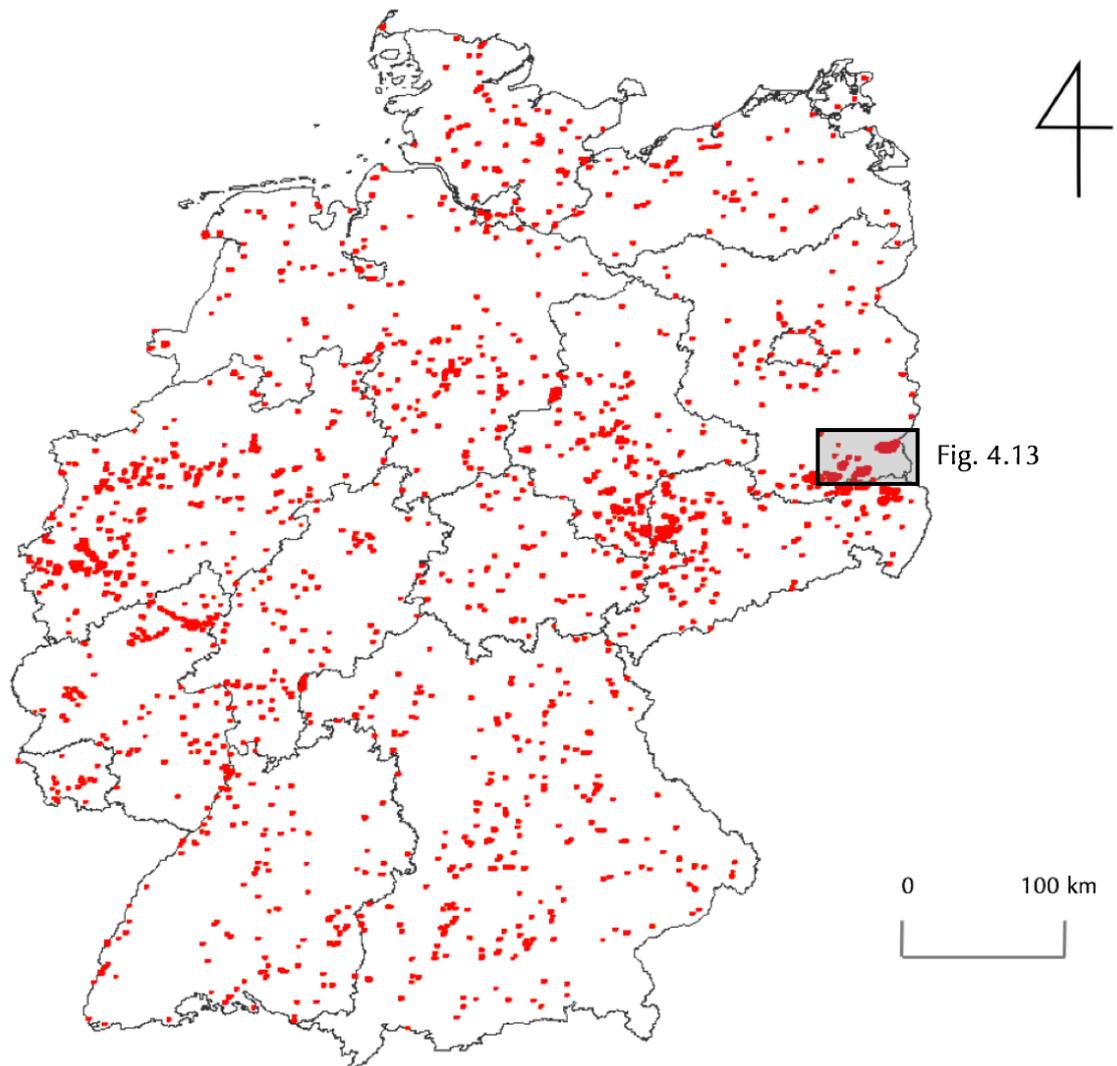


Fig.4.14 Distribution of anthropogenic disturbance  
(red point: mining and filling site)

## 4.4 Discussion

### 4.4.1 Estimation of HF by comparing results of top-down and bottom-up approach

In this study, we used two methodologies, bottom-up accounting and top-down accounting to analyze Germany domestic material flow, especially focusing on DE and fill, where were starting and the ending points of material flows. Here, we discuss about industrial minerals, ores, construction minerals, and coal that would be measured by both top-down and bottom-up methodology. The result of top-down method; statistics based calculation shows the total DE and fill is 9.32 billion tonnes and 1.77 billion tonnes, on the other hand, bottom-up method; DEM and landcover based calculation of DE and fill achieves to 15.3 billion tonnes and 7.76 billion tonnes.

