(Proceedings of the Workshop held at Hyderabad, India, September 2009). IAHS Publ. 349, 2011.

An overview of sediment problems and management in Iran

SEYED HAMIDREZA SADEGHI

Department of Watershed Management Engineering, College of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor 46417-76489, Mazandaran, Iran

sadeghi@modares.ac.ir

Abstract As a developing country, Iran currently faces many sediment-related problems. The high potential sensitivity of much of the country to erosion, inappropriate and unnecessary infrastructure development, land-use change, and unlawful exploitation of resources all contribute to increased soil erosion and sediment mobilisation and associated increased sediment fluxes. However, lack of recognition of the long-term value of soil, the limited numbers of hydrometric stations, the short duration of most records, unreliable and inconsistent data and information, lack of understanding of sediment yield processes and the apathy of both the population in general and experts in the field, serve to mask the severity and intensity of the problem. This contribution attempts to identify and describe the existing sediment problems in the country and presents a number of examples of major changes in sediment fluxes due to natural and human-induced controls. In the present paper an attempt is firstly made to identify and describe the existing problems in the country. Appropriate solutions aimed at combating or minimising the problems and developing effective sediment management strategies are proposed.

Keywords soil erosion; land degradation; sediment management; sediment problems; Iran

INTRODUCTION

Soil erosion represents the result of many complex interactions between the living and non-living elements of a watershed system. The magnitude of the sediment yield from a watershed therefore reflects the degree of balance or imbalance in the system and provides a useful index of land degradation, soil erosion severity, and trends in the operation of these processes. There are numerous factors that control the severity of erosion and many of these are driven or accelerated by human activity. In many areas, land degradation is increasing or accelerating and this is frequently the case in less-developed countries. Such nations frequently suffer from soil erosion and related processes. In some cases, land degradation is considered a precursor to, and the trigger for, natural disasters (Hudson & Alcantara-Ayala, 2006). The existing imbalance in most natural ecosystems encourages scientists to compromise between human demands and the production potential of the land by developing a better understanding of the governing mechanisms and processes (Sadeghi *et al*., 2008).

Studying suspended sediment yields, as representing one of the most important exports from a watershed, must be seen as a key tool in managing soil and water resources. Sediment problems are causing increasingly adverse effects in developing countries, where high levels of demands are frequently linked to limited capability of the land resources. The existing imbalanced conditions affect both living and inactive components of the system and can lead to further instability in the ecosystem. In Iran, no universal country-wide solution and strategy has been developed to manage sediment-related problems. Many watershed management activities are implemented in a limited way throughout the country and their effectiveness remains to be accurately and scientifically assessed.

It is therefore necessary to accurately monitor the behaviour of the fluvial system on a long-term and continuous basis, in order to collect the key data required to develop effective and sustainable watershed management strategies. Sediment transport by a stream reflects control by many factors including climate, vegetation cover, and soil type (Lai & Detphachanh, 2006) and needs to be continuously monitored to provide a sound basis for watershed management. However, sound management cannot be achieved without proper understanding of the governing system. In other words, integrated river basin management aims to coordinate the various

functions of a river basin in order to protect the safety of the people and support economically productive, socially equitable, and environmentally sustainable watershed management. Understanding and controlling soil erosion represents a top priority (Ghazanfari *et al.*, 2003; Singh, 2003). At the present time, increases in watershed sediment yields resulting from human activity are a major concern in Iran, as in many other developing countries (Sadeghi & Saeidi, 2009; Sadeghi *et al.*, 2009).

Iran, as an actively developing country that covers 1 645 000 km^2, currently faces many sediment-related problems. Since the 1960s, reservoir sedimentation has been recognised by water engineers and watershed managers as a serious problem. Since that time, many attempts have been made to develop a comprehensive assessment of the magnitude of sediment loads and yields within the country. The resultant estimates, many of which are of questionable reliability, range from 0.8 to 8 billion tonnes per year and provide associated estimates of average rates of sediment yield 700 to 7000 t km^{-2} year^{-1}. This information has been used in the design of much short-term infrastructure and for mid- and long-term project planning. Accurate estimates of sediment yield and its temporal variation are needed for various purposes, including the design of impoundments and erosion control structures, predicting changes in river morphology and evaluating the effects of land-use change and land management practices (Kothyari *et al.*, 1997; Lana-Renault *et al.*, 2007).

This contribution aims to describe the key sediment problems existing in Iran, to identify the key factors causing and influencing these problems and to suggest several approaches for mitigating and preventing further increases in these problems.

