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Geomorphic effects of gravel mining on coastal plain rivers in Mazandaran, Iran

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A B S T R A C T

Rivers in Iran are heavily influenced by human activities, so that they have undergone many changes. In the meantime, gravel mining is one of these activities that has several environmental impacts on the various aspects of river environments. The study area is located in the plain of Mazandaran Province in Iran. The concerned rivers originate from the northern slopes of the Alborz Mount and flow into the Caspian Sea. Most of the mountainous areas are covered with thicket forests, and in the plain section, agricultural lands and human habitats are the dominant land uses in the region. The geomorphic effects of sediment mining from river have been investigated in four aspects including river longitudinal profile and transverse profile, as well as river pattern and changes in sediment size and amount. In Mazandaran Province, there are more than 60 rivers in which there are more than 80 active gravel mines. These mines are run by governmental, cooperative and private sectors. Currently, the dependence of the construction and development activities of the province on these gravel resources has seriously threatened the river bed with excessive exploitation, so that these exploitations would be of the most destructive activities imposed on the aquatic ecosystems. The results also show that the unauthorized sediments removal from the river bed and the construction of engineering structures to control its geomorphic consequences only delay the performance of river processes and, consequently, delay the morphological adjustments.

A R T I C L E I N F O

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1. Introduction

Rivers in Iran are heavily influenced by human activities, so that they have undergone many changes. In the meantime, gravel mining is one of these activities that has several environmental impacts on the various aspects of river environments. Gravel mining from river is a process in which gravel is removed from the bed and the banks of the river (Anger, 2003). In recent years, as a result of human progress in various fields, gravels have been more widely used, and the main source of which are rivers. As a consequence, such mining has had a significant negative impact on river landscape (Ako et al., 2014).

Gravel mining from the rivers with the aim of proper management of the river environment can have positive effects such as shipping and sewerage facilitation, flood control and channel stabilization. Flood plains and rivers are of the most important economic gravel resources. Despite the importance of these resources, previous studies have shown that gravel mining from river bed and banks can have adverse environmental and ecological impacts on the river environment, which are rarely considered in making decisions on sediment exploitations.
Mining of these resources from flood plains can affect the level of groundwater and change the land use for agricultural purposes (Anger, 2003).

It also can change the natural cycle of erosion and sedimentation and cause undesirable effects on river ecosystems (Ako et al., 2014). Some studies have reviewed the geomorphic and environmental effects of gravel mining (Kondolf, 1994; Rinaldi et al., 2005). A number of case studies have also examined the effects of gravel removal from the river bed and banks, such as changes in the river pattern (Wishart et al., 2008), sediment transport and river morphology (Li et al., 2008; Jabbari and Farzi, 2008), river response modeling (Lopez, 2004; Martin-vide et al., 2010), and environmental changes caused by gravel mining from the river bed (Gharamani et al., 2011). The purpose of this study is to review the geomorphic effects of gravel mining from the rivers of Mazandaran Province in Iran.

2. Material and Methods

2.1. Study Area

The study area is located in the plain of Mazandaran Province in Iran. The concerned rivers originate from the northern slopes of the Alborz Mount and flow into the Caspian Sea (Fig. 1).

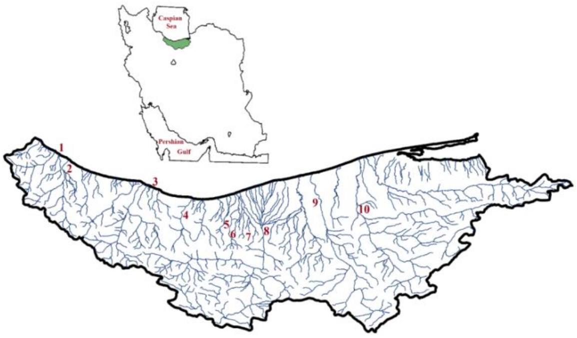

Fig. 1. Location map for show the Coastal Plain Rivers in Mazandaran (1. Shirood, 2. CheshmeKileh, 3. Mashlak, 4. Kojor, 5. Lavij6. Vaz rood 7. Alesh rood, 8. Haraz, 9. Talar, 10. Tajen)

From the viewpoint of mineralogy, the studied river basins include sedimentary, metamorphic and igneous rocks belonging to the periods from the first era to the quaternary era. The average annual precipitation in the plain is up to 900 millimeters and at altitudes, it reaches 300 millimeters. Most of the mountainous areas are covered with thicket forests, and in the plain section, agricultural lands and human habitats are the dominant land uses in the region. The rivers flowing in the plain section are predominantly alluvial due to the slopes in the mountainous part and their bed is composed of gravel sediments. The studied rivers and their associated characteristics are presented in Table 1.

