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Temporal monitoring of vast sand mining in NW Turkey: Implications on environmental/social impacts

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Abstract

Loose sand has a wide variety (over 200) of industrial usage where most of the sand is used in infrastructure. Due to its low cost / high benefit nature and international high demand, worldwide examples of excessive sand mining caused complete destruction of habitats and forcing natives change living practices or even to migrate. Sand mining is one of the most controversial and rapidly growing mining sector of the modern world.

Sand is rare and regarded as non- renewable source. The primary source of loose sand are river flood plains and low energy coastal zones, deposited within thousands of years. In the last decade, increasing studies focus on environmental, economic and social impact of sand mining. The most issued problem is quantifying the amount of sand extracted in active depositional environments where indirect estimations and forecasts indicate excessive amount of exploitation.

We focus on a long lasting and biggest sand mining zone, Sakarya River at Adapazarı Plain, NW Turkey. Located at close proximity to a high population city, forms a good example to study mining practices by identifying direct and indirect social / environmental impact of sand mining. Mapping and monitoring the last 40 years of the region by remote sensing and by field measurements revealed that, accelerating in the last decade, sand mining practice caused complete destruction of the recent flood plain of the river within ~970 hectares of area. The total amount of exploited material reaches up to ~50 million m^3, roughly 130 million tonnes of sand.

Even restricted or declared as illegal, these establishments continue to expand by using several ways. In our case, (1) changing the environment not suitable for cultivation by increased erosion close to mining area and also draining underground water (2) increasing conflicts and stress on habitation by noise pollution and heavy vehicle traffic (3) trapping sand by forming extensive and deep artificial lakes, causing coastal land loss.

Keywords: *Sand Mining, Sakarya River, Multi-temporal Remote Sensing, NW Turkey*

1. Introduction

River flood plains and sandy coasts are unique low slope environments developed under interactions between the water and the land and has always been most popular spots for human activities throughout the history. Flood plains stand for a constant fresh water resource and provide well drained land suitable for agriculture. Coastal zones are chosen for harbor settlements since the antiquity and important for transportation, commerce, fisheries and now recreation.

Rivers are the products of the evolutionary surface processes of the earth and a major actor of hydrological and rock cycle. Although rivers only occupy 0.1% of the earth surface, shape the 71% of the land and supply the 85-90% of total sediment yield to the oceans. Rivers also play an important role on the origin of survival and development of human beings, and closely related to civilization, culture and history. Today river-floodplain systems all over the world are greatly affected by human activities serving many functions, hence, they play an important role in people's living and agricultural production (Allan & Castillo, 2007).

Large scale anthropogenic stress over the river-floodplain systems has been introduced and widely discussed in the recent years (Kondolf, 1994; 1997; John, 2009; Krausmann et al., 2009, 2017; Saviour, 2012; Govindaraj et al., 2013; Peduzzi, 2014a; 2014b; Rege, 2016; Mngeni, et. al., 2016; Sutherland et al., 2017; Miatto et al., 2017; Torres et. al., 2017; Koehnken and Rintoul, 2018; UDEP, 2019; Koehnken et al., 2020). As a result of industrialization, growth of population and expansion of the urban areas, the usage of rivers as a natural source has been exponentially increased.

Floodplains which are traditionally not been used for agriculture has been made available by flood control practices such as by construction of reservoirs and embankments, artificial levee and barriers and river straightening (cf. Zhang et al., 2012) all leading to channel manipulation (irreversible alteration of the natural channel) (Ye et al., 2003; Dotterweich, 2008; Hoffmann et al., 2010). These activities can have wide variety of physical, ecological, and environmental effects in rivers, such as streambed mobilization, scouring, degradation, and aggradation; changes in hydrologic regime, etc. (Kondolf, 1994; Kondolf, 1997; Isik et al., 2008).
We focus on one of the major recent anthropogenic stress over rivers, sand mining, which stands for the most affective stressor over the river-floodplain system. As a result after thousands years of exploitation and usage, floodplains are now considered as one of the most fragile ecosystems in the world (Winarso, and Budhiman, 2001).

1.1. Sand Industry: A Global View

Sand and gravel, are formed within thousands of years of sedimentary processes outlined as weathering/erosion, transportation and finally deposition by rivers. Today, loose sand is considered as an important inorganic industrial raw material with over 200 usage and also forming the major portion of a product namely "aggregate" (Torres et al., 2017). In market terminology, aggregate stands for any inorganic fine-coarse grained material used in construction which covers loose sand, gravel and crushed rocks. From this point forward we will use the term "sand" just for the natural sediment deposited within the river floodplain.
Recent data suggests that the demand for sand grows exponentially (UNEP, 2019). This demand is related with the current state of civilization with growing populations, increased urbanization and infrastructure development, resulting consumption to three-fold over the last two decades. Miatto et al. (2017), reported that sand and gravel made up 31.1% and 40.8% of all non-metallic minerals extracted in 2010 respectively. Krausmann et al., (2009) estimate a higher ratio, attributing 65-85% portion of the total inorganic mining. Today, it is estimated that the annual market need for sand is 50 billion tonnes, which corresponds to an

average of 18 kg per person per day (UNEP, 2019). This assumption regards sand as the second largest resources extracted and traded by volume after water (Peduzzi, 2014b; UNEP, 2019). However sand extraction, usage and trade are one of the least regulated mining practices, especially in the low to moderate income and developing countries (Torres et al., 2017). Statistics for the total production of sand all over the world is not known for several reasons but can be estimated by production/consumption of anthropogenic material such as concrete production and consumption which is relatively well traced.

Concrete, the most common modern building material, is a composite material formed of fine and coarse aggregate bonded together with fluid cement. The nominal mix (M-15) composition of concrete is formed of (1:2:4) ratio for cement, sand and crushed gravel/rocks respectively. Therefore it is possible to estimate an annual demand/usage for sand and gravel by using cement production (Kraussman et al., 2009).

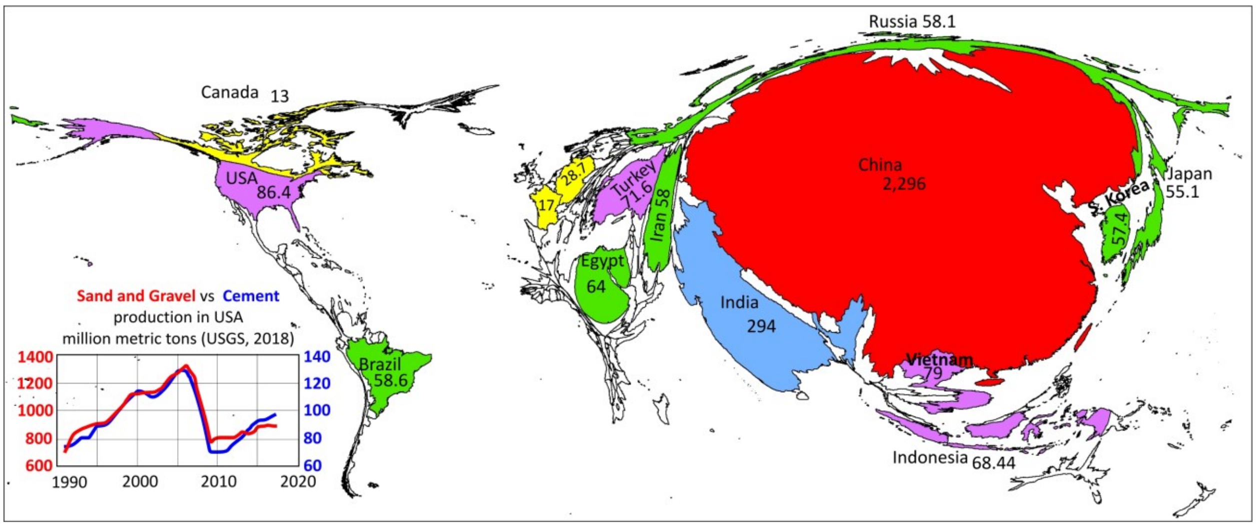

Figure 1 Cartogram view of the world generated by using 5 year (2015-2019) average annual cement production for the 15 leading countries (data from USGS, 2020) inset: relationship between sand and gravel vs cement production (Kraussman et al., 2009) for the last 18 years in the USA (USGS, 2013a, b, c, USGS, 2018, adapted from UNEP, 2019)

Figure 1 demonstrates the 5 year (2015-2019) average annual cement production for the 15 leading countries (USGS, 2020). The cartogram is generated using ArcGIS based on algorithm by Gastner and Newman (2004). China produces the most cement globally with an estimated 2.4 billion tonnes (BT), followed by India with 270 million tonnes (MT), USA (86.3 MT), Vietnam (79 MT), Turkey (71.6 MT) (USGS, 2018). The total production was 3.7 BT in 2013 (Peduzzi, 2014), which increased to 4.1 BT in 2019 (USGS, 2020) and estimated to raise up to 4.83 BT in 2030 (Krausmann *et al.*, 2009; Peduzzi, 2014; USGS, 2018). In the USA, for every 1 ton of cement ~10 tonnes of aggregate is used (Figure 1-inset, USGS, 2018; Krausmann *et al.*, 2009). Extrapolation of this ratio worldwide would provide an annual estimation of annual sand demand for countries where no data available.

