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Policy Options for Sustainable River Sand Mining in Sri Lanka

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Illegal and indiscriminate river sand mining is causing a large number of environmental and social problems in Sri Lanka. To find solutions to these significant challenges, a new EEPSEA study has identified policy options for sustainable river sand mining that minimize environmental degradation while meeting the requirements of industry and local people.

The study is the work of L.H.P. Gunaratne from the University of Peradeniya, Sri Lanka. It finds that a number of site-specific management alternatives can reduce the negative impacts of river sand mining. These are: the restriction of mining at vulnerable sites, the establishment of an environmental trust fund to pay for environmental restoration and involving the community in managing this resource. It also finds that using offshore sand is the best way to decrease the environmental pressure on rivers. It outlines various policies to make this happen, including making the use of offshore sand compulsory for large construction projects.

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EXECUTIVE SUMMARY

Indiscriminate river sand mining, due to the recent boom in the construction industry in Sri Lanka, has created a number of environmental and social problems. Within this context, this study attempts to identify policy options for sustainable river sand mining that minimize environmental degradation while meeting the requirements of the construction industry and local people. The study followed four separate analyses: comparison of annual costs and the benefits of selected mining sites, analysis of miners' views and preferences using choice modeling, evaluation of expert opinion using multi-criteria analysis, and a comparison of alternative sources of river sand.

The comparison of the costs and benefits of sample mining sites revealed that the social cost of river sand mining exceeds the private costs; however, the fact that social benefits were still found to be non-negative at the study sites may be due to the under-reporting of environmental effects and the exclusion of off-site costs. It was observed that although the increased costs of restoration and other costs of over-mining are borne by government institutions, government income has remained at a very low level. The results of the discrete choice experiment with the miners indicated that they believe the negative effects of sand mining can be partly mitigated by increasing government revenue towards an environmental trust fund (ETF) with some level of co-management. Strict rules, regulations and awareness programs, as suggested by the media and environment groups, were not found to be productive. Alternative policies for sustainable sand mining in three major rivers were ecologically, economically, socially and technically evaluated using multi-criteria analysis. The restriction of mining at vulnerable sites was found to be the best management alternative followed by the establishment of an ETF for the Ma Oya River, where there are more than 70 mining sites. Community-based management was found to be the best option for the Mahaweli and Deduru Oya rivers.

Using off-shore sand was found to be the best way to decrease pressure on rivers for sand. However, at present, the price of off-shore sand is slightly higher than that of river sand and it is less popular because there is the possibility that shells and chlorides are present in it. Prices could be brought down further by expanding off-shore sand mining operations because off-shore dredging is sensitive to economy of scale. This could be achieved by mandating the compulsory use of off-shore sand for large construction projects and landfilling, especially in Western Province.

1.0 INTRODUCTION

Sri Lanka is an island with a land area of 65,525 square kilometers, endowed with 103 distinct rivers and streams and 94 coastal basins. Most of these rivers originate in the central highlands and travel to all corners of the country. Except for the longest river, the Mahaweli, which stretches for 335 km, all of the other rivers are less than 160 km in length. These rivers have always been an integral part of life for the people of Sri Lanka as the location of various resources, including water, and as a means of development for cities and villages throughout the country's 25 centuries of agricultural civilization.

River sand is an essential raw material in the construction industry and mining furnishes the rural population with work as miners, transporters and vendors. Sand is a resource that can be freely accessed and mining activities have expanded dramatically – in some river basins by 2.5 times more than the number of original sites[1]. As reported by Ingall (2006), this expansion is related to the boom in the construction industry that followed the Asian Tsunami of 2004. The tsunami changed the appearance of rivers and gave rise to a substantial number of environmental problems.

Indiscriminate river sand mining has resulted in a large number of environmental and social problems in Sri Lanka. Environmental problems include on-site effects such as the erosion of riverbanks, lowering of water tables, intrusion of salt water, damage to riverine vegetation, loss of habitat of the aquatic population, increase in mosquito-related health problems, and damage to bridges and structures. Off-site effects include the impairment of rural roads and increased coastal erosion. These environmental issues have affected most of the rivers and streams of Sri Lanka.

Unregulated and unmonitored sand mining has taken place without a clear regulatory framework and this has aggravated environmental problems. In addition, sand prices have increased several times over thanks to a ban imposed on traditional sources of supply. Elevated sand prices have driven the exploitation of sand from fragile and remote places, causing more damage to the road infrastructure due to heavy loads carried on weak rural roads. This situation has been further complicated by politics. No tangible benefit can be derived from current institutional activities unless there is a mechanism that meets both demand for sand and the need for conservation goals. In addition, the needs of the rural poor, who benefit from river sand mining, need to be considered.

This issue poses a number of policy questions that are worth investigating. The strategies adopted so far have not been based on sound economic analysis and so have led to policy failures. Moreover, ad hoc and inconsistent policies have contributed to a short supply of sand, further degradation of the environment, and increased social upheaval. Therefore, there is an urgent need to identify appropriate policy guidelines that guarantee environmental protection with minimum regulatory costs and high levels of public cooperation.

[1] Appendix 1 provides a list of rivers that have been subjected to heavy mining, i.e. rivers with more than 25 mining locations along them.

2.0 RESEARCH OBJECTIVES

2.1 General Objective

The main objective of this study is to identify appropriate policy options that minimize environmental degradation from river sand mining while meeting the requirements of stakeholders, including the construction industry and local people who depend on sand mining.