Table 1. Studied rivers and their associated characteristics in Mazandaran

River	Basin area	River length
Chashma kilah	776	51.6
Shiroud (Tirom)	108	22.9
Mashlak	49	34
Kojor	514	45
Lavij	146	25.4
Vaz	141	25
Aleshrood	81	15.1
Talar	2852	119
Tajan	4313	116

3. Results and discussion

The geomorphic effects of sediment mining from river have been investigated in four aspects including river longitudinal profile and transverse profile, as well as river pattern and changes in sediment size and amount.

Longitudinal profile: The longitudinal profile follows a general trend with decreasing slope downstream. This is associated with an increase in river discharge, change in geometry and hydraulic features, and decrease in particle size. In Shiroud River, the mining of river materials has led to a 3-meter altitude difference between the river bed and the surrounding lands. The fall of the bed has led to a drop in the groundwater level at the river margin, deteriorating erosion, damaging and destroying the existing structures in the river (Alidoust and sabetraftar, 2013) (Fig. 2). In Talar River, gravel mining has increased the slope of the main channel and caused a breakage in the river bed displacing it upstream. As a result of bed digging, the level of the river bed fell lower than the branches, leading to an increase in the branches slope and erosion (Nahvi and Feizi, 2010). In fact, as a result of mining, the downstream transport of sediment has been stopped and the flow energy has been increased downstream (Rinaldi and Simon, 1998). In the downstream intervals of Talar River, despite no mining, it is still possible to observe the bed digging and erosion continued until reaching the bedrock (Nahvi and Feizi, 2010). Now, all the structures traverse with Talar River face scouring problems. The observed deflected bridges and sills are not in a proper position in terms of structure, and downstream scouring of the bridge as well as evacuation of the bridge undercutting and buttress are seen in almost all of them. On the slope removing structures, there are also relatively deep runnels and damages due to the collision of the rocks transported by water and the erosion of the flow (Fig. 3).

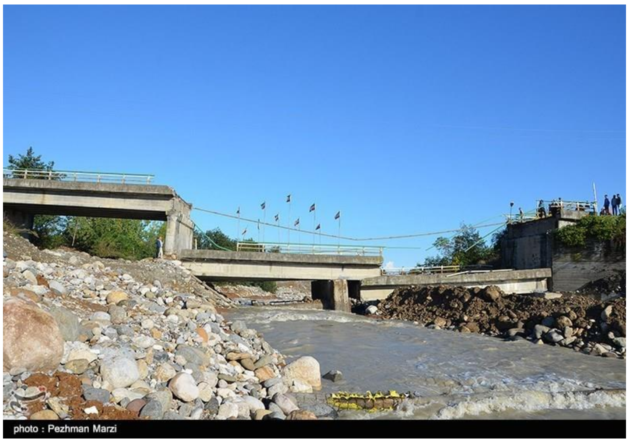

Fig. 2. Damaging and destroying the existing structures in Shiroud River

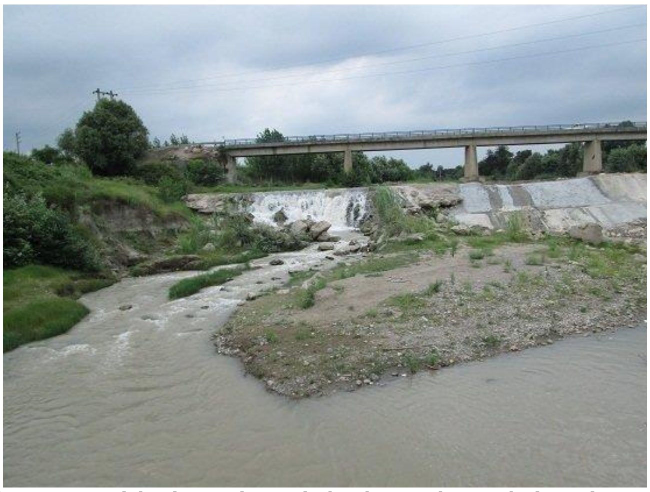

Fig. 3. Increased the slope and caused a breakage in the river bed in Talar River