During the last century the amount of natural resources for construction of buildings and infrastructure has folded by 23 times where loose sand and gravel compromise 79% of these materials (Kraussman et al., 2017; Schandl et al., 2016; Torres et al., 2017). Correlated with expected increase in globally annual cement production, related aggregate demand will likely reach close to 50 billion tonnes per year in 2030 (Krausmann *et al.*, 2009; USGS, 2013b; Peduzzi, 2014; USGS, 2018). This number doubles the total amount of sediment yield carried by the rivers (Milliman and Syvitski, 1992). In another saying, at our current state of civilization, we move three times more sediment than all the rivers and glaciers of the world could transport annually (Waters et al., 2016).

Sand is a bulky, heavy material. It is cheap to extract and simple to process but expensive to transport. Therefore mines are normally close to where the sand is needed. Rather than there being one global market for sand, the trade is made up of many smaller national and sub-national markets, each with its own demand and supply dynamics and challenges (Peduzzi, 2014). As an example, Singapore increased its national area by over 20% between 1960 and 2017 by land reclamation from the sea thus to be the world's largest importer of sand, mainly from Malesia and Indonesia (Koehnken, 2018). Likewise, the monumental architectural projects at the City of Dubai, UAE; such as The Palm Jumeirah, Palm Jebel Ali and World Island required ~1 BT of sand resulting complete destruction of marine sand sources of the region. Dubai also imported considerable amount of sand from Australia during the construction of Burj Khalifa tower (Peduzzi, 2014a; b), which is regarded as the highest building (828 m) in the World. All these exemplify that any urgent and vast need for sand was covered by unregulated means, causing environmental crisis in the close vicinity.

River-floodplain systems are a preferred source of sand and gravel for a number of reasons: cities tend to be located near rivers so transport costs are low, the energy in a river grinds rocks into gravels and sands (thus eliminating the costly step of post-mining process, grinding and sorting rock), and the material produced by rivers tends to consist of naturally sorted, angular shaped resilient minerals that are preferred for construction (Kondolf, 1997; Koehnken and Rintoul, 2018). As a result, sand is being increasingly produced through environmentally damaging extractive practices in sensitive river ecosystems (Koehnken et al., 2020).

1.2. Environmental and Social Impacts of Sand Mining

River-floodplain systems, by the nature of formation, are very limited and narrow environments with a dynamic equilibrium between river flow, river slope, sediment supply and sediment size (Lane, 1954; Langbein & Leopold, 1964). These components can be depicted as a balance to demonstrate how a river channel will respond to changes to any of these factors. Any unscientific effort concerning river-floodplain environment result in destruction of a large habitat for long distances, affecting other interconnecting systems, located dozens of kilometers downslope or upslope. The response of river ecosystems to sand mining is complex, with no one simple cause–effect model applicable to all systems. Channel incision is the most common physical change, but other responses are highly variable and linked to the inherent characteristics of the river system and other stressors (Koehnken and Rintoul, 2018; 2020).
Peduzzi (2014a; b) reviewed and classified major impacts of sand mining in riverine environments which may reach to extremes with the amount and techniques of mining practices such as complete destruction of the floodplain, in-channel extraction by removal of bars and deepening of channel, building and harnessing artificial sediment traps.

- **River Channel:** incision, instability, widening/narrowing (Surian and Rinaldi, 2002), deep pools, upstream progression of nick points (Kondolf 1997; Isik et al. 2008).
- **Sediment:** Bed coarsening, Increase in bed and suspended sediment load, decrease in saltation sediment load
- **Water supply:** Regulating water flows, lowering of water aquifers (Myers et al., 2000) exacerbating drought occurrence and severity (John, 2009).
- **Water Quality:** Increased turbidity and pollution, changes in pH levels (Saviour, 2012).

- **Biodiversity:** Impacts on related ecosystems, destruction of aquatic/riparian habitat, Afforestation, deforestation (Koehnken and Rintoul, 2018; WWF, 2018). Reduction and changes to the diversity and abundance of macro invertebrates and fish populations, increased viability of invasive species (Koehnken et al., 2020). Impact on migratory / local bird species for loss of land and habitat (Lai et al., 2014).
- **Climate:** Directly through extraction and transport emissions, indirectly through cement production.
- **Landscape Changes:** Damming and extraction have reduced sediment delivery from rivers to coastal areas, leading to reduced deposits in river deltas and accelerated beach erosion (Kondolf, 1997).
- **Extreme events:**-Decline of natural protection against extreme events (flood, drought, storm surge), leading to increased flood frequency and intensity (Sreebha and Padmalal, 2011).
- **Infrastructures**: downstream erosion including bank erosion and the undercutting or undermining of engineering structures such as bridges, side protection walls and structures for water supply (John, 2009; Padmalal et al., 2008).

European countries experienced the detrimental impacts of sand and gravel mining as early as the 1950s, notably in northern Italy where large-scale mining provided the raw material for the vast extension of the motorway network. In France, the impact of gravel and sand mining was seen as detrimental at the end of the 1970s, then non sustainable in the 1980s and in-channel mining was finally banned in the early 1990s (Bravard, et. al., 2013). By looking at the current state (Figure 1), an increasing number of countries in the middle-east (Turkey, Iran and Egypt) and east-south Asia (India, Malesia and Indonesia) has taken lead in sand production (Figure 1). The lack of proper scientific methodology for river sand mining has led to indiscriminate practices (John, 2009), while weak governance and corruption have led to widespread illegal mining (Saviour, 2012; Ashraf et al., 2011). Sand trading is a lucrative business, and there is evidence of illegal trading such as the case of the influential mafias in India (Peduzzi,2014a; b).

1.3. A growing actor: Turkey

Turkey is a growing economy where one of its leading domestic production and export commodity is construction. The state of urbanization of Turkey, which has accelerated rapidly in the last 40 years, is classified into four phases (1) post-republic-slow urbanization (1923-1950, State of Urbanization: 25%), (2) industrialization and rural to urban migration period (1950-1980, 50%), (3) post-liberalization, expansion of major cities (1980-2000, 65%), (4) post-earthquake urban transformation and growth (2000-2017, 92.5%) (Gedik, 2003; Koca, 2015; TURKSTAT, 2017). As a result, the amount of resident inventory of Turkey reached up to 32.7 million (TURKSTAT, 2017) where ~11.7 M was constructed or renovated after the 1999 Marmara Earthquake (TOKİ, 2018). Accordingly, Turkey's 5 years average cement production has reached to 72 MT, where an average of 12 MT is exported abroad (TURKSTAT). This amount places Turkey into forth rank in the 5 year average global production where ~60 MT is used for serving domestic urbanization and renovation policies including major infrastructure projects such as highways, dams, hydroelectric power plants, fast train tracks financed by the central government.

The state of sand production in Turkey, likewise to the world, is neither regulated nor measured. Limited and discontinuous statistics declared by State Statistics Institution (TURKSTAT) states that the aggregate industry occupies 45% of the total mining products of Turkey. In 2000, the total amount of sand/gravel production reaches up to 90 MT. A report by İstanbul Chamber of Commerce, declared the composition of aggregate used in concrete as 17% riverine sand and crushed rock to 83% (Alp, 2004). According to our previous assumption, the total amount of sand required for concrete production would be estimated as

~100 MT. This number should point out minimum where riverine mining also extracts gravel which is also used for producing crushed rocks extending the total estimation to ~200 MT per year. Turkey also exports sand abroad with five year average to ~60 kT (Chatham House, 2020).