2.2 Specific Objectives

The specific objectives are to:

a) Present an overview of the present situation related to river sand mining, including the general causes of environmental degradation and the institutional and policy set-up.

b) Compare the private profitability and the social cost of river sand mining.

c) Analyze the preferences and trade-offs of various options for miners.

d) Evaluate the policy alternatives under social, economic, ecological and technical criteria, based on stakeholder views.

e) Assess suitable alternatives for river sand mining that reduce the pressures on rivers whilst also sustaining the construction industry.

3.0 OVERVIEW OF THE STATUS OF THE INSTITUTIONAL SET-UP OF SAND MINING AND THE SAND MARKET

3.1 Present Status

The key impact of excessive river sand mining in Sri Lanka falls on the environment because sand mining alters natural ecosystems. Identified major negative environmental impacts include: the lowering of riverbeds, the reduction in capacity of water intake, water pollution, saline water intrusion, riverbank and coastal erosion, soil quality deterioration, environmental changes, damage to riparian vegetation and in-stream habitat and biota. Other detrimental impacts of sand mining are: the alteration of flow patterns due to the modification of riverbeds, overloading of suspended sediment, damage to the channel beds due to the use of heavy equipment, permanent flooding conditions or the presence of pooled water, disturbance of the natural hydrology of the riparian zone because of infrequent elevated flow levels, the exclusion of large woody debris from the riparian zone, and reduced vegetative bank cover.

Kamaladasa (2008) reported that the amount of sand being extracted from the main rivers along the west coast of Sri Lanka is far in excess of the supply of sand from the upper parts of the catchment, causing the lowering of riverbed levels – in some cases the riverbeds have been lowered by up to 7 meters. Kamaladasa described further consequences of the lowering of riverbed levels as salt water penetrates inland, affecting the drinking and agricultural water supply and lowering the water table near rivers, which in turn lowers water levels in wells. The drying up of irrigation channels has reduced the flooding of paddy fields with nutrient-laden water and increased the unsteadiness of the banks of rivers.

Environmental problems related to sand mining are reported from most parts of Sri Lanka. The problem is more severe in the districts of Kurunegala and Puttlam in North-Western Province, as revealed in reports from various NGO environment groups such as *Lanka Jalani*, the Japan Water Forum, Associated Development Research Consultants, the NGO forum of the ADB, the Network of Women Water Professionals in Sri Lanka, and the *Navoda* Farmers' Organization.

Of these environmental problems, salt-water intrusion appears to have the most detrimental effect. A survey conducted by the Department of Geology of the University of Jayawardenepura on the Deduru Oya river basin found that sand mining had caused large-scale salination and the drying up of water resources. Some media reports indicate that in one particular area of the Deduru Oya River, illegal sand mining has created environmental, health and social problems in the surrounding villages as over 1,000 cubic meters of sand are mined daily. The large-scale removal of sand from dunes in the Kalpitiya Peninsula and the sea belt from Udappuwa to Palavi in the Puttalam District of the North-Western Province has caused serious damage to the natural ecosystem as well as to the livelihood of the villagers, who mainly depend on agriculture. Phase one of the National Sand Study (NEI 1992) estimated the loss of land due to collapsing riverbanks to be about 12 ha per year in the three main rivers of Western Province.

Coastlines are enriched by river sand entering the sea and inland sand mining has hindered sediment flow, leading to coastal erosion. A study by Nanayakkara (1999) clearly identified the relationship between too much sand mining in the Ma Oya River and coastal erosion north of the Ma Oya river mouth. This study estimated that coastal erosion caused by the reduced sand supply from the Ma Oya, Kelani and Kalu rivers was equivalent to an average land loss of about 5 to 6 ha per year.

Other losses caused by present sand mining practices include: loss or damage to houses, churches, graveyards and archaeological sites, loss of livelihood for coastal fishermen and changes to natural estuarine vegetation. The three main rivers near Colombo, specifically the Kalu River, the Kelani River and the Ma Oya have been particuarly exploited. The effects on the coast north of the Deduru Oya River are only just beginning to be felt. However there will be serious erosion in the areas north of Chilaw.

River sand mining also has some positive impacts. The main benefit of river sand mining is the work it offers to sections of the community that have few other options. Rural people who live below the poverty line are relatively well paid for involvement in sand mining during certain months of the year.

3.2 Institutional Set-up

Sand is the property of the state and a permit is required to mine and transport it (Mines and Minerals Act No. 33 (1992) of Sri Lanka). Artisanal sand mining was the norm until the introduction of the current Mines and Minerals Act (which replaced the former Mines and Minerals Law No. 4 of 1973) established the Geological Survey and Mines Bureau (GSMB), which regulates the exploration for and mining of minerals, including sand. The GSMB is responsible for identifying the locations and quantities of sand deposits. Expressions of interest for mining tenders are issued by the Divisional Secretary because the custodian of rivers and state land is the government. Including the Mines and Minerals Act No. 33 of 1992, the National Environmental Act of 1980, the Coast Conservation Act of 1981 and other relevant legislation, regulations and policy statements reflect Sri Lanka's constitutional, international and national obligations. These policies support other national policies such as the National Environmental Policy, which was adopted by the cabinet of Sri Lanka on 15 May 2003. The Ministry of Environment and Natural Resource Management prepared a draft policy on sand as a resource for the construction industry and opened this up for public comment (http:www.elaw.org/resources/text.asp?id=2793) (this document is now closed to public comment).

3.3 Demand for Sand

Sand is used for building construction, road surfacing and landfilling around bedding pipes and telecommunication lines. According to Road Development Authority (RDA) specifications (HSR 2000), the total amount of sand needed to surface-seal main roads once every two years across the whole country is estimated to be 0.5 million m^3 per year. This is a relatively small amount of sand in terms of total national usage. An insignificant amount of river sand is used by by Sri Lanka Telecom as bedding material for laying telecommunication lines and by the National Water Supply and Drainage Board for bedding in pipelines. Therefore, the construction industry remains the main consumer of river sand, accounting for more than 95% of demand.