The gap of results between two methodologies for DE and fill are 5.98 billion tonnes and 5.99 billion tonnes. Fig.4.15 is diagram, which represents gap of DE and fill by bottom-up accounting (GIS) and top-down accounting (Stat). Bottom-up accounting includes used and unused material extraction, and top-down accounting covers only used material extraction, hence, the gap of DE between them is unused material; HF. From 2000 to 2010, 5.98 billion tonnes of domestic HF would have produced in Germany. On the other hand, there is also big gap of mass of filled materials, between bottom-up accounting, 7.76 billion tonnes and top-down accounting, 1.77 billion tonnes. As Fig. 4.13 shows, fill sites locate close to material extraction sites, in order to manage waste rocks by backfill voids or making mine waste dump. The components of backfill materials and mine waste dump are unused materials, which are coming from mining site. Therefore, the unaccounted DE by top-down accounting; 5.98 billion tonnes of HF would have used to fill voids created by material extraction. That's why the differences of DE and fill calculated by bottom-up accounting and top-down accounting have close value in the same order.

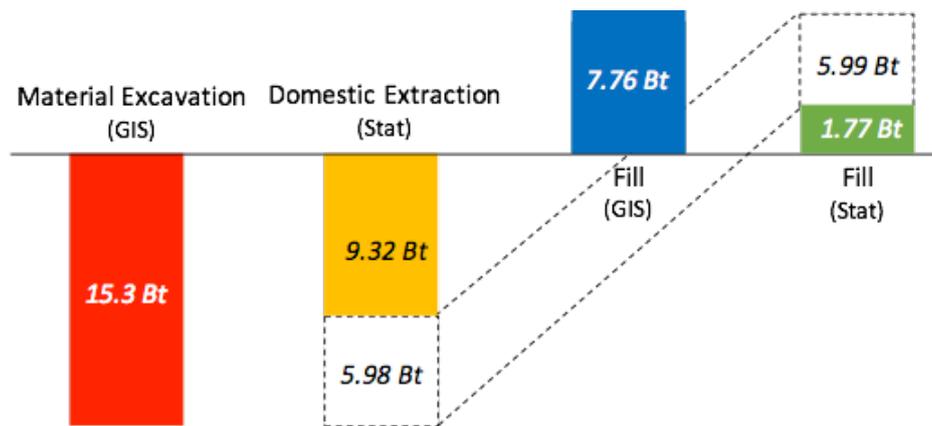


Fig.4.15 Diagram of DE and fill calculated by top-down method (Stat) and bottom-up method (GIS)

On the other hand, according to material flow statistics, 20.1 billion tonnes of HF were generated behind the 9.32 billion tonnes of material extraction (industrial minerals, ores, construction minerals, and coal). Therefore, statistically, used and unused material extraction of Germany from 2000 to 2010 achieves 29.4 billion tonnes (Fig.4.16). When we compare total material extraction of top-down accounting, 29.4 billion tonnes to bottom-up accounting, 15.3 billion tonnes, the gap of them would be 14.1 billion tonnes. This gap (14.1 billion tonnes) would be HF that bottom-up method cannot account.

We can explain three reasons for the unaccounted volume of mining by bottom-up method, DEM and landcover dataset in order to detect location and measure volume of anthropogenic disturbances. Firstly, accuracy of landcover dataset would not be enough to detect all of mining and filling sites throughout German land. However, the accuracy of CORINE landcover is more than 85%, hence it is difficult to imagine that only miss-detection caused 14.1 billion tonnes of calculation gap. Secondly, vertical accuracy of DEMs; SRTM and ASTER GDEM affect calculation results of bottom-up accounting. However, Sugimoto et al. (2015) and Yoshida et al. (2017) confirmed methodological accuracy of volume calculation by DEM is less than 17% that is not enough to explain 14.1 billion tonnes of calculation gap. Thirdly, because of backfill that was operated between 2000 and 2010, DEMs; SRTM and ASTER GDEM could not observe true landform change by material extraction operation. Waste materials generated from material excavation were backfilled to improve productivity and increase recovery rate, the

backfilling reduce elevation change inside mining sites or sometimes completely fill voids. This issue is a typical methodological limitation of study with remote sensing. The most convincing explanation of 14.1 billion tonnes of gap of DE and fill between two methodologies, would be backfill that is operated from 2000 to 2010. Fig.4.17 shows different types of material balance of mining and filling. Case.2-3 represent backfilling void, that is created by material extraction, and both mining and filling will be under estimated by DEM based method. Case.1 shows all waste materials regarded to material extraction were put aside to extraction site, hence all mining and filling volume can be measured. The numbers (100 and 165) are ratio of bank volume and loose volume applied by bulking factor (1.65). Case.2 shows partially extracted materials were used to fill the void, that makes difficult to accurate measurement of mining and filling volume. Case.3 shows all the materials were used to backfill the voids. In this case, we were unable to measure mining volume, and partially can measure filling volume. Case.2 and case.3 become the main reason of gap (14.1 billion tonnes) between top-down accounting and bottom-up accounting.