In Mashlak River, the river bed mining phenomenon is rapidly moving upstream, and the excessive removal of gravel from the river bed causes formation of deep pits and breakage of the bed, and disconnects the upstream and downstream of the river which has negative impacts on the environmental conditions of the river. In particular, it limits the access of fish to the upstream spawning grounds (Nemati et al., 2010). In Lavij River, the mining of river materials has made the most prominent slope changes in the river bed. The presence of 4 sudden breakages with altitude differences of 6.5, 3.3, 2.5, and 1 meter from the river bed confirms this issue (Esmaili et al., 2012) (see Fig. 4). The slope decrease at the downstream of the breakages has reduced the flow rate and caused the sedimentation of fine particles (clay and silt). Transverse profile: Mining the sand and gravel from the river bed has led to the expansion of the channel and the destruction and erosion of the river banks. In the studied area, the river bed is located adjacent to the alluvial terraces, and any channel expansion stimulates the front and submergence of the riverbank.

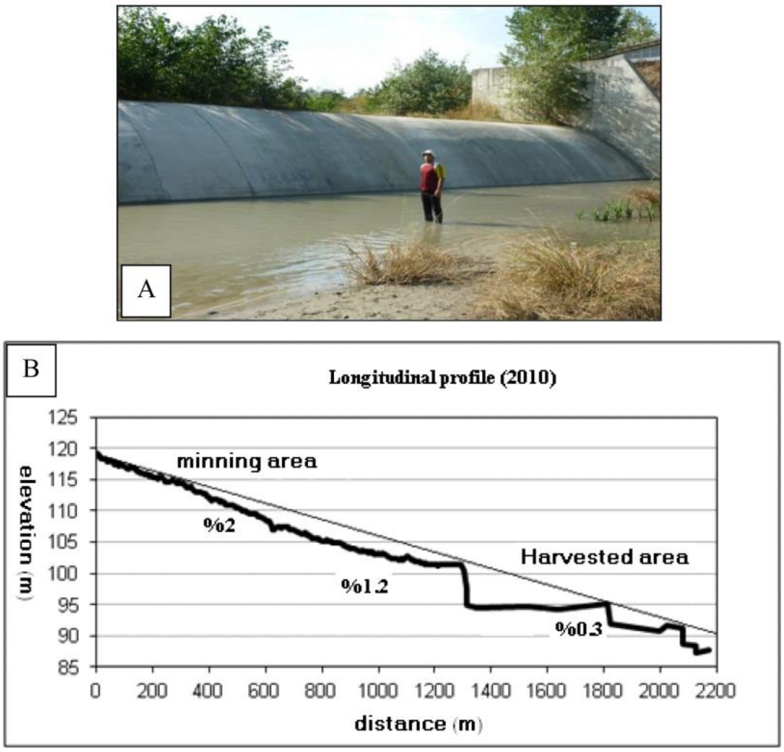

Fig. 4. A) Fracture longitudinal profile of bed river and B) Create small falls in Lavij river

In Talar River, the expansion of river bed has led to the destruction of agricultural lands and paths adjacent to the river, high concentration of sediments, water pollution, and instability of the structures constructed. Following the excessive and frequent removal of sediments from the river, the groins and protective covers on the river banks of Talar River have been destroyed, e.g., the destruction of the protective wall of the left bank of Rostamkola Bridge (Fig. 5, A, B).

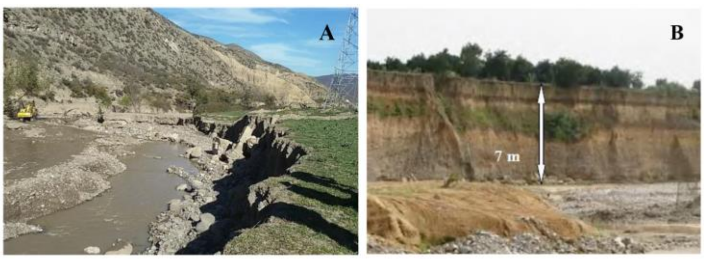

Fig. 5. A & B: expansion of the channel and bank erosion in Talar river

3.1. River Plan

The clearest feature of the river is its plan form or geometrical form. The channel pattern indicates the form adjustment in the horizontal plan of the river. One of the effects of gravel mining in Talar River is arterial river pattern. In fact, sediment mining from the bed causes the formation of parallel drains along the river, and during succulence, the flow of water cannot find its main path and is divided into several branches. Samples of arterial pattern and formation of sedimentary obstacles can be observed at the downstream of Shirgah deflected dike. In Lavij River, the river pattern has been converted into arterial and direct patterns in the mining area.