However, the total national demand for sand is difficult to estimate directly for the following reasons: the GSMB does not have a complete database as it only formalized the issuing of licenses for river sand mining quite recently; illegal sand mining takes place in most parts of the island and is not recorded; sand is used in the preparation of block bricks, plastering and rendering, but there is no information available on the quantities of sand used for these activities; and according to the Mines and Minerals Act, sole authority for issuing mining licenses is vested with the GSMB but discussions with various key informants revealed that the practice is somewhat irregular, and in some situations other government agencies have issued licenses.

Studies (Katupotha 1998; Dias et al. 1999) that have attempted to estimate sand demand have been found to be incomplete, as these have covered only a part of the country or a section of the construction industry. However, based on cement usage, a reasonable estimate of sand requirement can be obtained. Based on engineering computations (i.e. cement consumption and the ratio of cement to sand for various construction purposes) sand demand for 2007 was estimated to be 17.37×10^6 m^3. The GSMB currently keeps records of all the licenses issued for sand mining and transportation, and according to these records the approximate annual sand supply is 7.99×10^6 m^3, which is far below the estimated demand. The difference may exist due to a several factors. One such factor is that sand usage in relation to the number sand mining licenses issued was not accounted for in the northern and eastern provinces as data was not available for these areas (except for the Kantale area in Trincomale District). Another reason is that when estimating sand usage by looking at cement consumption, a considerable amount of sand is already included instead of bricks, cement blocks are mostly used for construction. The other is that there may be some over-estimation of sand consumption when taking the overall cement to sand ratio into account. Despite all of these factors, the gap between licensed sand mining and the estimated need for sand is quite high, indicating the use of an unofficial supply of sand, i.e. illegal sand mining.

Table 1. Projected sand demand (2007-2011) – X 10^6 m^3 per year

Province	2007	2008	2009	2010	2011
Western	4.62	4.45	4.58	4.72	4.87
Central	1.33	1.39	1.46	1.53	1.60
Southern	1.66	1.83	2.05	2.31	2.42
Northern	0.22	0.23	0.24	0.25	0.26
Eastern	0.46	0.51	0.56	0.61	0.68
North Western	1.15	1.29	1.45	1.63	1.83
North Central	0.77	0.81	0.85	0.89	0.93
Uva	0.33	0.35	0.38	0.41	0.44
Sabaragamuwa	0.77	0.83	0.89	0.95	1.02
Total	**11.01**	**11.69**	**12.46**	**13.30**	**14.05**

Source: Reports of the Geological Survey and Mines Bureau, Sri Lanka

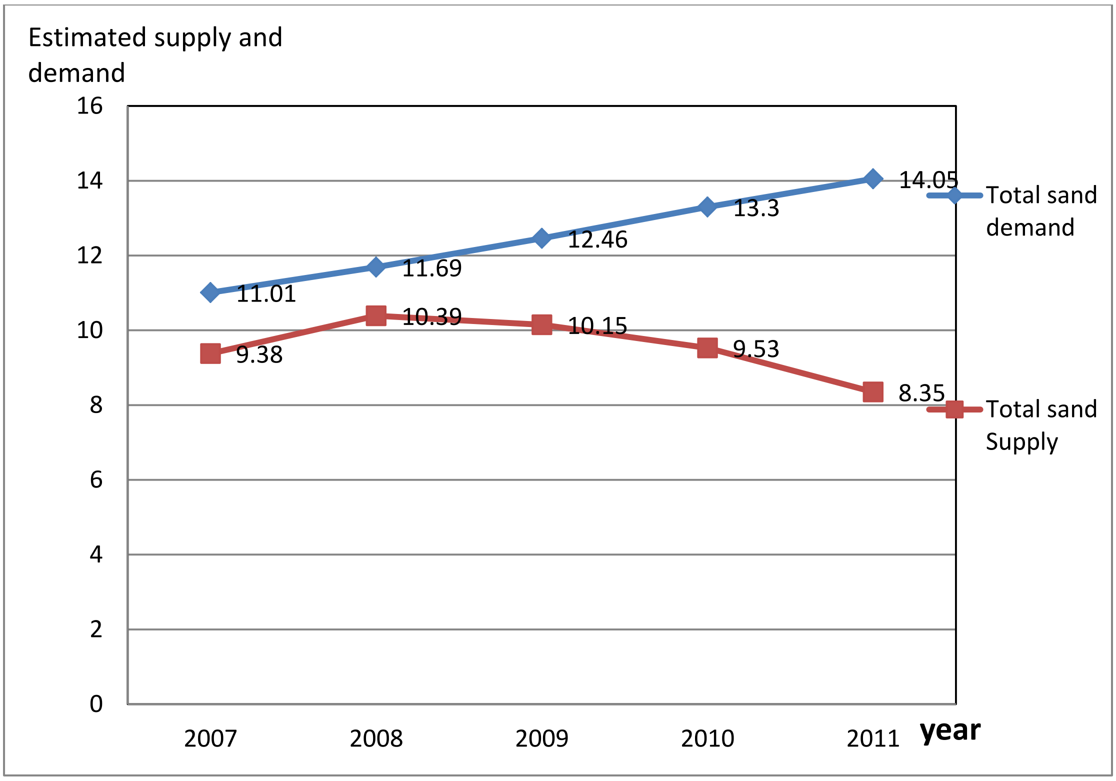

Figure 1. Supply and demand for river sand, 2007-2011 (values are m^3 10^6 per year)
Data source: Reports of the GSMB