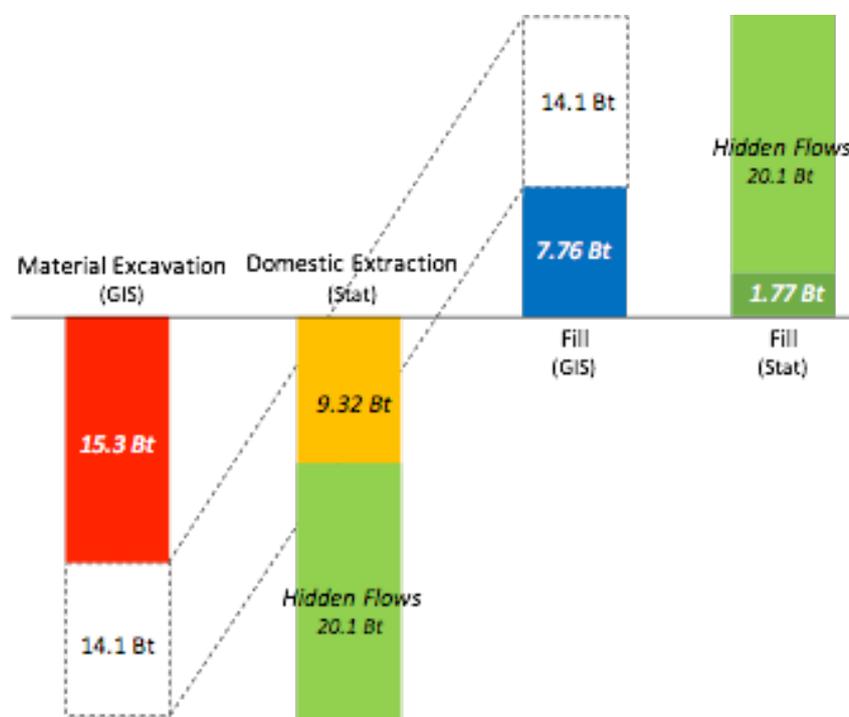


Fig.4.16 Diagram of DE, fill, and HF by top-down method (Stat) and bottom-up method (GIS)

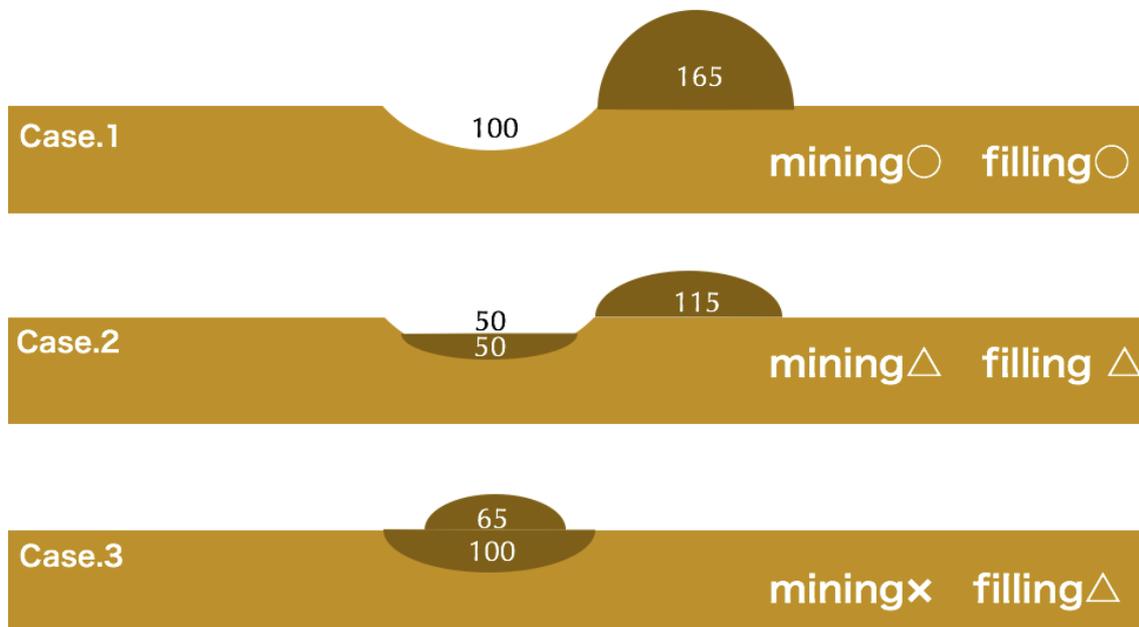


Fig.4.17 Different types of material balance of mining and filling, 2010

#### 4.4.2 Characteristic of German anthropogenic disturbance

In a comparison of anthropogenic disturbances in mining and filling site in two industrialized countries, some correspondence become visible. For instance, Japanese total area and volume of mining is 170 million  $m^2$  and 5.8 billion  $m^3$  (Yoshida et al. 2017), while German total area and volume of mining is 570 million  $m^2$  and 4.85 billion  $m^3$ . Japanese and German mining volume per area ( $m^3/m^2$ ) is 33 m and 8.45 m. This gap would be caused by difference of national geography and efforts of conservation of nature. Both countries have almost same land area (Japan, 377 billion  $m^2$  and Germany, 357 billion  $m^2$ ), while more than 70 % of Japanese land is covered by mountain and hillock, and 60 % of mining sites locate at mountain area. Hence the majority of Japanese mining would cut the mountain that is narrow and deep mining styles. On the other hand, many of German mining sites locate at flat land because of uneven distribution of coal and conservation of nature, especially mountain forest area. Additionally, the open pit mining style requires large area hence the characteristic of wide and shallow mining can be observed in Germany. Backfill is also a large factor of low mining volume per area. The analysis of geographical features can contribute to assess the environmental impact of anthropogenic disturbance in a common framework.