SEDIMENT ASSOCIATED ISSUES IN IRAN

Most of the problems associated with river sediment loads in Iran are similar to those reported from other areas of the world, although some may be more specific to the conditions in Iran. According to official statistics provided by the Iran Ministry of Energy (http://daminfo.wrm.ir/tabularview-fa.html), there are 281 functioning dams in Iran, though some 700 other small and large dams are also under construction or being planned. Existing bathymetric surveys of 27 large dams with a combined watershed area of some 270 000 km^2 and a total volume of 24.2 billion m^3, indicate that almost 132.7 Mm^3 (~172.5 Mt) of sediment are trapped in the reservoirs behind these dams annually. This represents a specific sediment yield of 628 t km^{-2} year^{-1} and an annual volume reduction of 0.54%. The increasing damage from natural hazards represents a major constraint on the expansion of capital investment in the country (Blagovechshenskiy *et al.*, 2004). High sediment yields are not only responsible for serious reductions in the life time of reservoirs, but also result in the deposition of some 400 Mm^3 of sediment in the rivers downstream of reservoirs and in irrigation networks, resulting in a loss of irrigated land and a reduction of irrigation and power generation capacity (e.g. Sharifi & Ghafouri, 2007). Examples of these types of problem are presented in Fig. 1.

Fig. 1 Some examples of sediment associated problems in Iran.

In addition to the physical problems highlighted above, the high rates of soil erosion and sediment yield in Iran have also caused many ecological problems resulting in declining biodiversity, the ascendency of undesired species, low productivity and reduced sustainability. Based on available statistics (http://www.irandoe.org/en/), Iran is home to some 8000 plants (22% of which are endemic), 164 wild mammals (equal to the number for the whole of Europe), 502 birds, 174 fish, 196 reptiles and 20 amphibious species, and many of these are affected by human activities which cause ecosystem imbalance. Accelerated soil erosion and increased sediment yields are closely linked to such ecosystem imbalance.

Soil erosion and sediment problems in Iran have an important economic and social dimension. Direct economic losses associated with flooding and associated sedimentation have greatly increased year by year during the last century and in total now exceed some 3.7 billion US$ (Sharifi & Ghafouri, 2007). Almost 745 people were killed and economic losses of more than 212 million US$ were caused by 21 major flood events that occurred during the last 8 years in Iran (http://www.emdat.be/Database/). Many villages and areas of agricultural land have been abandoned as a result of low agricultural productivity and reduced incomes associated with accelerated erosion and floods. These changes can result in increased pressures on other parts of the country and result in further degradation and related problems. In many instances people moved to existing areas of intensive activity and increased vulnerability, causing further problems.

Dust storms have recently occurred over Iran and these can be seen as another sediment-related problem linked to frequent floods and sedimentation over extensive areas and droughts, either in Iran or adjacent countries.

Off-site sedimentation problems have also affected the behaviour of the downstream reaches of river systems and in some cases have resulted in serious limitations to navigation, fish mobility and other living organisms. For example, heavy siltation from increased erosion in upstream areas can result in the shrinking and shallowing of lakes and lagoons, increased pollution of the source waters and eutrophication due to increased nutrient inputs, contributing to the decline and destruction of fisheries. The increased growth of aquatic macrophytes, primarily the non-native water-fern, *Azolla filiculoides*, can cause further increases in eutrophication and reduction of dissolved oxygen levels to levels below those required for fish survival.

CONTROLLING FACTORS

To understand the role of both human-induced and natural soil erosion and sediment transport in the effective management of ecosystems, comprehensive studies are required to recognize and possibly prioritize the key controls on the sediment status of a watershed. In the following section, the controls on soil erosion and sediment yield, and constraints on their effective management in Iran are considered.

Diverse natural conditions

Iran is one of the most environmentally diverse countries in the world, as a result of the wide range of climatic, topographic, pedological and geological conditions within the country, which in turn give rise to diverse human responses. This diversity must be seen as a key reason why it is not possible to develop a standard approach to management and regulation to support national resource management. The requirement for more local and specific planning increases the requirements for time and money, and even technical knowledge, and this hampers the implementation of management plans and supporting studies, sometimes making them unfeasible.

High landscape sensitivity

In addition to the diversity of environmental conditions and human responses, the landscape of Iran is highly sensitive to the controlling factors. Intense short-lived storms, irregular and unevenly distributed precipitation, highly erodible soils and geological formations, sparse vegetation, steep

topography and shallow and frequently immature soils combine to make the landscape particularly sensitive to soil erosion and increased sediment yields (Fig. 2).

Inappropriate and unnecessary infrastructure development

Despite the valuable experience provided by many developed countries regarding the potential adverse effects of infrastructure development on ecosystem balance (UNESCO, 2009), many developing countries derive pride in implementing and constructing huge projects and structures, which may not be necessary. Currently, many areas of valuable forest stands and productive rangeland in Iran are being destroyed by road construction, which cannot be readily justified. Many additional large dams are also under construction to store flood waters. These involve major investment and cost to deal with problems which could potentially be controlled *in situ* by improved catchment management at a relatively low cost and in a sustainable manner.