Sand mining was traditionally carried by construction related state organizations (municipalities, state hydraulic works and motorway directorates) which have had legal means and equipment for sand mining, but for the last 20 years private companies took the lead parallel to cement and aggregate production (Alp, 2004). As a consequence, today there are sand mining practices along almost every minor and major rivers of Turkey, especially near the developing cities and along major construction projects.

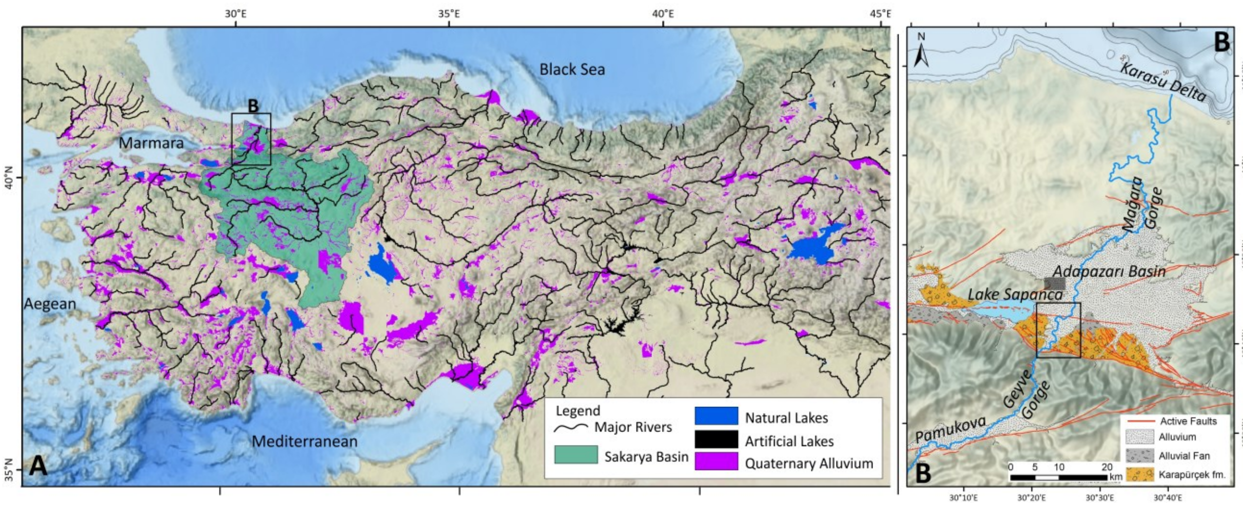

Figure 2 A General physiography of Turkey with major lakes, dams and rivers where green shaded area indicates Sakarya River basin, also showing the Quaternary alluvium coverage (modified from MTA 1/500k scale geological maps of Turkey). B the lower reaches of the Sakarya River, Quaternary basins formed on the North Anatolian Fault and the Karasu Delta (modified from Erturaç, 2020). Shaded square indicate Sakarya City center and box indicates location of Figure 3A).

Figure 2 A represents general physiography of Turkey showing major rivers and the distribution of Quaternary alluvium which cover 10% surface area of the whole country. The potential of riverine loose sand deposits (flood plain) only corresponds to 1%. Green shaded area is the Sakarya River basin where its lower reaches, the city of Sakarya (Figure 2 B), a fast growing metropole with 1 M residents, claims 18% of Turkey’s total sand production (Yüksel and Sandalcı, 2007).

This study focuses on temporal monitoring of intense sand mining operations within a relatively small and narrow (20 km^2) zone which led to total destruction of a river / floodplain system in 40 years. We wish to address and stress out the effects of uncharted sand mining causing social, ecological and environmental problems.

2. Study Area

The focus area which is subject to intense sand mining, is located at the southern part of Adapazarı Plain and in between two river type hydroelectric power plants (HPP), one at the northern outlet of the Geyve Gorge and other near the city center of Sakarya (Figure 2B and Figure 3a). The length of the study area is 15 km, covering 20 km^2 surface area.

2.1. Sakarya River

Sakarya River, flowing for ~824 km, with drainage basin ~63350 km^2, covers 8% of the total surface area of Turkey (Figure 2a). After running through series of narrow gorges formed within the western Pontide mountain range, the lower reaches of the river crosses Pamukova and Adapazarı tectonic basins formed on the North Anatolian Fault Zone (Figure 2B). The river reaches to the Black Sea forming the wide but narrow Karasu Delta (Figure 2B). The long term mean discharge (1953-2000) of the river is measured as 124 m^3/s, while hydrological extremes (500 m^3/s) in between 1963-1970 at Doğançay station at the northern outlet of the Geyve Gorge (Figure 3A). Sakarya River shares 15.6% portion of Turkey's total riverine sediment yield with 180-200 T/km^2, carrying ~12 MT suspended sediment to the Black Sea annually (Milliman and Syvitski, 1992; Öztürk, 1996). The discharge and sediment yield characteristics of the river reduced significantly after sequent construction of Sarıyar (1956) Gökçekaya (1972) and Yenice (1999) dam and hydroelectric power plants (Table 1, Işık et al., 2006; Gümrükçüoğlu-Yiğit et al., 2017). These dams regulated the flow reducing the peak flows and flood risk to 45-51% and suspended sediment load to 40-65% (Isik et al., 2006).

Table 1 Daily discharge and sediment yield for the Sakarya River at Doğançay station (DSİ and Isik et. al. 2006)

Period	Discharge (m^3/s)	Average sediment yield (T)
1964-1974	197.32	21490
1975-1999	157.4	9500
2000-	113.4	NA

2.2. Adapazarı Basin

Adapazarı Basin is an asymmetric trapezoid shaped Quaternary tectonic basin with 650 km^2 surface area, evolved under the control on the North Anatolian Fault Zone (Şengör et al., 2005) (Figure 2 B). The sedimentary sequence of the basin is formed of Early Quaternary Karapürçek formation deposited during the first phase of tectonic development (Qkpc; Emre et al., 1998) and Middle-Late Quaternary modern basin fill and river terraces (Adapazarı Plain, 330 km^2, Erturaç, et al., 2019). The formation of the modern basin is controlled by rapid tectonic subsidence (1.5 mm/year) and regional uplift of the mountain range (0.78 mm/year). The total thickness of the basin is estimated as ~1.1 km (Erturaç, 2020). Sakarya River reaches the Adapazarı Basin crossing the Samanlı Mountain Range (1800 m) through the 13 km long Geyve Gorge.

3. METHODOLOGY

3.1. Field Studies

The study area is extensively covered within the framework of studies concerning the timing and evolution of the Adapazarı Plain and terrace staircases (Erturaç et al., 2019; Erturaç, 2020). We have detailed the sedimentary facies of both terraces and the floodplain. The measurement of the position and thickness of the fluvial architecture was held using Real Time Kinematic (rtk) GPS (TOPCON GR-5) surveying aided with unmanned aerial vehicle (UAV), which was used for obtaining panoramic and stereoscopic shots for SfM photogrammetry. The average vertical position (elevation) of the terraces are given as relative elevation (above recent flood plain, afp), which is calculated by using the surface elevation (asl) of the closest flood plain. We have conducted several seasonal field surveys during 2017-2019, to achieve detailed observations on the sand mining practices, land use change, local problems, restoration practices and social impact of the sand mines.

3.2. Remote Sensing

In order to monitor the development of sand mining, we used 46 individual different types of remotely sensed imagery, covering 45 years (1975-2019). Each image is georeferenced for European Datum 1950 and UTM Zone 36, based on standard 1/25k topographic map sheet (printed in 1994). Due to the changes in major piercing points through the studied time period, each image was also cross georeferenced with eachother.

In order to detect the initiation of timing of the sand mines and classification of (now destructed) initial land use and environment, we used two sequent panchromatic images from Corona/Keyhole optical reconnaissance satellite mission (1975 and 1980, declassified in 2002) in conjunction with the pre-1975 geomorphological map of the region (Bilgin, 1984), and older 1/25k topographic map (1959).

Dealing with the orthographic errors of the analogue Keyhole imagery was a challenge. During georectification we used old bridges, road / railroad junctions, and major buildings as ground control points marked at a high scale at the topographic map which are also visible on most recent imagery served by Google Earth™ where these points were also precisely measured by rtk-GPS. As a result the image was georeferenced with an acceptable RMS value at flat areas lower than the ~5 m pixel resolution of the imagery.