In smaller slope intervals, the river pattern has been arterialized and in some intervals, the construction of artificial dikes at the banks of the river channel and the construction of sills have led to the formation of a direct flow pattern. In the studied rivers, most of the river pattern changes have been in the materials mining area and changes in the downstream and upstream of the channel have been insignificant.

3.1.1. Changes in Sediments

In Vaz River, as a result of gravel mining, the average diameter of the river bed sediments declines. Therefore, despite the stability of the river discharge and its hydraulic parameters, the critical speed decreases at levels lower than the gravel mining location, i.e., the movement of the material is slowly starting. In fact, the decrease in the average diameter of the sediment does not increase the flow power for sediment transport, but the flow can transport more sediment with the same previous power because the diameter of the sediments is reduced (Sadeghi and Khaledi Darvishan, 2007) (Fig. 6).

Fig. 6. Changes the average diameter of the river bed sediments in Vaz River

In Lavij River, in the area where sediments have been extracted, excessive mining has led to the fall of the river bed to a lower level. In order to prevent deterioration and erosion due to the lowering of the river bed, engineering techniques such as the construction of small drops and sills have been used. By doing so, river retreat has stopped temporarily. This has reduced the particle size to sand and clay, and sediment transport has also decreased to the downstream intervals. Beyond these small drops, the power of the river has also reduced due to the slope reduction, and fine grained sediments have deposited. This has led to a lack of continuity in the sediment flow. In Aleshrood River, the effects of sand and gravel mining on sediment concentration indicate that the amount of suspended load concentration in mining conditions and the intensity of mining have been greater than before. Other factors such as the types of the sections studied, the climatic conditions and slope, as well as the type of the tools used have affected the suspended load (Sadeghi et al., 2014). Gravel mining from this river has also affected the size of bed sediments. In Aleshrood River, the amounts of D10, D50 and D90 at the downstream of the mine has had an increase of relatively 10, 34 and 63 percent, compared to the upstream. Moreover, sphericity has also increased 24 percent compared to the upstream. Since the amount of changes in the values of the hydraulic and geometric variables in the upstream and downstream of the sand mining area has been very low, the values of the above variables are almost the same in the studied sections. As a result, the changes in the size analysis and morphological features of the bed sediments are due to gravel mining in this river (Sadeghi et al., 2014). Local deposition occurs in the inner arches of the bed bights of Talar River, at the contact between the lateral branches, on the upstream and downstream of the bridges, in the space between the adjacent groins, at the upstream of the deflected dams and other hydraulic installations. At the onset, sedimentation causes the stability of the river bed and banks, and, with the continuation of the sedimentation process, the bed level is increased and the river morphological changes are followed. The result is an elevation of the bed level, an expansion of the channel, and a flood threat for the marginal lands adjacent to the river.

3.2. Geomorphic Changes in River bed

According to the conducted research up to now and the comparison of the obtained data with the reference intervals, the findings show that the most important geomorphic effects of sediment mining from the river bed in the studied area are river bed falling, changes in the river slope, width, depth, power, and pattern, as well as decreased particle size. Table 2 shows the effects of sediment removal sand and gravel minning from the river beds in Mazandaran Province.

Table 2. effects of sand and gravel minning from the riverbeds in Mazandaran Province

River	Bed degradation	Slope change	Bank erosion	Planform change	Sediment resize	Increasing of suspended sediments	Environmental
Chashma kilah			*				*
Shiroud (Tirom)	*		*			*	*
Mashlak	*			*			
Kojor	*		*		*		
Lavij	*	*	*	*	*		*
Vaz	*	*	*		*	*	
Aleshrood					*	*	
Talar	*		*	*	*		*
Tajan	*		*	*			*