The current total deficit in Sri Lanka between the sand needed and the supply of sand from licensed sources is approximately 6 x 10^6 m^3. A reasonable fraction of this is met by illegal means, leading to intensified environmental problems. Moreover, this shortage has pushed up sand prices more than four-fold during the last decade, exerting pressure on vulnerable and remote sites. Western Province, which accounts for 50% of Sri Lanka's GDP, consumes 40% of total sand demand, mainly due to construction and industrial development. It is estimated that sand demand will grow at 10% per annum in addition to special requirements for development projects such as Weeravila airport, Hambantota harbour, and the Moragahakanda reservoir project and expressway projects. Reliable sources indicate that significant malpractice takes place and the illegal sand used amounts to a third of the total supply.

The economic feasibility of other sources of sand is masked by the low price of river sand which includes only the direct costs such as license fees, wages, equipment and transport. Environmental costs as well as other social costs, such as loss of livelihood and the damage to rural road networks, are not reflected in market prices. Several attempts have been made to estimate the cost of the environmental damage caused by river sand mining. In 1992 the Netherlands Economics Institute (NEI) estimated that 12 ha per year of riverbank in Western Province was lost thanks to erosion. Coastal erosion due to overexploitation of river sand has been estimated at 6 ha per year (Byrne and Nanayakkara 2002). In another study, the cost of coastal erosion was estimated at LKR[2] 220 million. Siripala (2002) estimated the social cost of river sand mining to be LKR 600 per cube of sand.

Some members of the media view this situation as a sand crisis as sand prices are very high for the construction industry because of intense demand and a lack of suitable alternatives. Currently, on average, a cube of sand can be sold at a minimum of LKR 6,000 in Colombo and once labor and transportation fees are deducted, around SLR 2,000 per cube is cleared, therefore it is inevitable that this lucrative business will continue. However, the royalty payment to the GSMB and the income that goes to local government is fairly low. Unsustainable sand mining occurs at two levels: one is illegal extraction over the quota by licensed miners with the help of police officers and local government officers; the other is mining from banned or vulnerable sites. In addition to environmental and other social costs, these practices deprive the government of income.

The estimated values indicate that the sand supply deficit will increase over time mainly due to the curtailing of the supply because of a government ban and the depletion of the resource base. The construction industry in Sri Lanka grew by 9% during 2007 over growth of 6.6% in the previous year (Central Bank of Sri Lanka, 2007). The construction industry led the mining and quarrying sector to growth of 19.2% in value added terms compared to growth of 24.2% during 2007.

4.0 COMPARISON OF PRIVATE BENEFITS AND SOCIAL COSTS

In line with objective (b), the private and social costs and benefits of river sand mining are examined in this chapter.

4.1 Analytical Framework

The miner is concerned with his private costs when making decisions, but not the costs borne by others, i.e. social costs. Social costs include both private costs and any external costs to society arising from sand extraction. When there is a negative externality, then social costs should be greater than private costs. The difference between private costs and total cost to society is the external cost which is directly associated with producing or delivering a product or service. This external cost is not paid directly by the producer. When external costs arise, because environmental costs are not paid, market failures and economic inefficiencies exist at local or national level.

A sand miner's decision to continue the sand mining process depends on private profitability – his revenue from selling the sand after deducting private costs, such as labor and material costs, and payments to the government. Similarly, society also benefits from an activity if the net social benefits are positive. The analysis is based on average benefits and costs; not on marginal costs and benefits.

[2] Sri Lankan Rupees. 115 LKR = 1 USD as of July 2009.

4.2 Field Data Collection

The field surveys to collect data relevant to the resource use, income, private costs and subsequent social costs were based on a structured questionnaire (Appendix 2) and were conducted at three sites; Doluwa (Central Province), Weragantota (Central/Uva Province) and Alawwa (North Western Province). The first two sites are located along the Mahaweli River while the third site is adjacent to the Ma Oya River. Mahaweli, being the longest river in Sri Lanka, provides more access to sand sites so two sites were chosen to represent the scale of mining on this river. There are two major rivers (the Deduru Oya River and the Ma Oya River) closer to Western Province but they are highly controversial with respect to sand supply and environmental issues. A site on the Ma Oya River was selected because mining in the Deduru Oya River was banned after a Supreme Court decision. At a particular site there may be a number of miners who carry out mining operations at the riverbank.

The data collected included: the amount of damage to riverbanks; the amount of damage to wetlands; the amount of damage to sensitive areas; the number of trees removed; the amount of soil erosion; the loss of productivity on adjoining land; the amount of damage to structures such as bridges, water pumping stations, etc.; the number of licenses issued/the number of miners involved per site; the amount of sand removed per day; the number of people employed (in all categories) by origin (local or outsiders); satisfaction with the mining activities and perceptions of the mining activities; the direct production costs borne (wages, license fees) by the miner; the price of sand at the site; other transaction costs; and damage to roads and the number of complaints received by the local authority. This data was used to estimate monetary values using direct market-based approaches.

4.3 Results and Discussion

4.3.1 Site-specific conditions

Site 1, Doluwa (Mahaweli River, Central Province): The site is administered by a Pradeshiya Sabha (local government) and it annually issues permits based on a tender criteria. The payment for the tender for 1 April 2007 to 31 December 2007 for 1,300 cubes was LKR 53,040. The miner/s should provide a schedule and pay a royalty of LKR 150 per cube to the GSMB. Other production costs at this site involved labor wages, the cost of shovels, and cane baskets. The private benefit came from the direct selling of 1,300 cubes per month at a price of LKR 2,000 per cube.