#### 4.4 Conclusion

In this study, we developed a novel method for a bottom-up method of anthropogenic disturbances based on the remote sensing techniques and applied it for Germany. In parallel, we employed top-down method that uses statistics and to form a common method of monitoring and measuring of the anthropogenic disturbance of soil and earth at mining and fill sites, which accounts not only for the material extracted for usage in the anthroposphere, but also its related unused extraction, which the most of parts were used as backfilling materials. This geographically explicit method allows to directly point out location and volume of anthropogenic disturbance. Understanding the dynamics of anthropogenic disturbance and its relevance to starting and ending point of material flows would be useful for policy making, green business strategy building for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management.

We discovered the dynamic of anthropogenic disturbance and its relevance to material flows such as DE and waste flows of Germany. Total area and mass of mining is 570 million m<sup>2</sup> and 15.3 billion tonnes, while total area and mass of filling is 390 million m<sup>2</sup> and 7.76 billion tonnes. In addition, location information of them may be useful for policy making, green business strategy building for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management. We also mentioned the existence of HF, which is used for backfill. HF such as waste rocks and overburden are regarded as no-economical materials, however, they have been used effectively to fill voids in material extraction site. We found the mass of effective use of unused materials by comparing the results of top-down accounting and bottom-up accounting.

However, we encounter a new set of questions and unresolved issues. Research of national scale anthropogenic disturbance can be divided into two parts, detecting location and measuring scale (area, depth, and volume). In this study, we performed landcover dataset to find the location of mining and filling sites. This method shown usefulness of detection, while they are not still available in all over the world, high accuracy and detailed landcover dataset is not support all over the world. The next research question of anthropogenic disturbance research is how to

detect locations of mining and filling site, we guess image recognition as well as height, slope, aspect and landuse change recognition would be useful for global anthropogenic disturbance detection.

## 5 Comparison of anthropogenic disturbances between Japan and Germany

Japanese total area and volume of mining is 170 million m<sup>2</sup> and 5.8 billion m<sup>3</sup>, while German total area and volume of mining is 570 million m<sup>2</sup> and 4.85 billion m<sup>3</sup>. Japanese and German mining volume per area [m<sup>3</sup>/m<sup>2</sup>] is 33 m and 8.45 m. In order to make a comparison between two countries, we took annual average of data of material excavation. The annual volume [million m<sup>3</sup>], area [million m<sup>2</sup>], and volume/area [million m<sup>3</sup>/m<sup>2</sup>] of Germany and Japan is shown in Table.5.1.

Fig.5.1 shows distribution of coals, construction minerals, industrial minerals, and ores of Germany, produced by Federal Institute for Geosciences and Natural Resources. Based on coal resource distribution map, we divided material extraction sites into coal extraction and non-coal extraction (Fig.5.2). When coal and other materials covers the same area, we gave priority to coal. According to statistics, construction minerals occupy 72% of DE and 24 % by coal, while our study shows annual non-coal and coal volume is 196 million m<sup>3</sup> and 290 million m<sup>3</sup>, coal mining volume is larger than non-coal mining volume. The statistics do not include HF related to material extractions, hence when HF of coal is accounted, actual material extraction volume would increase. Annual mass of material extraction including DE and HF of non-coal and coal is 614 million tonnes and 909 million tonnes by DEM used method, and 857 million tonnes and 2091 tonnes by statistics. The calculation gap of DEM and statistics is 242 million tonnes for non-coal and 1181 million tonnes for coal, and they are caused by backfilling activity. Coal mining produces great amount of waste materials, hence mass of backfilling is larger than non-coal mining.

The gap of volume/area between Germany (total) and Japan, 2.56 m<sup>3</sup>/m<sup>2</sup> would be caused by the difference of original national geography and sense of conservation of nature. Both countries have almost same land area (Japan, 377 billion m<sup>2</sup> and Germany, 357 billion m<sup>2</sup>), while more than 70 % of Japanese land is covered by mountain and hillock, and 60 % of mining sites locate at mountain area. Hence majority of Japanese mining need to cut trees and crash mountains, that represents narrow and deep mining styles. On the other

hand, many of German mining sites locate at flat land where uneven distributed coals exist under the ground. The open pit mining style requires large area hence the characteristic of wide and shallow mining can be observed in Germany. Additionally, the conservation of forest prohibits to material extraction at forest area that many of them locate at mountain area. Backfill is also a large factor of low mining volume per area. The analysis of geographical features can contribute to assess the environmental impact of anthropogenic disturbance in a common framework.