Land-use change and unlawful exploitation of resources

Human exploitation of natural resources is frequently responsible for dramatic changes in ecological systems. The land disturbance produced by the human activity may involve very different levels of impact on ecosystem balance, which may largely reflect the level of technology used. Agriculture, grazing, deforestation, changing the hydrological regime with dams, aqueducts and irrigation schemes, and planting cultivated trees and rotational crops can change the structure and function of the system for a long period of time, even if the land-use activities cease

Fig. 2 Erodible soils and geological formation, sparse vegetation cover, steep topography and shallow soils in Iran.

Fig. 3 Unlawful over-exploitation of natural resources in Iran.

(Bissonette & Storch, 2003). Heavy machinery, untimely and inappropriate harvesting activities, lack of rehabilitation plans, excessive and unseasonal grazing, intensive and improper river mining, over-emphasizing the apparent benefits of development and the lack of rigorous control policies can all be invoked as possible causes of ever-increasing sediment fluxes in Iranian watersheds. Several examples of unlawful over-exploitation of natural resources in Iran are depicted in Fig. 3.

Technical factors

A lack of recognition of the value of soil as a resource, the limited number of hydrometric stations, the limited length of most records, unreliable and inconsistent data and information, lack of understanding of sediment yield processes and the apathy of both people and experts, have served to mask the intensity and severity of soil erosion and associated increased sediment yields in Iran, despite the efforts of some who recognise the need for action. Furthermore, many basic concepts (e.g. throughfall, throughflow, stemflow, interception, root structure, landscape metrics) and their relationships with processes of sediment mobilisation and transfer are not well understood by those in executive positions and even by researchers, in Iran, as in many other countries across the world (Sadeghi *et al.*, 2008). In addition, no regular monitoring and evaluation is undertaken for projects aimed at controlling soil erosion and sediment yield, as well as watershed management measures, since most of the projects are not problem oriented and the necessary equipment and technical expertise to implement such monitoring and evaluation are frequently unavailable.

SOLUTIONS

Although, as indicated above, Iran suffers from many problems linked to accelerated soil erosion and increasing sediment yields, there is currently no practically-oriented national strategy aimed at comprehensive management and control of sediment-related problems. Although watershed management programmes have been implemented in several areas of the country, their effectiveness remains to be accurately and scientifically assessed. Available practical solutions for minimizing sediment-related problems in Iran are summarized below. Although some approaches must be seen as providing an essential foundation for others, each can be considered separately.

Understanding the system

It is very important to develop and disseminate good technical and non-technical knowledge and understanding of soil erosion processes. In this context, the role and impact of both natural and man-made controls on the intensity of erosion and sediment transport must be understood. Specialists working in the field must be well informed. There is a need for integration of available understanding and knowledge with site specific data and information. The available knowledge and information must be synthesised by specialists and the key elements conveyed to other specialists, planners, politicians and decision makers in a manner which is convincing in terms of directing support and investment to both erosion and sediment yield investigations and the development of management and control strategies. Demands on the environment must be kinked to its natural potential and capability, in order to limit accelerated erosion and land degradation.

Limiting unnecessary infrastructures development

As explained above, developments requiring the construction of large or extensive infrastructure frequently result in unwelcome environmental impacts and should therefore in many cases be avoided. The use of smaller low-cost local measures may prove more effective, durable and sustainable and produce more long-term benefits in controlling sediment yields. In this context, greater emphasis on biological and bioengineering measures may prove particularly beneficial. Thus, for example, the application of local torrent control measures in upstream areas is generally preferable to the construction of a large dam in the middle or lower reaches of a river basin. Other

demands, such as those for energy generation and support for agricultural production, which are also frequently met by dams, can be met by alternative sources of energy, such as biogas, wind and solar power, and by restructuring and reforming agricultural systems. Where dam construction proves unavoidable, it is important that sediment control and watershed management projects should be planned before the dam is constructed and ideally progressed in parallel with dam construction.

Control of resource exploitation and land use change

The exploitation of natural resources in Iran, and particularly the soil resource, must be limited to tolerable levels of erosion and aim for long-term sustainability, even though this may require some demand to be met by imports or use of alternatives or substitutes. Currently, many forest and rangeland areas are being over-exploited to meet demands for raw materials from pulp and paper factories and to support the unnecessary overproduction of meat protein Some of the overexploitation is instigated by the government to meet national needs, but other unlawful exploitation of resources and even land-use change have been promoted by the private sector in the absence of effective controls and associated penalties. In recent years, some attempts have been made to control resource utilisation by the Forest, Rangeland and Watershed Management Organization and the Ministry of Energy of Iran, but such measures are frequently opposed by other government bodies or they are not properly developed and implemented. The sustainable utilization of resources must be seen as a key aim and should always take precedence over short-term benefits, if sediment problems in Iran are to be controlled.