Site 2, Weragantota (Mahaweli River, Central/Uva Province): This is a well established large sand mining site with access to a large sand deposit. A fairly organized network was found at this site and boats and tractors were used to transport sand from the middle of the river to the land. Mining takes place throughout the year except for the rainy seasons. The adjacent riverbank is mainly comprised of shrubs and some agricultural land. The sand sites were well prepared to unload dredged sand easily. The miners should have rights to the adjacent land for sand extraction and they should pay a land rent to the Pradeshiya Sabha for mining 210 cubes per month on specified days of the week.

The production cost involves payments for boat and tractor hire in addition to wages and equipment costs. The sand at the site was sold (May 2008) at an average price of LKR 1,252 per cube. A licensed miner is permitted to dredge 210 cubes per month and 37 miners were operating at the site. Individual miners have to spend money to prepare their own sand site adjacent to the riverbank.

Site 3, Alawwa (Ma Oya River, North Western Province): This site has been well known for sand extraction for a long time but mining activities are currently not very active, mainly due to the low deposits available. Moreover, thanks to the heavy extraction and transportation of sand over a long period, a weak road structure was observed at the site. Permit holders are allowed to extract only 140 cubes per month and the sand is sold at LKR 1,300 per cube at the site. Twenty-four licensed miners operate at this site. The sand extracted from this site is mainly transported to Western Province. Apart from rice farming, no any other major land use was identified on adjacent land.

4.3.2 Private costs and benefits

Only one period of costs and benefits was compared without any discounting. The total production cost of site 1 was estimated to be LKR 2,163,893 per month[3] and the gross mining income was LKR 2,600,000 per month. Since there is a positive difference between income and expenditure (LKR 436,107 per month), sand mining is privately profitable at this site. Similarly at site 2, the total income received by selling sand was LKR 116,736,480 (= 210 cubes per month x 12 months x 37 miners x LKR 1,252 per cube) and the total direct cost of sand mining was LKR 84,741,470, so the total annual income over expenditure was LKR 31,995,010. The income and expenditure data related to the third site revealed that there were positive private profits of LKR 13,605,120–38,810,880 (140 cubes x 24 miners x 12 months x LKR 1,300 per cube 38,810,880). The private costs are detailed in Appendix 3.

4.3.3 Social costs

Social cost is the summation of private cost and external cost due to the environmental and non-environmental effects of sand mining. Of all the potential environmental damage that can be caused by river sand mining, the following effects were prominent in this area (source: personal communication with the Environmental Officers at the Pradeshiya Sabha): riverbank erosion, productivity loss in paddy fields, and the non-environmental social costs of damage to rural roads.

It was found that the opportunity cost of the sand site was zero for sites 1 and 3. The survey revealed that the average opportunity cost of site 2 per mining location was approximately LKR 27,500 per year. There were no conceivable social benefits from the sand pits, i.e. no increase in fish stocks or restoration of water during dry periods. It was assumed that all environmental damage was attributable to river sand mining during the permit period. Other environmental impacts, such as the effect on bathing, drinking water quality and access, the depth of wells and potential effects on cities downstream, were not prominent and so were not quantified or monetized.

[3] At this site the values were expressed on a per month basis.

Productivity loss

The geographical boundary of the impact area was determined after consultation with the Environmental Officers of the Pradeshiya Sabha, and the Divisional Officers at the Agrarian Services Centre. Loss of income due to lowering of the water table was computed. For example, at site 1 (Doluwa), the survey revealed that 68% of respondents from 21 households in the impact area believed that there was a decline in their paddy harvest due to less water in the dry season because of the lowering of the water table. The estimated yield loss, the extent of affected crops, and the loss of income were computed based on the information gathered from the survey and the information obtained from the Agrarian Services Centre. Only one cropping season was considered as only the *Yala* cultivation season[4] was included in the sand extraction period of nine months. The total farm income loss was estimated at LKR 311,190. Similar computations were made for the other two sites and the estimated losses amounted to LKR 596,000 for site 2 and LKR 186,000 for site 3.

Damage to roads

The destruction of roads appeared to be the main non-environmental social cost of river sand mining in the study area, where most of the village roads are class C roads. These roads are designed for low traffic volumes and repair and maintenance is usually conducted every three years. There are two ways to monetize this damage. One method is to use the annual allowable cost estimates for repair and maintenance available from the Road Development Authority. This requires knowledge of the length of the road damaged, but this is practically impossible once lorries have passed a junction because they then move in a number of different directions. The other method is to use the fines charged by another Pradeshiya Sabha for damage to roads. Bingiriya Pradeshiya Sabha charges LKR 100 for each cube of sand as a charge for damage to roads. This approach was used to value the road damage at sites 1 and 3. However, the Road Development Authority[5] estimated that the annual cost of road maintenance due to damage caused by heavy trucks and lorries transporting sand from site 2 was LKR 8,292 a month per miner, so the total replacement cost was taken to be LKR 3,681,648.

Riverbank erosion

It was assumed that if sand mining needs to be continued, the riverbank should be protected by fixing a retaining wall or similar structure. The wall would cover only the sand site at the bank and the residual effects, e.g. damage to the opposite side of the bank during the rainy season due to the presence of a dam on one side, were not taken into account. The length and height of the sand site was measured and multiplied by per unit cost of restoration. The cost of construction of the retaining wall was estimated based on the specifications (size of the foundation, width and height, and the concrete mixture) provided by the Irrigation Engineer, Irrigation Management Department, Kandy.

