GIS applied to determine environmental impact indicators made by sand mining in a floodplain in southeastern Brazil

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Abstract Since the late 1940s sand mining has been developing in the Paraíba do Sul River, especially in its floodplain. Today, sand extraction exceeds 15 million tons per year causing the relevant environmental problems. To examine the evolution over a 35-year time span of these environmental impacts, land cover data from a 31-km² floodplain were compiled from large-scale vertical aerial photographs from 1962, 1986/1988, and 1997/1998. These data were analyzed using a geographical information system (GIS). A number of environmental impact indicators were identified and measured through the application of aerial photo/GIS methodology. These include (1) total mining areas, (2) former agricultural land converted into open pits, open water ponds and mining ancillary installations, (3) deforested areas, (4) channel river morphology modification, (5) vegetation growth in reclaimed areas, and (6) mining encroachment on the legally protected riverside zone. Most indicators show a great increase in impact magnitude over the period.

Keywords Aerial photographs · Environmental impact indicators · GIS · Sand mining

Introduction

Sand is an important aggregate largely used around the world for roads, highways, and building construction. In many areas, aggregates are derived primarily from alluvial deposits, either from pits in river floodplains or by in-channel mining. Because of the large volume of material extracted, aggregate mining in river systems causes a number of environmental changes. Generally, in-channel mining produces channel bed adjustments, whereas floodplain mining results in more pronounced changes in channel position, associated largely with cut-off and avulsions during floods (Mossa and Mclean 1997). In-stream mining can result in erosion of the channel bottom, which can propagate for several kilometers upstream and downstream; disturbance can go as far as to undermine bridge foundations and pipelines (Bull and Scott 1974; Kondolf 1994). It may affect groundwater levels too, in the sense that groundwater aquifers that discharge into a stream may be lowered because the deepened streambed acts as a drain (Sandecki 1989). The removal of gravel bed load alters the rifle-pool spacing and other attributes of the river channel, affecting biotic communities habitats, resulting both in invertebrates densities and fish biomass reductions, especially in areas downstream from the larger mines (Brown and others 1998). The increased amount of suspended solids also impacts biotic communities negatively.

Floodplain pit mining transforms riparian woodland or agricultural land into open pits, which typically intersect the water table at least seasonally. Sometimes, floodplain pits have captured the channel during floods, converting formerly off-channel mines to in-channel mines. In this case, the effects of in-stream mining can be expected (Kondolf 1997).

In Brazil, the Vale do Paraíba region is the most important sand production area, responsible for about 10% of national production – estimated at 150 million tons in 1996 (DNPM 1999). In this area, in-channel exploitation began commercially in 1949, when the sand miners “migrated” from São Paulo basin looking for new production areas. Three decades later, sand became rare in the channel, bringing mine activities to the floodplain’s meander belt. Today, 90% of sand extracted in the Vale do Paraíba comes from the floodplain.

Former studies have shown that in-stream mining has been promoting some environmental impacts such as river channel morphology modification (Sausen 1988) and turbidity increase (Bauermeister 1996). On the other hand, floodplain mining generates a number of contaminated open water pounds, where water shows an increment of...
turbidity and metal concentrations, which affect the biotic community to reduce biomass (Lemos and others 1997; Lemos 1999). The present study aims at making a historical analysis of environmental transformations induced by sand mining on a part of the Paraíba do Sul River floodplain, quantifying temporal changes in land use and in the landscape. This was achieved by comparing land-use data from aerial photographs of 1962, 1986/1988, and 1997/1998, analyzed into the “Idrisi” geographical information system (GIS), produced by Clark University, USA. Indicators selected to represent these environmental changes were: (1) total mining areas, (2) former agricultural land converted into open pits, open-water ponds, and mining ancillary installations, (3) deforested areas, (4) channel river morphology modification, (5) vegetation growth in reclaimed areas, and (6) mining encroachment on legally protected riverside zones.

Study area

The Paraíba do Sul River, in southeastern São Paulo State, is a meandered river that drains one of the economically most important Brazilian regions, situated between São Paulo and Rio de Janeiro. The area targeted in this study is a part of the Paraíba do Sul River floodplain (Fig. 1) stretching from 23°12’30”S to 23°19’00”S, and 45°56’00”W to 46°01’00”W, located inside Jacareí municipality, about 80 km eastward of São Paulo city. The site is part of the Taubaté Sedimentary Basin, composed of sedimentary clastic rocks deposited in the Tertiary period, predominantly in the fluvial system (Hasui and Ponçano 1978; Ricomini 1989; Campanha 1994). Unconsolidated clastic Quaternary sediments occur in the floodplain, represented by gravel, sand, silt, clay, and occasionally peat, disposed in a typical fining upward sequence that is very well defined into the riverside meandered belt (Instituto Geológico 1997). The tropical climate of the area has a mean annual precipitation of about 1,200 mm, and the average temperature is 20 °C. The Paraíbuna-Paraitinga dam, built in 1974, has since prevented the occurrence of floods in the river basin. The total study area is 3,100 ha.

Methods

Aerial photos have been used for mapping purposes since the early twentieth century. The principles of their application went through strong developments between the two world wars (Ricci and Petri 1965). Today, historical aerial photographs are used, especially in integration with a GIS, in a number of environmental studies based on digital mosaic or traditional photo-interpretation, involving