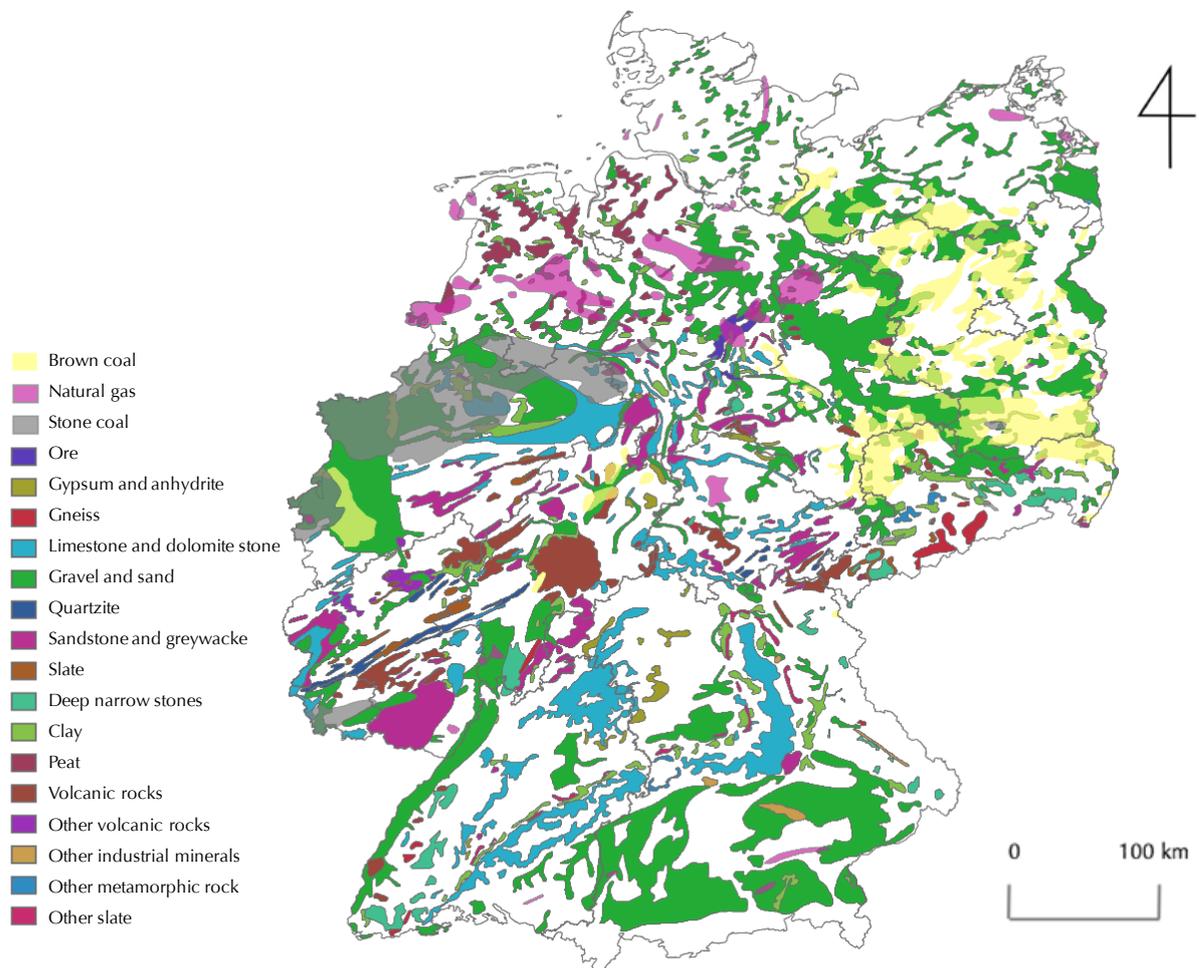


Fig.5.1 Resource distribution map of Germany

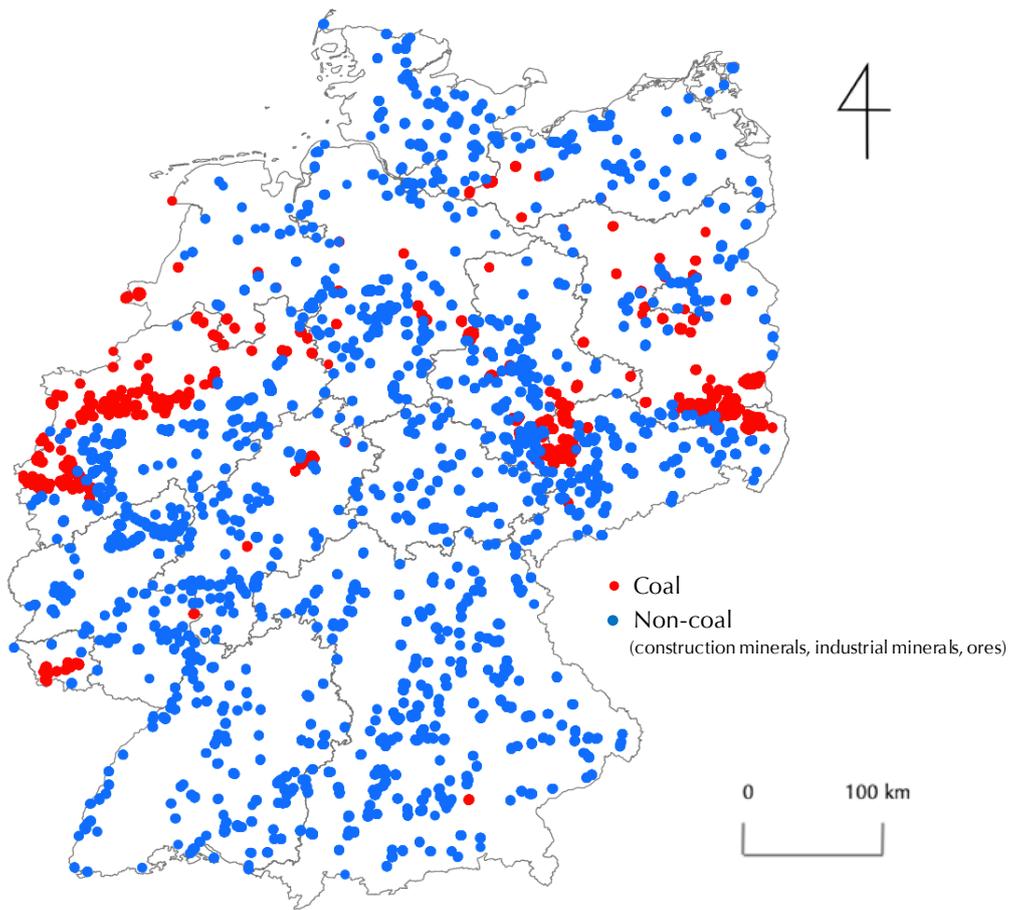


Fig.5.2 Coal and non-coal mining distribution of Germany

Table.5.1 Comparison of anthropogenic disturbance between Japan and Germany

	Germnay, non-coal (10 years average)	Germnay, coal (10 years average)	Germnay, total (10 years average)	Japan (15 years average)
Volume [million m3]	196	290	485	387
Area [million m2]	26	31	57	11
Volume/area [m3/m2]	0.75	0.94	0.85	3.41

## 6 Conclusions

### 6.1 Anthropogenic disturbance of nations

In this study, we developed a novel method for a bottom-up method of anthropogenic disturbances based on the remote sensing techniques and applied it for two industrial countries, Japan and Germany. We employ top-down method that uses statistics and bottom-up method; geographic information systems (GIS) with digital elevation model (DEM) and landcover datasets, to form a common method of monitoring and measuring of the anthropogenic disturbance of soil and earth at mining and fill sites, which accounts not only for the material extracted for usage in the anthroposphere, but also its related unused extraction which would be used for backfilling. This geographically explicit method allows to directly pinpoint the location and volume of anthropogenic disturbance. Understanding the dynamics of anthropogenic disturbance and its relevance to starting and ending point of material flows would be useful for policy making, green business strategy building for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management.

This study mainly consists of three parts, anthropogenic disturbance by domestic extraction of construction minerals in Japan, material stock's overburden: automatic spatial detection and estimation of domestic extraction and hidden flows and anthropogenic disturbance of Germany. The results suggest that the methodology of which using digital elevation model and landcover can be useful for monitoring and measuring used extraction, unused extraction and fill as environmental impacts by comparing statistics data by estimating national scale HF.

Firstly, we discovered the location and volume of anthropogenic disturbance of Japan by means of two types of DEMs, 10-m basic map information mesh and 50-m digital map information mesh based on 1/25000 topographic map that were produced by Geospatial Information Authority of Japan. We spatially quantify the impact of humans on the natural environment by estimating the anthropogenic disturbance of mining and quarrying, and contribute to the knowledge of HF by examining the phenomenon using relatively unexplored