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[4] There are two major cultivation seasons; *Maha* (November–February) and *Yala* (April–August). Only the *Yala* crop was included in the permit period, 1 April–31 December.

[5] Personal communication with the Executive Engineer, Road Development Authority, Kundasale.

No major loss to biodiversity was reported from the study areas. Though there were complaints related to health, these were not considered at the time of data collection, as people did not appear to be concerned with this aspect of sand mining. Other potential negative externalities such as salt-water intrusion, damage to infrastructure and houses, loss of bathing water and decline in inland fisheries were not reported during the study. The estimated social costs are depicted in Table 2.

Table 2. External cost of sand mining (LKR) per year

Cost Items	**Site 1**	**Site 2**	**Site 3**
Net income loss from crops	311,190	596,000	186,000
Damage to the riverbanks (adjusted per year)	1,900,000	4,300,000	1,321,000
Damage to roads	1,300,000	3,681,648	336,000
Opportunity cost of the land		1,017,500	
Total	3,511,190	9,595,148	1,843,000

4.3.4 Social profitability

The major social benefits of river sand mining are the provision of employment opportunities to local people, flood control, and the supply of raw materials to the construction industry. These are in addition to the private benefits of miners. Due to the vagueness of this information, only the net private profits were considered as a lower bound value of social profitability. The summary of social costs and net private benefits were computed for each of the study sites and can be seen in Table 3.

Table 3. Summary of private and social costs and benefits (LKR) per year

Cost/benefit	**Site 1**	**Site 2**	**Site 3**
Private cost	25,966,716	84,741,470	38,810,880
Private benefit	31,200,000	116,736,480	52,416,000
Net private benefit	5,233,284	31,995,010	13,605,120
External cost	3,511,190	9,595,148	1,843,000
Social cost	29,477,906	94,336,618	40,653,880
Net social benefit	1,722,094	22,399,862	11,762,120

In all cases, social costs exceeded private costs. Although the net social profits were non-negative at all the study sites, the results should be interpreted with caution. The results have contextual validity as mining at none of these sites has major environmental impacts such as salt-water intrusion or damage to infrastructure. Also, there is the possibility of under-reporting of the values of identified impacts. For instance, although the third site shows a positive net social profitability, the site was subjected to over-exploitation for a longer period. The other impact which has been excluded is coastal erosion, which is non-point pollution.

5.0 ANALYSIS OF PREFERENCES OF SAND MINERS

This chapter covers objective (c) of this report by investigating the trade-off behavior of resource users (i.e. sand miners) in the conflict between indicators of ecological integrity, conservation outcomes and policy options. This information is important as miners are the people causing a social problem motivated by personal gain or profit. Therefore without considering miners' preferences and perceptions, realistic solutions to these issues cannot be sought. However, the miners may not be in a position to provide values that will be widely shared or agreed to by other members of society.

A Discrete Choice Experiment (DCE) was used to accomplish objective (c). The DCE is a stated preference technique, i.e. respondents are asked to evaluate hypothetical scenarios as opposed to the researcher modeling the actual behavior.

Discrete Choice Experiments were originally developed in the market and in transport literature but they have now become familiar in environmental economics (Adamowicz et al. 1994; Adamowicz et al. 1998; Loueviere et al. 2000). DCEs are closely linked to two economic theories known as Lancaster's Characteristics Theory of Value (Lancaster 1966) and the Random Utility Theory (Thurstone 1927; McFadden 1974). In choice experiments, respondents are presented with a series of alternative profiles of environmental goods or policies and asked to choose their most preferred choice (Bateman 2002). These profiles are set out in terms of the attributes (characteristics) of these goods and policies (Adamowicz et al. 1994). Usually a monetary value is included as one attribute. Two components are required to implement a DCE: a) a statistical design to create the hypothetical scenarios, and b) a statistical method to analyze the responses (Louviere et al. 2000). The widely used statistical method of analysis is the multinomial logit model, which is based on the behavioral assumptions of random utility theory (McFadden 1974). Fractional factorial designs can be used to reduce the number of profiles, thereby reducing the cognitive burden faced by the respondents in the choice experiment (Carson et al. 1994).

5.1 Theoretical Framework

Each alternative is described in terms of a number of attributes. For each attribute there are multiple levels that describe the attribute and usually these attribute levels are varied in each choice set according to an orthogonal statistical plan. By aggregating the responses from all the respondents, it is possible to derive part worth utility functions for each attribute. These part worth utilities demonstrate the importance of various attribute levels to the choice selection of an individual.

Assuming that an individual's preference can be represented as a function, each choice (alternative) is represented with an indirect utility function. The utility function consists of an observable deterministic or systematic part (V) and an unobservable stochastic or random element (ε). Therefore the indirect utility function of i^{th} individual for the j^{th} alterative can be represented as

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

The individual would choose the alterative j in the choice set to any alternative k, if $U_{ij} > U_{ik}$

Since the utilities include a random element, predictions cannot be made with certainty. Thus, analysis becomes one of probabilistic choice (Bateman 2002). The probability of choosing the alternative j over k can be expressed as

$$P\ [(U_{ij} > U_{ik})\ \forall\ k \neq j] = P\ [(V_{ij} - V_{ik}) > (\varepsilon_{ik} - \varepsilon_{ij})] \tag{2}$$

McFadden (1974) showed that if the error term in equation (2) is independently and identically distributed (IID) with a type one extreme value (Gumble distribution) the probability of any alternative j being chosen as the most preferred can be expressed in terms of the logistic distribution. This model is known as the Conditional logit model or Multinomial Logit (MNL) Model (Bateman 2002).