In this section, Lavij River is studied as the case. In the mining area, from B6 interval to B1 interval, the river width increases, while its depth, strength and slope as well as the size of the sedimentary particles decrease. The highest slope variations belong to the intervals B1 and B2. In these intervals, with decreasing the slope, the power of the river decreases. This decrease in the power of the river leads to the accumulation of sediment as longitudinal obstacles in the river channel and as a result of these conditions, in these intervals, the river pattern is arterial with sand and clay obstacles. In the mined area (downstream), excessive sediment mining has led to the fall of the river bed to a lower level. In order to prevent deterioration and erosion due to the lowering of the bed, engineering techniques such as the construction of small drops and sills have been used. The small drops have been constructed in A1 interval, with the height of 6.5 meters with three steps, and in 4A interval, with the height of 3.3 meters. Beyond these small drops, the power of the river is also reduced due to the reduction of the slope, and fine grained sediments are deposited (Fig. 7). This leads to a lack of continuity in the flow of sediment, and the water that flows from these small drops to the downstream is low-sediment and so-called hungry water. In the ending intervals, where the river channel is direct and the slope increases, to reduce the effect of the river, a sill is constructed. However, the presence of the hungry water and the increasing power of the river cause the destruction of a part of the upstream short drop, and its continuity can once again produce destructive effects (bed degradation and bank erosion) (Esmaili et al., 2012) (Fig. 8).

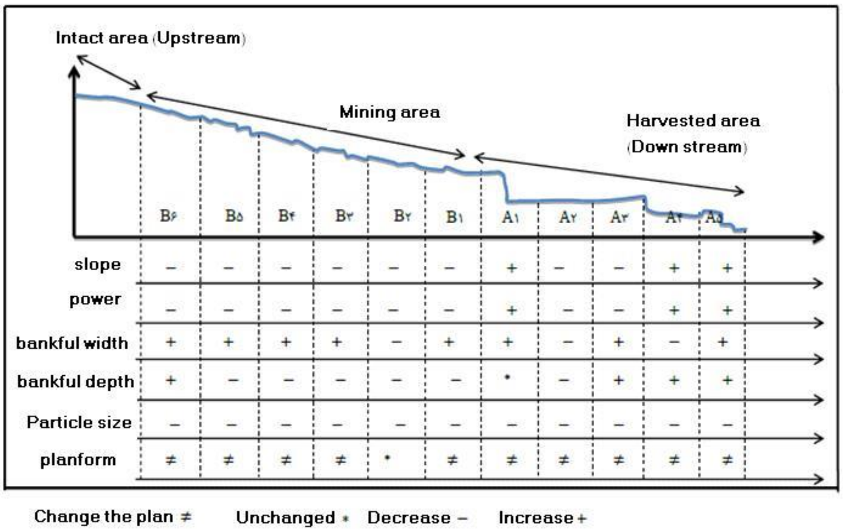

Fig. 7. Morphological changes in the river bed as a result of sediment mining in Lavij River

Fig. 8. Destruction of short drops constructed on the river bed to prevent degradation in Lavij River

4. Conclusion

In Mazandaran Province, there are more than 60 rivers in which there are more than 80 active gravel mines. These mines are run by governmental, cooperative and private sectors. Currently, the dependence of the construction and development activities of the province on these gravel resources has seriously threatened the river bed with excessive exploitation, so that these exploitations would be of the most destructive activities imposed on the aquatic ecosystems. The most important destructive effects of gravel mining from the rivers of the province are as follows:

1. Abnormal changes in river morphology and decrease of river natural capacity;
2. Erosion of river bed and river banks has led to changes in the hydraulic conditions of the flow and the occurrence of destructive floods and severe erosion.
3. Creation of waterfalls, pits and marshes, apart from the channel morphology, have led to environmental consequences on the rivers of the province.
4. Destruction of the existing structures in the rivers - including the destruction of the bridges, buildings, concrete structures and river bank walls.
5. Destruction of the natural vegetation and the change of the vegetation ecosystem of the river bank as well as providing the conditions for erosion.
6. Gravel mining has also led to the decreased water quality of the rivers in the province and threatened the life of the aquatics there.

The results also show that the unauthorized sediments removal from the river bed and the construction of engineering structures to control its geomorphic consequences only delay the performance of river processes and, consequently, delay the morphological adjustments. Therefore, the removal of the sediments from the river and the improvement of the river bed with engineering structures cannot control the processes and behavior of

the river in the long run. Therefore, in order to reduce the geomorphic and environmental impacts of sediment removal from the river bed, the following issues can be considered:
- Studying the river system at the interrelated level of basin and interval;
- Analyzing the process of river adjustment in the past and present as well as river behavior;
- Examining natural forms, such as waterfalls or artificial ones, such as dams which affect the sediment flux;
- Studying the sediment production areas in the basin and calculating the actual sediment transport in the desired intervals;
- Periodic monitoring of sediment mining from the bed and river management based on the results of this monitoring.

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