Monitoring and evaluation strategies

It is important that appropriate monitoring stations and equipment should be installed to support project planning and to ensure the effective control of projects. Currently there are some 450 functioning hydrometric stations, mostly located in western and northern Iran. However, most of these stations are used for monitoring water discharge and less attention is given to documenting sediment loads. Sediment measurements are often undertaken irregularly and then during stable flow conditions, which are unrepresentative of the main periods of sediment transport. There is a need to develop simple methods for providing a preliminary assessment of the nature and magnitude of any potential sediment problems. Furthermore, projects should be problem oriented to ensure that planners and decision makers are able to undertake a meaningful assessment of the level of success in controlling specific problems. Such assessments can provide a basis for ongoing justification and adjustment of both current projects and those planned for the future.

CONCLUSION

In this contribution an attempt was made to firstly describe and explain the main sediment problems that exist in Iran. Several examples of major changes in sediment flux due to both natural and human-induced factors were then presented. Attention was then directed to solutions to the problems, taking account of both the natural and social conditions and other existing constraints. Better understanding of the sediment yield process, improving monitoring and measuring systems, developing geo databases, establishing legislation to control land use and land management and passing the laws needed to prevent unlawful exploitation of the nation's natural resources are seen as key requirements for developing appropriate short, medium and long-term strategies to control soil erosion and related sediment problems in Iran.

REFERENCES

Blagovechshenskiy, V. P., Gulyaeva, T. S. & Kokarev, A. L. (2004) Natural hazards estimation and mapping in the Dzunger Alatau range (Kazakhstan), In: *10th Congress Interpraevent 2004 Proceedings* (24–28 May, Italy), **I**, 27–36.

Bissonette, J. A. & Storch, I. (2003) *Landscape Ecology and Resource Management*, first edn. Island Press, USA.

Ghazanfari, H., Namiranian, M., Sobhani, H. & Mohadjeri, R. (2003) Traditional forest management and its application to encourage public participation for sustainable management of forest resources in northern Zagros (Kurdistan-Iran), In: *The international IUFRO Workshop: The Forest Science/Policy Interface in Europe, Africa and the Middle East* (abstract proceedings), 23–27 June, 2003, Copenhagen, Denmark, www.flec.kvl.dk/scipol/Abstracts.pdf.

Hudson, P. F. & Alcantara-Ayala, I. (2006) Ancient and modern perspectives on land degradation. *Catena* **65**, 102–106.

Kothyari, U. C., Tiwari, A. K. & Singh, R. (1997) Estimation of temporal variation of sediment yield from small catchments through the kinematic method. *J. Hydrol.* **203**, 39–57.

Lai, F.S. & Detphachanh, S. (2006) Sediment production during an unusually dry year in the steep forested Sungai Pangsun catchment, Selangor, Peninsular Malaysia. *Forest Ecol. Manage*. **224**, 157–165.

Lana-Renault, N., Regüés, D., Martí-Bono, C., Beguería, S., Latron, J., Nadal, E., Serrano, P. & García-Ruiz, J. M. (2007) Temporal variability in the relationships between precipitation, discharge and suspended sediment concentration in a small Mediterranean mountain catchment. *Nordic Hydrol.* **38**(2), 139–150.

Sadeghi, S. H. R., Mizuyama, T., Miyata, S., Gomi, T., Kosugi, K., Fukushima, T., Mizugaki, S. & Onda, Y. (2008) Determinant factors of sediment graphs and rating loops in a reforested watershed. *J. Hydrol.* **356**, 271–282.

Sadeghi, S. H. R. & Saeidi, P. (2009) Accuracy of decentation technique for estimation of different suspended sediment concentrations. In: *International Conference on Land Conservation-LANDCON0905* (abstract proceedings). Serbia, Tara Mountain Park, 26–30 May, 2009, 118 (Full paper published in CD, 4p).

Sadeghi, S. H. R., Saeidi, P., Noor, H. & Raeisi, M. B. (2009) Understanding sediment yield processes in a Hyrcanian Forest Watershed. In: *International Conference on Land Conservation-LANDCON0905* (abstract proceedings). Serbia, Tara Mountain Park, 26–30 May, 2009, 119 (Full paper published in CD, 4p).

Sharifi, I. F. & Ghafouri, M. (2007) Assessment of causes and effects of disastrous erosion and sediment flows and mitigation measures in Caspian Sea Watersheds-Iran. In: *Proceedings of Expert Meeting on Erosion and Sedimentation in Arid and Semi-Arid Regions* (Chaloos, Iran, 15–19 April 2007), 1–17(Full paper on CD).

Singh, R. V. (2003) *Watershed Planning and Management*. Yash Publishing House, India.

UNESCO (2009) *Integrated Water Resources Management Guidelines at River Basin Level*, Part 1, 24p.