methodology of assessing the relationship between anthropogenic disturbance and material transfer. The results show that from 1987 to 2005, DEM-based methodology may produce an overestimation of as much as 1.6%–6%, depending on the accuracy of the original DEM. In the bottom-up accounting, the total area of the anthropogenic disturbance (170 million m<sup>2</sup>) and volume of the anthropogenic disturbance (5.8 billion m<sup>3</sup>) which comprised the DE and HF. Top-down accounting, the total volume of the DE (3.2 billion m<sup>3</sup>). By comparing the two results, we estimated the potential volume of domestic HF (2.6 billion m<sup>3</sup>) of the mining sector. A special feature of this study was the use of a direct analysis of the anthropogenic landform change to calculate the material extraction.

Secondly, we developed a methodology of automatic detection and measurement of anthropogenic disturbance of soil and earth at excavation and mining sites which accounts not only for the material extracted for usage in the anthroposphere, but also its related unused extraction. This geographically explicit method allows to directly pinpoint the location and volume of anthropogenic disturbance. Using Japan as a case study, ArcGIS's Weighted Overlay Tool is used, a computational tool which can solve geographic multi-criteria problems such as site selection and suitability model. The changes in the three attributes of elevation, slope, and aspect between the two examined periods were used as input criteria. The results suggest that the ratio of unused extraction to used extraction may exceed 1:1 for construction minerals in Japan. We also find that the environmental effects of anthropogenic activity are bigger than natural soil disturbance by several orders of magnitude. The yearly average volume of material removed by AD per area is thus about 3.1 m<sup>3</sup>/m<sup>2</sup> per year, while loss of surface soils by natural phenomena such as water flow or wind is 0.00028 m<sup>3</sup>/m<sup>2</sup> per year, four orders of magnitude less than AD. And the mining and quarrying site are distributing to all over Japan, because of its low-cost and that were not transported over long distance to shorten the supply (mining) and demand (urban) area. This shows the strength of artificial landform change and clarifies the scale of pressures to the natural environment. Highlighting the need to reduce raw material extraction and increase the efficient use of the existing material stock.