$$P\ [(U_{ij} > U_{ik})\ \forall\ k \neq j] = \frac{\exp(\mu V_{ij})}{\sum_j \exp(\mu V_{ik})} \tag{3}$$

Here, μ is a scale parameter which is inversely proportional to the variance of the error term. The MNL model can be estimated by maximum likelihood procedures, with the respective log likelihood function (Bateman 2002).

$$\log L = \sum_{i=1}^{n} \sum_{j=1}^{j} Y_{ij} \log \left[\frac{\exp V_{ij}}{\sum_{j=1}^{J} \exp V_{ij}} \right] \tag{4}$$

5.2 Survey Development

The survey instrument for DCE was developed through focus group discussions and the outcome of a mailed survey. The environmental NGOs listed in Appendix 4 were contacted for the mailed survey. The attributes and levels chosen for the DCE are summarized in Table 4.

Table 4. Attributes and levels used in the choice experiment

Attributes	Level
Monitoring and regulation	Strict regulation, i.e. identify the vulnerable sites and police them
	Contribute to environmental trust fund and continue mining
	Status quo, i.e. no contribution to trust fund but continue mining
Awareness programs for resource users	By environmental organizations
	By the government, i.e. GSMB and local government environment officers
	Status quo, i.e. no awareness programs
Willingness to pay	Reduce by 50% the amount of sand allowed to be mined with the current royalty
	Increase the royalty by 50% and increase how much sand can be mined
	Status quo, i.e. no change in amount or royalty
Community-based management	Apply only for small sites
	Co-management with local government for all sites
	Status quo, i.e. no community-based management

These attributes reflect possible changes in resource management and in the livelihoods of local communities. Of these, regulation and monitoring represent the role of law enforcement bodies, which is fairly weak at present. Obviously there is a certain administrative cost associated with the first level, while at the second level the environmental damage is accepted and will be dealt with via an environmental trust fund. Miners usually have few concerns about the environment so awareness programs for local people involved in various aspects of mining may mitigate the damage the industry inflicts. The attributes included were: passing the communication of awareness programs on to voluntary organizations; keeping the government in control of awareness programs, which is less efficient; or no awareness activities at all. Miners were also asked about their willingness to pay (WTP) for various changes in the volume of sand that can be extracted. The last attribute tests one of the policies identified in the draft sand mining act, which is community-based management (CBM). The attributes deal with the application of CBM for small sites or with local government or with no CBM at all.

The scenarios created by combining the four attributes and three levels generated 81 (3^4) combinations that resemble possible management actions. Two profiles were then combined into one choice set and respondents were asked to choose one of these two. A fractional factorial representation of a resolution III main effects design requires only nine replications. The data were collected in personal interviews where each respondent was shown only four choice sets, out of nine choice sets. Each choice set was printed on a separate colored sheet and laminated. The data was entered into MS EXCEL and the statistical analysis was undertaken in STATA v.10.

The study was conducted at the sand mining sites of the Ma Oya River in the Polgahawela, Alawwa, and Narammala Secretariat Divisions in Kurunegala District. Figure 2 provides a map of the geographical area.