The second set of dataset is formed of Thematic Mapper multispectral imagery from Landsat 4-5 and 7 mission with spatial resolution ~30 m. The dataset is formed of 9 imagery, covering 1987-1998 time period, where we chose the least cloudy frames for the late spring-summer periods, in order to eliminate errors due to the radiometric and atmospheric conditions. During digitization of the mining activities we used 7-5-1, 7-4-1 and 4-3-2 band combinations. The last image from Landsat Mission is an ETM+Pan imagery (2001) with 30-15 m spatial resolution.

Each of these images described above was downloaded from the US Geological Survey data distribution system (http://earthexplorer.usgs.gov/) where each were georeferenced with low RMS values as described.

The last dataset is the imagery served on Google Earth™ system. In order to eliminate initial georeferencing errors, we have downloaded the served image by tiling into 1/2500 scale reference tiles. The obtained multi-temporal database consist of 21 imagery covering 2005-2019 time period with ~5 m ground resolution. This dataset has increased the spatial resolution of digitization process significantly.

During field surveys, the active sand mining zones have been partially covered by stereoscopic aerial imagery, by deploying DJI INSPIRE-1 PRO UAV by using programmed grid flight pattern with 100 meters average flight altitude. These photographs have been analyzed by Pix4D Mapper™ photogrammetric software to achieve orthophotos and decimeter scale digital elevation model, aiding to perform detailed topographic profiles and also detecting mining practices.

3.3. Geographic Information System

All the dataset described above was gathered to build up a temporal database in ArcGIS ™ environment. The base (pre-sand mining era) map was produced by digitizing the geomorphological map drawn by T. Bilgin (1984). The river/floodplain and terrace staircases was classified according to rtk-GPS profiling and field observations where the thickness of each sedimentary unit is determined (Erturaç et al., 2019). The initial land use of the study area was determined from 1975 keyhole imagery. For achieving the study goal, the temporal monitoring of the sand mines, we choose manual classification during the digitization process where the spatial (Landsat) and spectral (Keyhole and Google) resolution of the image database was not effective. The areal coverage and estimated volume for each mine during each time-step is calculated in GIS environment.

All digitized polygons are classified according to classes of sand mining practices from remotely sensed imagery for each focus year. The area (a) of the polygons are calculated in hectares (1 ha= 0,01 km^2= 10000 m^2), and extracted volume (v) of sediment from a sand mine / artificial lake is calculated in cubic meters (a × h) where h is determined by using the determined relative height of the terrace and estimated lake depth. The geochemistry of Adapazarı fluvial sediments are determined by ICP-AES analysis (ALS Global) of 14 samples which yielded average composition of major oxides as SiO_2 (52.7%), Al_2O_3 (11.3%); CaO (11.3%), Fe_2O_3 (4.7%), MgO (2.3%) and LOI (12.2%). This composition indicates the average density (d) of Sakarya sediments as 2.6 g/cm^3. We calculated the total weight (w) of extracted sand by using the calculated volume and estimated density.

4. Results

The results of this study details two interconnected topics: (1) The geometry and extend of the terrace staircases (TSC) and the modern floodplain of the Sakarya River at the study area (Figure 3) and (2) temporal expansion of the sand mines and relevant statistics (Figure 4).

The geometry and the thickness of the terraces (T2, T1 and T0) varies significantly along the ~10 km course of the Sakarya River at the study area. We used six topographic profiles derived from rtk-GPS and UAV-DSM (Figure 3B) to determine the sediment thickness of the excavated terrace which aided to calculate total volume of sediment removed by sand mining.

4.1. Quaternary Geology and Geometry of the Sakarya River terraces at Adapazarı Basin

The Quaternary geological units exposing at study area consist of the Karapürçek formation (Qkpc, Ünay et al., 2001; Figure 2B and 3A) and four step late Pleistocene (T4 and T3), Holocene (T2, T1 and T0) terrace staircases. Observable sections of the Karapürçek formation are mostly abandoned and active sand quarries and consist of intercalation of coarse and fine grained clastic sediments. The terraces are formed by interactions between fluvial response to Black Sea level changes, climate pulses during Late Holocene and the steady regional uplift of the region (Erturaç et al., 2019). All the terraces sit unconformably on the Qkpc, hence will be called as substratum from this point forward. The terrace T4 deposited in between 84-72 ka and stands at +55 m afp (Erturaç, 2020). It is observed covering a wide flat area, at the southeastern side of the river, however the terrace section was only observable topping Karapürçek formation at a former sand quarry (Figure 3A). The measured thickness of the terrace reaches 8 meters. The terrace T3 started to form at 40 ka until 30 ka. It stands at +21.5 m afp and max observed thickness is 8-10 m. This terrace step forms a wide surface at the western part of the river, occupied by settlements (Kirazca and Karaçam, Figure 3) and mostly free of sand mining (Erturaç et al., 2019).

After a long erosional period during MIS 2, the terrace T2 started to form at 9 ka, responding to the abrupt rise of the Black Sea level (Ryan et al., 2003; Erturaç et al., 2019). The terrace continuously deposited and filling out the vast Adapazarı Plain, until 1.8 ka. The Sakarya River started to incise its own channel during the high flow regime during the Roman Warm Period (1.8-1.1 ka; Erturaç et al., 2019). This terrace also forms the surface of the Adapazarı Plain, a fertile agricultural land with thick alluvial soil. The relative elevation and thickness of T2 is higly variable. Near Alancuma at north (Figure 3A, I) relative elevation of T2 is 3-3.5, where it reaches 8-10 m near Kirazca-Mollaköy (Figure 3A, zones II and III; Figure 3B, Profile 2-3). The terrace sediments consist of intercalation of coarse-fine grained sand of point bars and horizontal silty clays. The terrace base is formed of coarse sand and fine pebbles. The maximum observable thickness of the terrace is measured as 6 meters.

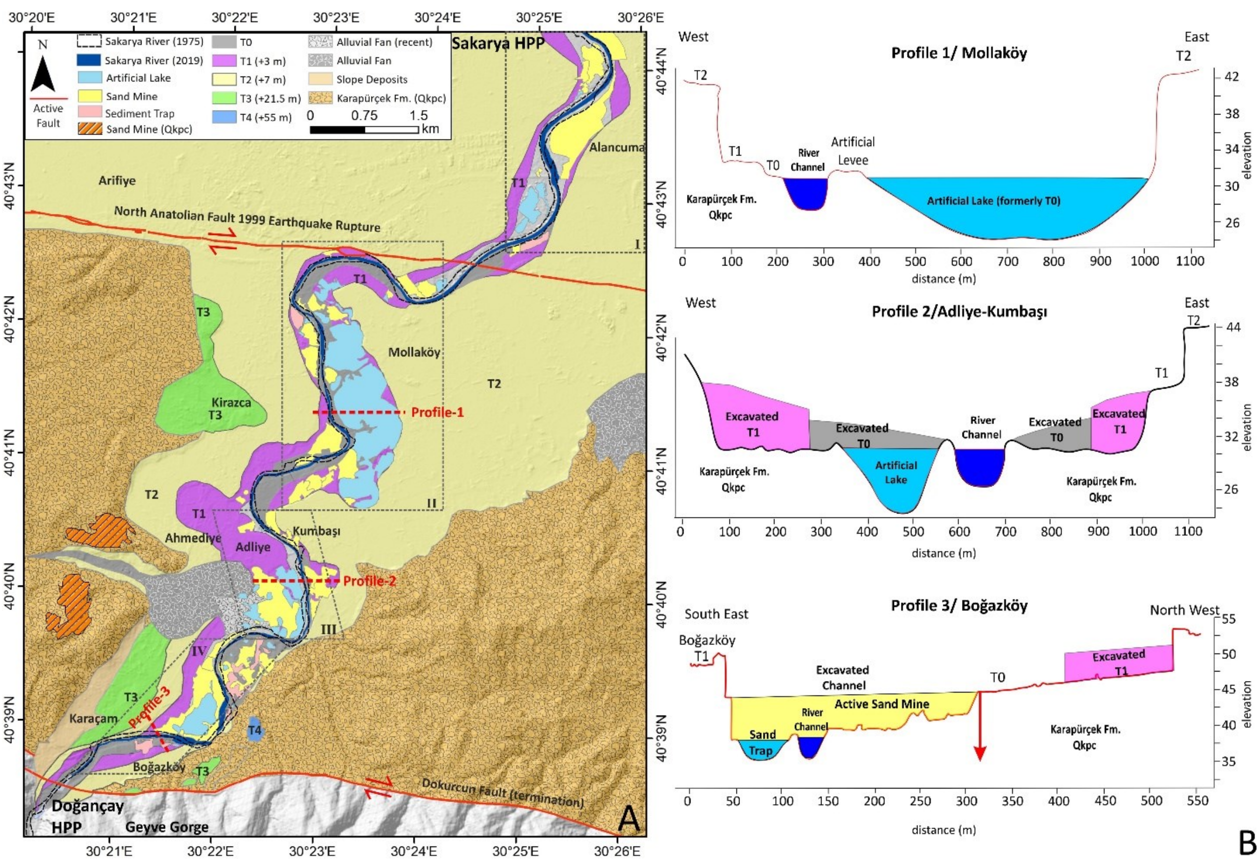

Figure 3 A Quaternary geological map of the study area (adapted from Erturaç et al., 2019) displaying the current (2019) state of destruction of the flood plain due to sand mining B. Interpreted rtk-GPS and UAV-SfM derived DSM profiles for determining the thickness of the lower terraces, and also calculating the volume of extracted sediment.