Finally, we discovered the dynamic of anthropogenic disturbance and its relevance to material flows such as DE and waste flows of Germany. Total area

and mass of mining is 570 million m<sup>2</sup> and 15.3 billion tonnes, while total area and mass of filling is 390 million m<sup>2</sup> and 7.76 billion tonnes. In addition, location information of them may be useful for policy making, green business strategy building for manufacturing industry and mining industry, as well as for sustainable management of resource extraction and waste management. We also mentioned the existence of HF, which is used for backfill. HF such as waste rocks and overburden are regarded as no-economical materials, however, they have been used effectively to fill voids in material extraction site. We found the mass of effective use of unused materials by comparing the results of top-down accounting and bottom-up accounting.

## **6.2 Future researches and limitations**

The findings of this research have increased the understanding of the practical relevance of material stock & flow to anthropogenic disturbance. Especially the novel method of using DEM would contribute to database build in statistically poor countries since the methodology is based on remote sensing dataset. In a comparison of the anthropogenic disturbances of soil at mining and filling site in the two industrialized countries, some correspondence become visible. However, we encounter a new set of questions and unresolved issues. Research of national scale anthropogenic disturbance can be divided into two parts, detecting location and measuring scale (area, depth and volume). In this study, we performed three types of independent method for detection, visual interpretation, automatic detection and combination with landcover. All method shown usefulness of detection, while they are not still available in globe. Visual interpretation takes lots of times, automatic detection would not available in different types of geographic area and mining style, and high resolution and quality landcover dataset is not support all over the world. The next research question of anthropogenic disturbance research is how to detect locations of mining and filling site as well as construction site. At the automatic detection, image recognition as well as height, slope, aspect, and landuse change recognition would be useful for global anthropogenic disturbance detection.

## 7 Acknowledgment

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Table.3.3 The weight values of each attribute

Table.3.4 Details of mining for landfill at airport construction

### **Chapter 4**

Table.4.1 DEMs and landcover dataset

Table.4.2 Statistics data of used, unused, waste, and landfill materials

### **Chapter 5**

Table.5.1 Comparison of anthropogenic disturbance between Japan and Germany

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## 11 Appendix to anthropogenic disturbance by domestic extraction of construction minerals in Japan

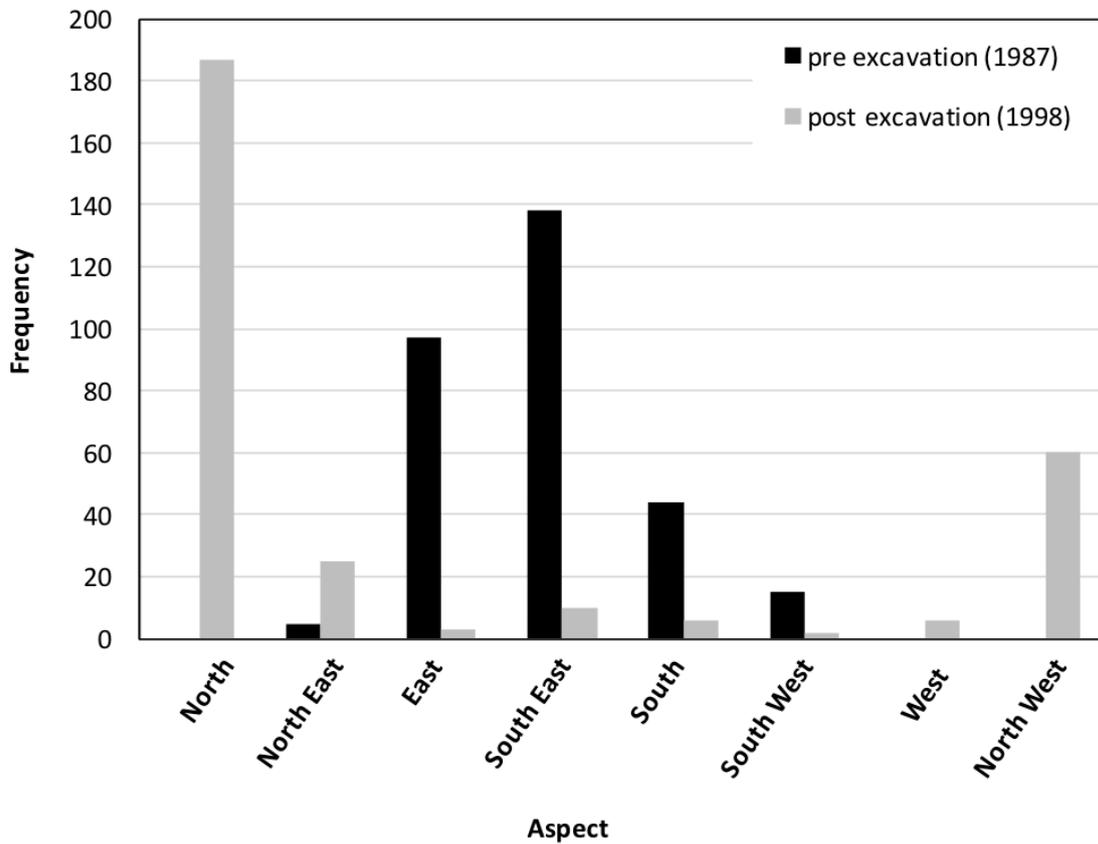


Fig.11.1 Histograms of the aspect in 1987 and 1998

Figure.11.1 displays dramatic landform change by showing histograms of aspect in 1987 and 1998. The distribution change is clear that east and south east faced area turned to north and north west.

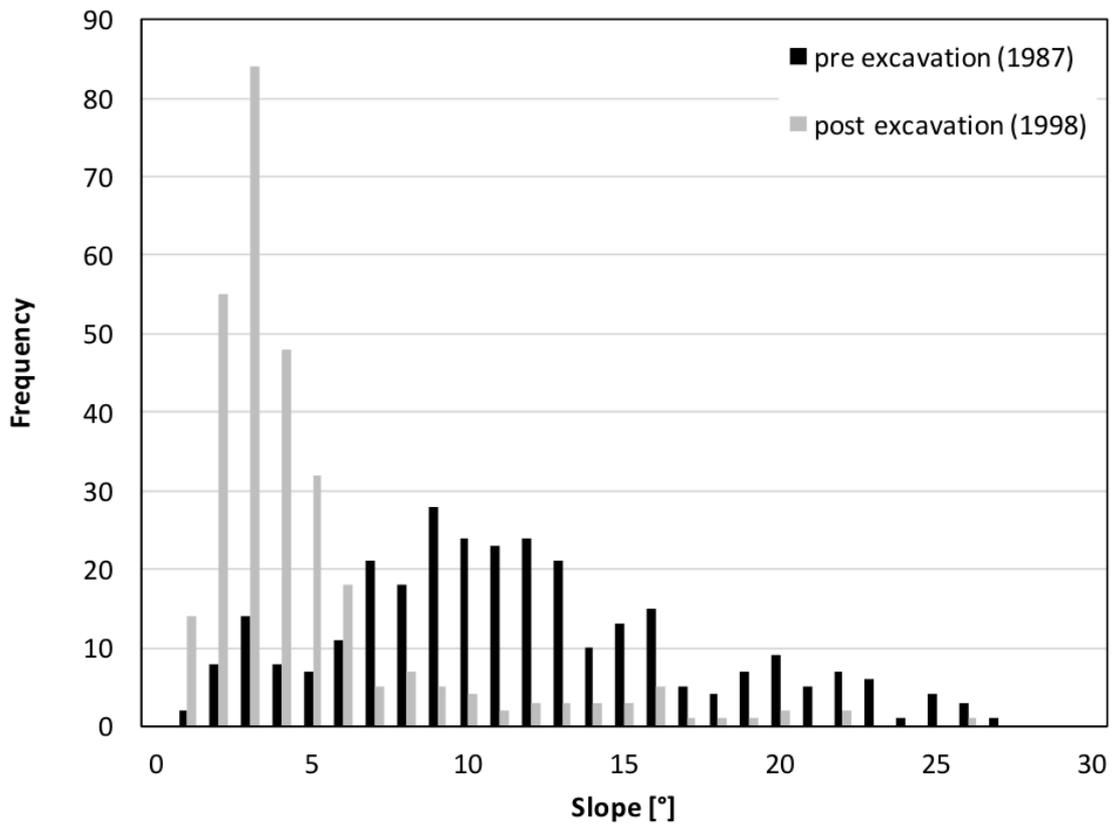


Fig.11.2 Histograms of the slope in 1987 and 1998

Figure.11.2 displays dramatic landform change by showing histograms of slope in 1987 and 1998. The original distribution that is similar to normal distribution turn to heavy-tailed distribution.

Table.11.1 Variety of global and local DEMs

Data	Agency	Data sources	Coverage area	Measured year	Published year	Resolution [m]	Height accuracy [m]	
Japanese domestic DEM	250m mesh				2002	250	7.2	
	50m mesh	Geospatial Information Authority of Japan(GSI)	1/25000 topographic map	All Japan	1972-1999	2001	50	7.2
	10m mesh					2006	10	5
	5m mesh				2005-2009	2010	5	0.7 (Aerial photo), 0.3 (LIDAR)
Global DEM	ASTER GDEM	METI/NASA	ASTER(satellite-borne sensor)	N83°-S83°	2000-	2009	30	7 - 14
	SRTM	NASA/USGS	Space shuttle laser	N60°-S56°	2000	2003	90, 30	10, 5
	GTOPO 30	USGS	DEM from some countries	All land areas	-	1996	1000	30
	ALOS World 3D- 30m	JAXA	Satellite images by ALOS	Part of World	2006-2011	2015	30	5

This table.11.1 represents examples of local and global digital elevation models. All of them have different types of resolution, high accuracy and published year.

Table.11.2 Elevation changes between 1987-1998

	Minimum [m]	Average [m]	Maximum [m]
Digital information map 50m mesh (1987)	52	121	253
Basic Map information 10m mesh (1998)	41	83	204

The information shown in table.11.2 is minimum, average and maximum elevation in 1987 and 1998 at Hannan mining site. It helps us to understand how the material excavation alter landform by showing change o elevation.