T1 terrace are formed during relatively shorter time period (1-1.1 ka) as response to decreased flow during the Medieval Drought Period (Erturaç, et al., 2019). It is mostly observed as of 150-200 m wide patches along the river channel, but reaches up to 1 km in width at an abandoned meander, near Adliye-Ahmediye villages (Figure 3). T1 stands at 2-2.5 m relative elevation (Figure 3B). The majority of the terrace strata are formed of coarse-fine grained cross laminated sand bars and horizontal silty-clay layers with max observable thickness is 2.5 m.

Although these steps are distinct and easily separated with each other at the study area, they fade away and coincide with the T2 surface at the center of the Adapazarı Plain, where Sakarya River forms a deeply incised channel.

The modern floodplain of the Sakarya River is today completely destructed by sand mining. However it is possible to map the undisturbed meandering geometry and extend of the floodplain by using 1975 Keyhole (Corona) imagery. The river had a 20 km channel length in 13 km total distance forming 10 meanders where sinuosity ratio is calculated as 1.5. The average channel width was 70 m (standard deviation: 20 m), meander amplitude is 2.4 km, wavelength 2.6 km, and radius of curvature is ~ 500 m (Figure 3A). The complete section of the T0 can be observed at the outlet of the Geyve Gorge, at the southwest corner of the study area, where the natural channel is lowered ~5 m during the construction of the Doğançay hydroelectric power plant (HPP). The terrace consist of ~2 meters of bedload deposits overlain by 4 m fine grained sediments where a tree trunk in between is ^{14}C dated to 750 yr/BP (Erturaç et al., 2019).

4.2. Sakarya Sand Mines (SSM)

In this study we classified the sand mines according to the excavation practices which varied through time and space (Figure 3A and B). The first type is **"sand mine"** which stands for total excavation of the terrace step, varying in areal extend but through whole depth until the lithified clastic substratum (Qkpc). In many cases these sand mines, especially operating on T1 surfaces, later modified into new facilities such as greenhouses or industrial facilities or factories. The second type is **"artificial lake"** which indicates deep excavation, either operating on T1 or T0 surfaces, reaching below the water table therefore become a lake. This practice was popular at first at wide T0 planes near Mollaköy, which has started in 1980 and ended in 1998 and were excavated under 5 to 10 depths below the water table. These artificial lakes are formed of excavating 326 hectares of the floodplain. These lakes are now part of the landscape with having its own habitat (Ongun-Sevindik, et. al., 2014). with a total area of 136 hectare. The Mollaköy lakes are not protected and continuously going under rearrangements.

More recent and advanced mining practices are introduced operating close to the main river channel. In this case, the T0 surface is completely destroyed and excavated deep inside the substratum. The miners continuously divert the river channel in seasonal manner by forming artificial levee(s) forming series of interconnected lakes adjacent to the channel. This type is named as **"sand traps"** as the main aim is to trap the coarse sediment yield of the river carried during the high flow period (winter) and harvest during the low flow period (summer). This type of mining practice is most common to the south as the T0 is narrower and the terraces are mostly occupied by settlements or cultivated.

4.3. Temporal Changes of the Flood Plain and Estimated Sand Extraction

The natural flood plain of the Sakara River is completely destructed and altered at the study area. In order to monitor the changes through time, we first used the satellite imagery (1975, 1980) and the 1/25k scale topographic map (1959) and geomorphological map of pre-mining era (Bilgin, 1984), to map the land use and original physiography of the vicinity. Figure 4 A outlines the temporal changes at the study area for 9 distinct time steps where Figure 4 B expresses the cumulative amount of sand extracted, determined both in area and volume.

Four distinct zones were defined for mining activities (polygons namely I-IV in Figure 3 A). The numbering also indicates temporal expansion of the sand mining activities. The first focus area were wide floodplains at zones I (Alancuma) and II (Mollaköy) which were excavated with an increasing trend in between 1980-1987, was initiated with the Anatolian highway construction (opened to service in 1984). After exploiting for ~20 years, Alancuma (I) sand mines were abandoned and partially restored to create space for temporary emergency settlements after 1999 earthquake. At Mollaköy (II), mines were operated on wide point bars of T0 and partially on T1, which in long term resulted in formation of the artificial Mollaköy lakes. This zone (II) has stopped expanding in 2005, but still being operated with rearrangements. The river channel was remained mostly untouched during the sand extraction in both zones. These zones are very close to the Sakarya metropolitan area and are now within the industrial zone, therefore most of the former sand mines are restored for creating space for major and moderate size factories.

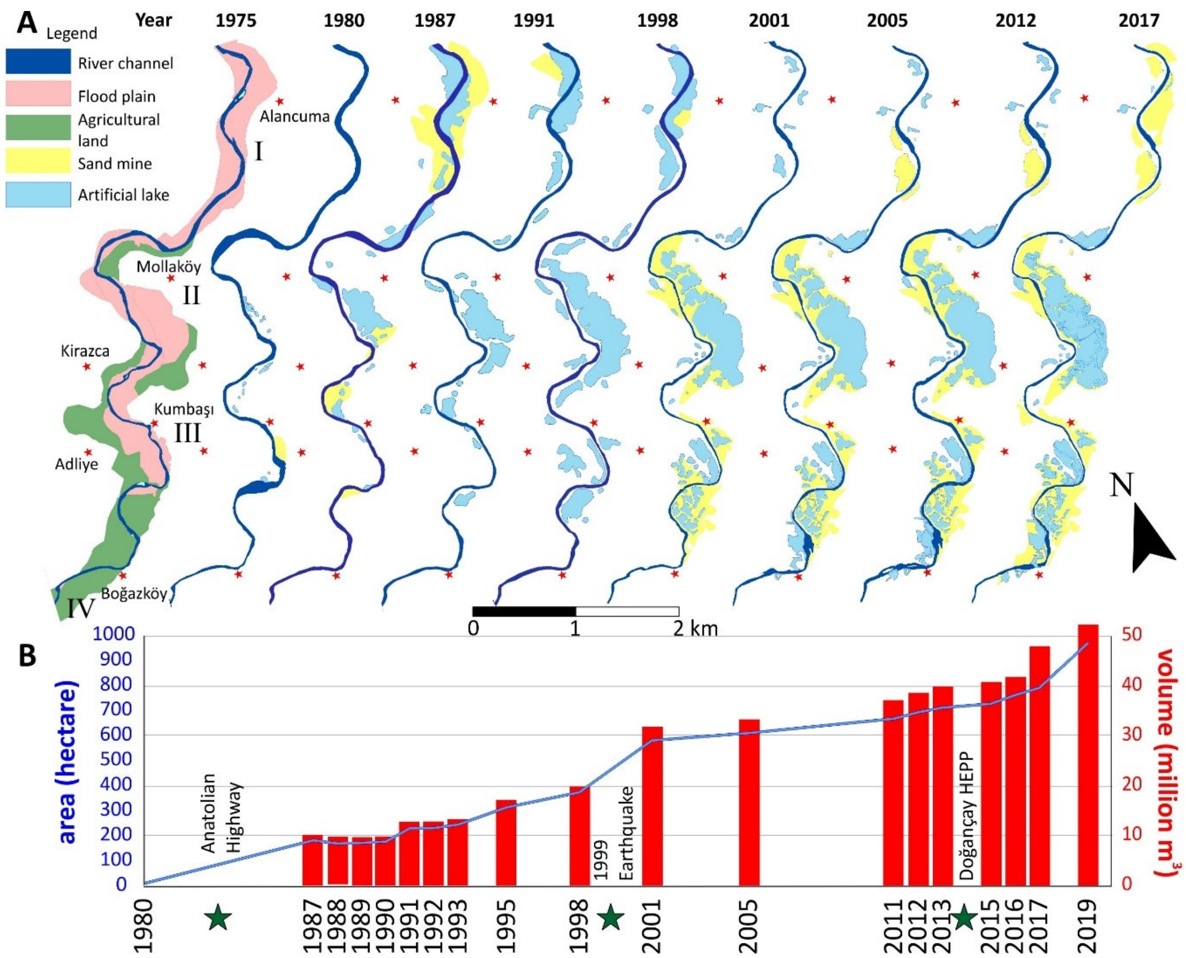

Figure 4 Time-laps of Sand Mining along Sakarya River. A. Selected annual maps showing the expansion of SSM B. Calculated total area of the mining zones and estimated volume of the extracted sediment.

Kumbaşı (III) and Boğazköy (IV) zones were initiated in 1991, accelerated after 1999 and reached apex in 2005 when most of the mining facilities migrated to the south because of increasing land value at north due to the industrialization. Boğazköy Zone (IV) extends from the northern outlet of the Geyve Gorge at south and occupies two wide meanders which are now totally excavated. In 2014, Doğançay Hydroelectric Power Plant (HPP) was constructed. Due to the operational needs, the floodplain of the upslope was extensively extracted to provide the reservoir of the HPP. At the downslope of HPP, the Sakarya River channel had been excavated down to -5 m. This construction coincides with the 3rd boost for the sand mining operations in the floodplain. Following this period, the miners had extracted the floating low terraces and further excavated deep in to the river channel, which is artificially widened 2-3 times. A new sand mining practice has been introduced by forming deep parallel lakes (sand traps) on the former meander bends. This practice is still in use to harvest the yearly fine sediment yield of the river. Year 2012 also marks the initiation of large scale sand mining of the clastics of the Karapürçek formation at the west of the study area (Figure 2 A and Qkpc in Figure 5).

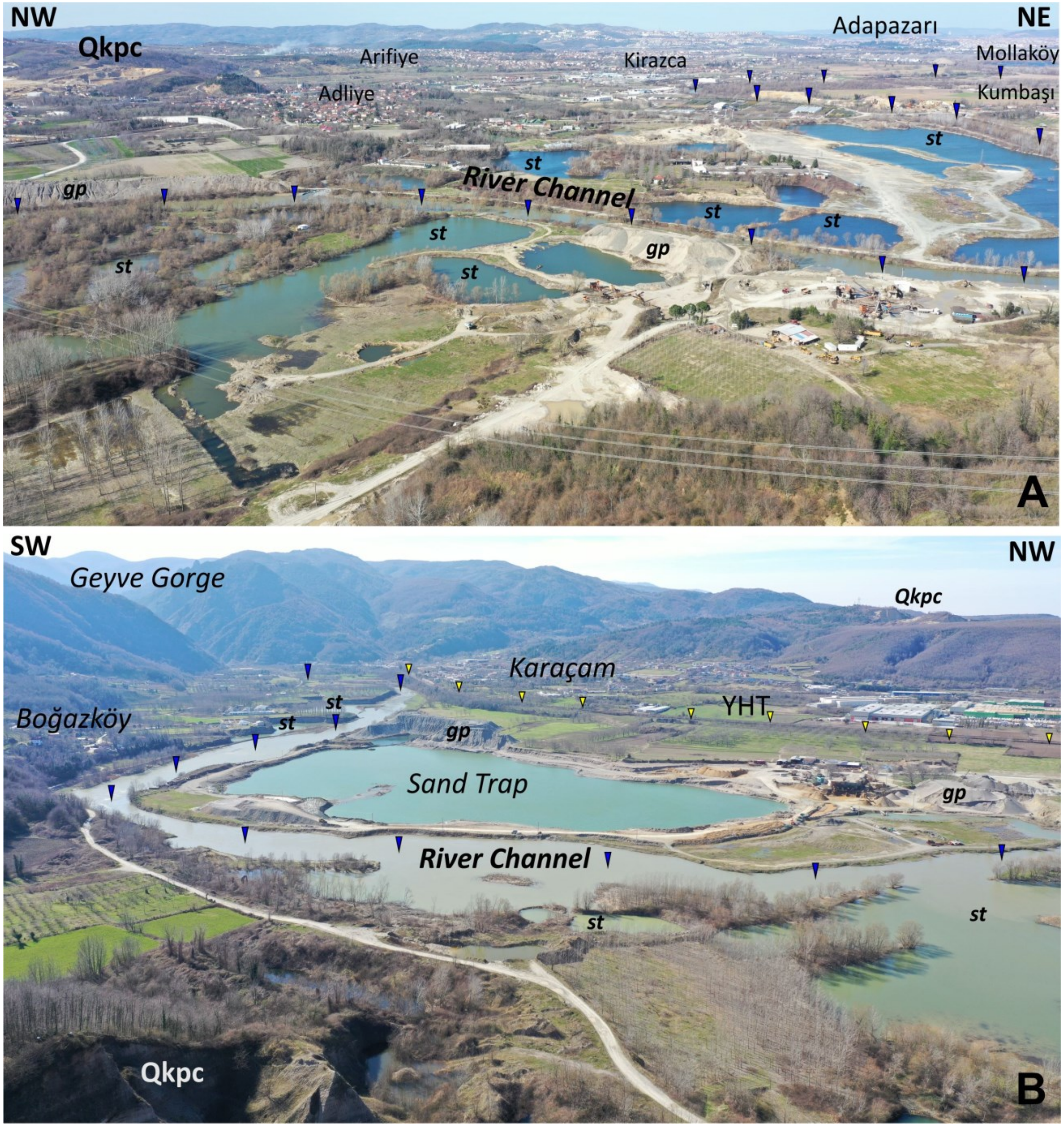

Figure 5 Panoramic pictures covering Kumbaşı (A) and Boğazköy (B) mining zones and practices. Abbreviations: ***st*** *(sand trap), gp (sand and gravel pile), Qkpc (sand/gravel quarry on Karapürçek formation), YHT (fast train track)*

The sand mining operating in the study area for 40 years has reached a total area of **~970 ha** (1980-2019). The volume calculation based on two different estimations for artificial lake depths 5 and 10 meters which yielded **41 M m^3** or **52 M m^3** respectively (Figure 4B). Geochemical determination of major oxides for 14 samples within the floodplain resulted in estimation of average density of the material extracted as 2.6 g/cm^3. This value is used to calculate the total weight of the extracted material to **107 MT** to **137 MT**.

5. Discussion

5.1. Initiation and Boosting of the SSM

The politic economy of Turkey, has started to change following 1980's initiating a large scale urbanization and infrastructure program. The post-liberalization period (1980-2000), lead to expansion of major cities reaching 65% urbanization. This timing also marks the initiation of sand mining in the study area with the construction of Anatolian TEM and renovation of the D-100 state highway, connecting Istanbul to Ankara. Sakarya floodplain was chosen as the closest and the most efficient source of sand, contributing 20 M m^3 of sand in 20 years. The second boost is marked with the 1999 earthquake series (August and November), causing total destruction of over 20000 buildings and at least 100000 severely damaged (Gurenko et al., 2006). This damage was scattered along the major cities Bolu, Düzce, Sakarya, Kocaeli and İstanbul. These settlements are located close to the SSM, where 10 M m^3 of sediment was extracted just in 2 years, and initiating the expansion of the mines to the south, in order to provide aggregate for reconstruction. The third boost (2007-2019) was related with the declaration of urban renovation program (2012) of the Turkish government. New mining practices within the river channel was introduced and quarry mining from the clastics of Karapürçek formation has initiated. During this period 15 M m^3 of sediment is extracted from the river (Figure 5).

5.2. Sand Mining Practices

There are two general types of sand mining practices at the study area (Figure 5): (1) using potential of the natural terraces T2, T1 and T0, by excavating the terrace completely and also deep trenching under the water level forming artificial lakes. This practice took place in the first and second phases (and zones) of sand mining and (2) excavating sand traps to harvest the annual sand yield of the river and also dissolving the sand of the substratum (Qkpc) by freshwater input. This practice was carried out in zone III and IV and after 2012 and still operational. The mining facilities continuously alter and excavate deep into the river channel, extract sediment from terraces, sand traps and also loosened material from Qkpc (Figure 5). Post-operations including sieving the extracted material in order to separate sand and gravel/blocks, building up large scale piles of blocks and artificial levees are widely scattered within the active zones (Figure 5).

5.3. Impact on Environment

Adapazarı Plain has a long history of agriculture and was a major supplier for Istanbul during Roman, Ottoman Empires and today Republic of Turkey. Previous to the mining era (1980) the agricultural land of the plain has widened by draining the swamps. Due to the classification of 1975 Keyhole satellite imagery, there were **496** ha of agricultural field scattered on T2 and T1 surfaces at the study area. The floodplain was mostly covered by natural habitat. After 40 years of sand mining, T1 terrace surface is partially and the natural floodplain (T0) of the Sakarya River is completely excavated, causing destruction of the natural ecosystem. The abandoned sand mines and the vicinity of the lakes are afforested with poplar plantation or restored for construction of factories. Due to the advancing mining practices, the river is excavated deep into -10 meters which has reduced the underground level significantly at zones III and IV. This has resulted in partial abandonment of the agricultural land on T2 surfaces which are now also subject to severe erosion, in addition 35% (174 ha) of agricultural land has been directly destructed by mining. At the northern part, the activities around Mollakoy artificial lakes were silent enough for a new ecosystem to develop for 20 years, but the region is not protected and would be subject to mining again in the future.

5.4. Coastal Erosion

There is a prominent coastal land loss reported in Sakarya River Delta at Karasu, 50 km north of the study area (Ozcan et al., 2012). The amount of loss since 1975 is ~ 35 ha which correspond to 400 m retreat at delta mouth threatening the settlement. This loss has accelerated since 2012, directly related with the sand mining practices and the construction of 2 sequent HPP's at the study area. To prevent the coastal loss, systematic coastal dikes are erected since 2012.

5.5. Conflicts due to Sand Mining

The mining facilities are mostly active during spring to autumn causing serious noise and dust pollution with an extreme 24h truck traffic. The SSM are located at zones III and IV are located very close (25-100 m) to the villages with ~5000 total population and causing increasing stress and conflicts. This villages are now transforming into suburbs of the Sakarya City, where most of the local population work at the city or nearby factories. The local village authorities have complained to the governmental organizations and filed law suits against the SMM where neither one had a meaningful outcome. Therefore the villages now have closed their roads to avoid the trucks traffic, increasing stress between the miners and the locals.

6. Conclusions

We have detailed the history of the Sakarya Sand Mine (SSM), located in a highly industrialized and populated zone of Turkey. Laying as an example for sand production practices at a growing actor in global cement / aggregate production, consumption and trade. The trend and total amount of sediment extracted is monitored by using multi-temporal satellite imagery due to the lack of relevant data regarding the mining operations. SMM was initiated in 1980 (the construction of Anatolian Highway), rejuvenated first after 1999 Earthquake, reached its apex and expanded since 2012. The sand mining operating in the study area for 40 years has reached a total area of **~970 ha** (1980-2019). The volume of extracted sediment is calculated as **41 - 52 M m^3** which corresponds to **107 MT** to **137 MT** and on average, **3-4 MT / year**. Considering the annual sand/gravel production of Turkey is estimated as 65 MT, we may conclude that SMM (20 km^2) covers the 7-8% of the total demand. The result is the total destruction of the flood plain which has direct effects on environment, agriculture and local residents, and causing accelerated coastal land loss.

Available literature on sand and gravel mining represents and stresses out numerous common concerns on direct impact and need for action. This is a global problem and effects river ecosystems, people and economy on various scales. Loose sand and gravel (aggregate) mining is defined as one of the main sustainability issues of the 21st Century (UNEP, 2019). The accelerating rate of urbanization causes increase in construction of buildings and infrastructure, driving need for aggregate. As a result, the civilization now acts as a major earth surface process, eroding, moving, and depositing sediment during the Anthropocene epoch, rapidly depleting natural resources. Sand is an extremely rare, and definitely not an infinite source. Global examples lay out that the sand mining has always been aggressive, benefiting from the luxury of being prerogative due to urgent demands, unregulated, practice irresponsible to the natural environment and local residents, directly causing stress and conflict. Complex questions arise on how to deliver on ecosystem and biodiversity conservation goals while necessary improvements in transport, infrastructure, housing and living standards are looming (UNEP, 2019). Urgent actions are needed for (1) applying or extending available national regulations and limitations to curb irresponsible and illegal extraction for sand, (2) reducing sand demand by investing research for finding means and ways for using recycled /

alternative material to use as aggregate, (3) imposing dialogue between key players, and stakeholders in the sand value chain based on transparency and accountability (UNEP, 2019).

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7. References

Allan, J.D., Castillo, M.M., 2007. Stream Ecology: Structure and Function of Running Waters. 2nd Edition, Chapman and Hall, New York. http://dx.doi.org/10.1007/978-1-4020-5583-6.

Alp, S., 2004. Sand, Clay and Quarries Industry Report. İstanbul Chamber of Commerce.

Ashraf, M.A., Maah, M.J., Yusoff, I., Wajid, A., Mahmood, K., 2011. Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia. Scientific Research and Essays 6(6), 1216-1231.

Aslan, G., Lasserre, C., Cakir, Z., Ergintav, S., Özarpaci, S., et al., 2019. Shallow Creep along the 1999 Izmit Earthquake Rupture (Turkey) From GPS and High Temporal Resolution Interferometric Synthetic Aperture Radar Data (2011–2017). Journal of Geophysical Research Solid Earth 124: 2218-2236. doi: 10.1029/2018JB017022.

Bilgin, T., 1984. Adapazarı Ovası ve Sapanca oluğunun aluviyal morfolojisi ve Kuvaterner'deki Jeomorfolojik tekamülü. İstanbul: Edebiyat Fakültesi Matbaası. (in Turkish).

Bravard, J.-P., Goichot, M., Gaillot, S., 2013. Geography of Sand and Gravel Mining in the Lower Mekong River. EchoGéo 0–20. https://doi.org/10.4000/echogeo.13659.

Chatham House (2020), 'resourcetrade.earth', https://resourcetrade.earth/

Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: deciphering the long-term interaction between humans and the environment—a review. Geomorphology, 101(1-2), 192-208.

Emre, Ö., Erkal, T., Tchepalyga, A., Kazanci, N., Keçer, M., & Ünay, E., 1998. Neogene-Quaternary evolution of the eastern Marmara Region, Northwest Turkey. Mineral Research Exploration Bulletin 120: 119–145.

Erturaç, M.K., Şahiner, E., Zabcı, C., Okur, H., Polymeris, G.S., Meriç, N., İkiel, C., 2019. Fluvial response to rising levels of the Black Sea and to climate changes during the Holocene: Luminescence geochronology of the Sakarya terraces. Holocene 29, 941–952. https://doi.org/10.1177/0959683619831428.

Erturaç, M.K., 2020. Late Pleistocene-Holocene characteristics of North Anatolian Fault at Adapazarı Basin: evidence from the age and geometry of the fluvial terrace staircases. Turkish Journal of Earth Sciences. 29: https://doi:10.3906/yer-2006-25.

Gastner, M.T., Newman, M.E.J., 2004. Diffusion-based method for producing density-equalizing maps. Proc. Natl. Acad. Sci. U. S. A. 101, 7499–7504. https://doi.org/10.1073/pnas.0400280101.

Gedik, A., 2003. Differential urbanisation in Turkey, 1955-97. Tijdschr. voor Econ. en Soc. Geogr. 94, 100–111. https://doi.org/10.1111/1467-9663.00240.

Govindaraj, G., Raveesha, S., Ahmed, T., Suryaprakash, S., Rajan, K., Harsha, K., 2013. Sand mining from agricultural and common property lands in peri-urban areas: an assessment of economic loss and factors responsible for transformation from agriculture to mining. Indian J. Soil Conserv. 41, 61–68.

Gurenko, E.N., Lester, R.R., Mahul, O., Oguz Gonulal, S., 2006. Earthquake Insurance in Turkey, Earthquake Insurance in Turkey. https://doi.org/10.1596/978-0-8213-6583-0.

Gümrükçüoğlu-Yiğit, M., Doğan, E., Köklü, R., 2017. Landuse changes related to sand and gravel mining on Sakarya River. Dicle University J. of Engineering 8, 25–32 (in Turkish).

Isik, S., Dogan, E., Kalin, L., Sasal, M., Agiralioglu, N., 2008. Effects of anthropogenic activities on the Lower Sakarya River. Catena 75, 172–181. https://doi.org/10.1016/j.catena.2008.06.001

Isik, S., Sasal, M., Dogan, E., 2006. Investigation on downstream effects of dams in the Sakarya River. Journal of the Faculty of Engineering and Architecture of Gazi University Ankara 21 (3), 401–408.

John, E., 2009. the Impacts of Sand Mining in Kallada River (Pathanapuram Taluk), Kerala. J. Basic Appl. Biol. 3, 108–113.

Koca, D., 2016. Türkiye'de Çağdaş Konut Üretiminin Yeniden Okunması. Tasarım + Kuram 11, 19–19. https://doi.org/10.23835/tasarimkuram.239591 (in Turkish).

Koehnken, L., Rintoul, M., 2018. Impacts of Sand Mining on Ecosystem Structure, Process and Biodiversity in Rivers. WWF. ISBN: 978-2-940529-88-9 WWF.

Koehnken, L., Rintoul, M.S., Goichot, M., Tickner, D., Loftus, A.C., Acreman, M.C., 2020. Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research. River Res. Appl. 36, 362–370. https://doi.org/10.1002/rra.3586.

Kondolf, G.M., 1994. Geomorphic and environmental effects of instream gravel mining. Landsc. Urban Plan. 28, 225–243. https://doi.org/10.1016/0169-2046(94)90010-8.

Kondolf, G.M., 1997. Hungry water: Effects of dams and gravel mining on river channels. Environ. Manage. 21, 533–551. https://doi.org/10.1007/s002679900048.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.H., Haberl, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecol. Econ. 68, 2696–2705. https://doi.org/10.1016/j.ecolecon.2009.05.007.

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., Haberl, H., 2017. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. Proc. Natl. Acad. Sci. U. S. A. 114, 1880–1885. https://doi.org/10.1073/pnas.1613773114.

Lai, X., Shankman, D., Huber, C., Yesou, H., Huang, Q., & Jiang, J., 2014. Sand mining and increasing Poyang Lake's discharge ability: A reassessment of causes for lake decline in China. Journal of Hydrology, 519(B), 1698–1706.

Lane, E., 1954. The importance of fluvial morphology in hydraulic engineering., s.l.: US Department of the Interior, Bureau of Reclamation.

Langbein, W. and Leopold, L., 1964. Quasi-Equilibrium States in Channel Morphology. Americal Journal of Science, Volume 262, pp. 782-794.

Miatto, A., Schandl, H., Fishman, T., Tanikawa, H., 2017. Global Patterns and Trends for Non-Metallic Minerals used for Construction. J. Ind. Ecol. 21, 924–937. https://doi.org/10.1111/jiec.12471

Milliman, J.D., Syvitski, J.P.M., 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. J. Geol. 100, 525–544. https://doi.org/10.1086/629606.

Mngeni, A., Musampa, C.M., Nakin, M.D. V., 2016. The effects of sand mining on rural communities. Sustain. Dev. Plan. VIII 1, 443–453. https://doi.org/10.2495/sdp160371.

Ongun-Sevindik, T., Tunca, H., Önem, B., Tamer, S.A., 2014. Temporal fluctuations of the phytoplankton community in an isolated floodplain lake (North Mollaköy Lake) of the Sakarya River (Northern Turkey). Oceanol. Hydrobiol. Stud. 43, 381–392. https://doi.org/10.2478/s13545-014-0156-5.

Ozcan, O., Musaoglu, N., Seker, D.Z., 2012. Environmental impact analysis of quarrying activities established on and near a river bed by using remotely sensed data. Fresenius Environ. Bull. 21, 3147–3153.

Öztürk, F., 1996. Suspended sediment yields of rivers in Turkey. International Association of Hydrological Sciences Publications- series of Proceedings and Reports 236: 65–72.

Padmalal, D., Maya, K., Sreebha, S., Sreeja, R., 2008. Environmental effects of river sand mining: A case from the river catchments of Vembanad lake, Southwest coast of India. Environ. Geol. 54, 879–889. https://doi.org/10.1007/s00254-007-0870-z.

Peduzzi, P., 2014a. Sand, rarer than one thinks. United Nations Environment Program (UNEP) 2012, 1–15.

Peduzzi, P., 2014b. Sand, rarer than one thinks. Article reproduced from United Nations Environment Programme (UNEP) Global Environmental Alert Service (GEAS). Environ. Dev. 11, 208–218.

Rege, A., 2016. Not biting the dust: using a tripartite model of organized crime to examine India's Sand Mafia. Int. J. Comp. Appl. Crim. Justice 40, 101–121. https://doi.org/10.1080/01924036.2015.1082486.

Saviour, N., 2012. Environmental impact of soil and sand mining: a review. Int. J. Sci. Environ. Technol. 1 (3), 125–134.

Schandl, H., Fischer-Kowalski, M., West, J., Giljum, S., Dittrich, M., Eisenmenger, N., … Fishman, T. (2016). Global Material Flows and Resource Productivity. Assessment Report for the UNEP International Resource Panel. Paris: UNEP.

Sreebha, S., Padmalal, D., 2011. Environmental impact assessment of sand mining from the small catchment rivers in the southwestern coast of India: a case study. Environmental management, 47(1), 130-140.Surian, N., Rinaldi, M., 2002. Morphological response to river engineer- ing and management in alluvial channels in Italy. Geomorphology, 50, 307–326.

Sutherland, W.J., Barnard, P., Broad, S., Clout, M., Connor, B., Côté, I.M., Dicks, L. V., Doran, H., Entwistle, A.C., Fleishman, E., Fox, M., Gaston, K.J., Gibbons, D.W., Jiang, Z., Keim, B., Lickorish, F.A., Markillie, P., Monk, K.A., Pearce-Higgins, J.W., Peck, L.S., Pretty, J., Spalding, M.D., Tonneijck, F.H., Wintle, B.C., Ockendon, N., 2017. A 2017 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity. Trends Ecol. Evol. 32, 31–40. https://doi.org/10.1016/j.tree.2016.11.005.

Şengör AMC, Tüysüz O, İmren C, Sakınç M, Eyidoğan H, et al., 2005. The North Anatolian Fault: a New Look. Annual Reviews of Earth Planetery Sciences 33: 37–112. doi: 10.1146/annurev.earth.32.101802.120415.

Torres, A., Brandt, J., Lear, K., Liu, J., 2016. Global sand trade is paving the way for a tragedy of the sand commons 3–4. https://doi.org/10.13140/RG.2.2.27573.68323

UNEP., 2019. Sand and Sustainability: Finding new solutions for environmental governance of global sand recources. GRID- Geneva, United NAtions Environment Programme, Geneva, Switzerland.

USGS., 2013a. Cement, statistics and information. U.S. Geological Survey, Reston.

USGS., 2013b. Sand and gravel (construction) statistics, in: Kelly, T.D., Matos, G.R., (Eds.), Historical statistics for mineral and material commodities in the United States. U.S. Geological Survey Data Series 140, Reston.

USGS., 2013c. The 2011 Minerals Yearbook, Cement, U.S. Geological Survey, Reston. Global Material Flows and Resource Productivity. An Assessment Study of the UNEP International Resource Panel, syf:159, Ocak,2016.

Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Gałuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., Jeandel, C., Leinfelder, R., McNeill, J.R., Richter, D.D.B., Steffen, W., Syvitski, J., Vidas, D., Wagreich, M., Williams, M., Zhisheng, A., Grinevald, J., Odada, E., Oreskes, N., Wolfe, A.P., 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. Science (80-.). 351. https://doi.org/10.1126/science.aad2622.

Winarso, G., Budhiman, S., 2001. The potential application of remote sensing data for coastal study. In Proc. 22nd. Asian Conference on Remote Sensing, Singapore (pp. 1-5).

Ye, B., Yang, D., Kane, D.L., 2003. Changes in Lena River streamflow hydrology: Human impacts versus natural variations. Water Resour. Res. 39. https://doi.org/10.1029/2003WR001991.

Yüksel, İ., Sandalcı, M., 2007. Sakarya Havzasında Katı Madde Taşınım Dengesi Ve Havzanın Kum-Çakıl Sektöründeki Yeri. 6. Ulusal Kıyı Mühendisliği Sempozyumu. Tam Metin Bildiri. (in Turkish).

Zhang, Q., Li, L., Wang, Y.-G., Werner, A.D., Xin, P., Jiang, T., Barry, D.A., 2012. Has the Three-Gorges Dam made the Poyang Lake wetlands wetter and drier? Geophys. Res. Lett. 39.