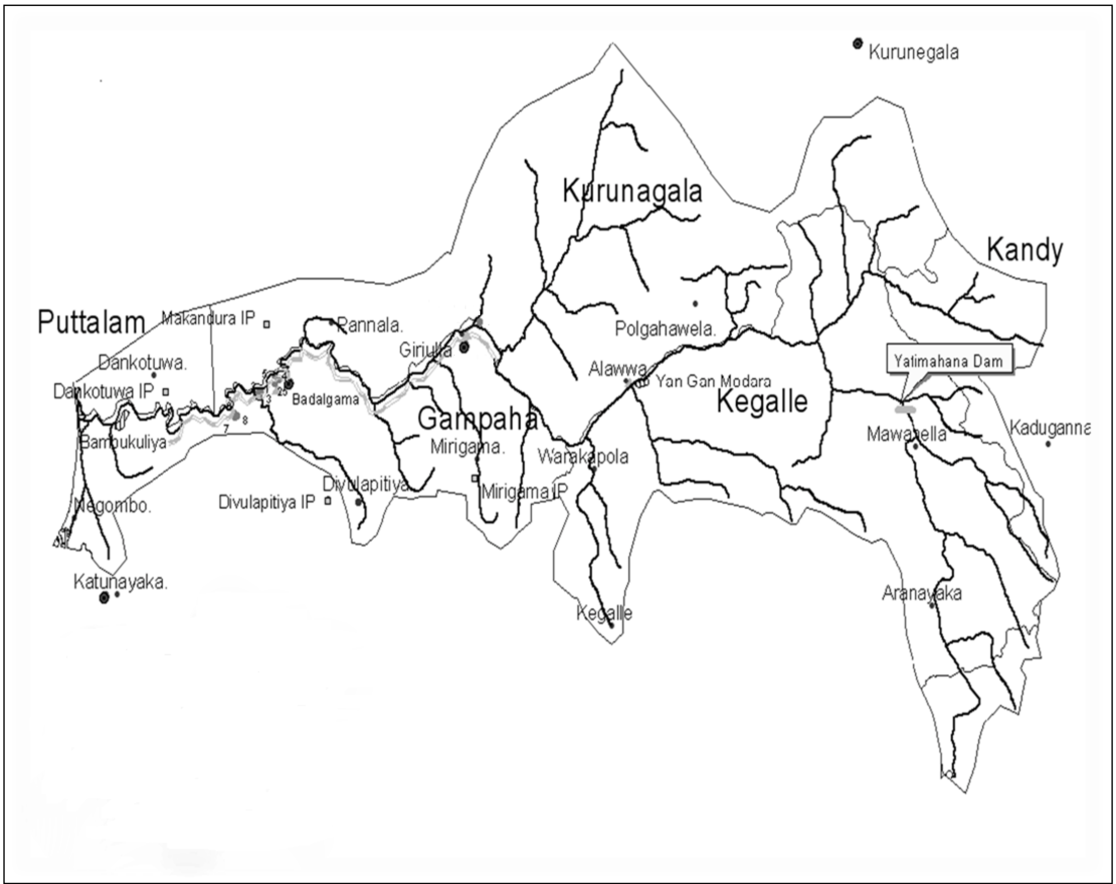

Figure 2. The basin of the Ma Oya River

Information about all the license holders presently engaged in sand mining in the Ma Oya River was collected from the regional GSMB office at Kurunegala. The survey dealt with a random sample of 150 miners and mine workers.

5.3 Results and Discussion

Table 5 presents the MNL parameter coefficients, their standard errors, and p-values for each attribute for the entire sample. The respondents assigned the highest priority to continuing mining (with the existing royalty or an increased royalty) followed by the establishment of an environmental trust fund. According to Table 5, regarding the regulation and monitoring attribute, respondents accepted that the present regulations are either weak or inefficient. Also, they perceived that strict regulations result in bureaucratic inefficiency. They want to continue mining and environmental damage could be corrected via their contribution to an environmental trust fund maintained by the GSMB, but rehabilitation should be done with the collaboration of local government. The surprising finding is that "no awareness" is statistically significant in the analysis, implying that local people do not perceive any tangible benefits from such activities. This is contrary to most arguments which posit that providing persuasive instruments is effective in managing this issue. Another striking finding is that they have rejected the awareness programs conducted by environmental organizations.

Table 5. Estimates of the Multinomial Logit Model

Attributes	Level	Coefficient	SE	P value
Monitoring and regulation	Strict rules, regulations and monitoring	0.1286	0.4856	0.945
	Establishment of ETF	0.6284	0.1910	0.001
	Status quo	-0.7570	0.5218	0.149
Awareness programs for resource users	Environmental organizations	0.1023	0.1669	0.540
	GSMB and environmental officers	-1.0401	0.2793	0.000
	No awareness programs	0.9378	0.3254	0.004
Willingness to pay	Increase the royalty by 50% and increase allowable amount	1.4622	0.3680	0.000
	Reduce by 50% allowable amount with current royalty	0.1211	0.1427	0.396
	No change in royalty or amount	-1.5833	0.6946	0.000
Community-based management	Fully managed by CBM	-1.2471	0.4728	0.008
	Co-management with local government	0.4694	0.1873	0.049
	No CBM	0.8777	0.8402	0.297

Log likelihood = -157.51

It was found that the miners were willing to contribute more to the royalty given so that they could mine more sand. This implies that they have accepted that the present royalty should be increased but that they should also benefit. With respect to community-based management, the respondents were not in favour of being fully managed by Community Based Organizations (CBOs). Instead they preferred the involvement of CBOs with some control by local government, i.e. co-management.

The parthworth utilities presented are consistent with the field observations made by the researchers. The field survey showed that respondents placed the highest priority on continuing the present levels of mining even if it means increasing the royalty payment. They were not concerned about sustainability due to a lack of other livelihood opportunities.

The results of the discrete choice experiment suggest that the negative effects associated with sand mining can be partly mitigated by increasing government revenue towards an environmental trust fund with some level of co-management. Strict rules and regulation as well as the awareness programs, as suggested by the media and environment groups, may not be productive.

6.0 EVALUATION OF POLICY ALTERNATIVES

In line with objective (d) of this research report, this chapter attempts to evaluate management options for rivers that are subjected to heavy sand extraction. This is a parallel piece of research where a holistic evaluation has been made for each of the rivers studied.

Effective management of the environmental issues related to sand extraction is workable only by linking the activities, interests and perspectives of all the groups concerned, including civil society, industry, non-government organizations and government agencies. Current and potential policy alternatives were evaluated based on Multi-criteria Analysis (MCA), where stakeholders' assessments of policy options were accommodated. The following sections describe the analytical framework, field procedure and results.

6.1 Analytical Framework

Given the complexity of any given environmental issue and the impact of management decisions, an evaluation based on a single criterion cannot be relied upon to generate pragmatic results. MCA uses a set of criteria that utilizes available qualitative and quantitative information. These multi-objective decision support techniques can play an important role in environmental management as the complexity, time scales and diversity of environmental effects, as well as the implications of decisions, are usually beyond the imagination of most people involved. The application of a multi-criteria approach is further justified by the number and variety of people involved in environmental decision-making processes and the complexity of information related to environmental problems.

These multiple-criteria evaluation methods have assisted urban and regional planners, allowing them to make objectively informed choices and to consider social preferences, development needs, and conservation requirements (Cochrane and Zeleny 1973; Voogd 1983; Nijkamp and Van den Bergh 1990; Ferdinando et al. 2000). Multi-criteria analysis was used to zone Asinara Island National Marine Reserve in Italy. In this study special multiple-criteria analysis was used to determine the suitability of marine areas for different uses and levels of protection. Multi-criteria analysis was used to integrate objective data with the constrained priorities of different stakeholders in the planning of a marine protected area. Janssen and Padilla (1999) used MCA to evaluate the conservation of mangrove forest in the Philippines, in particular the conversion of protected mangrove forest to aquaculture and forestry.

Here the decision rule or the evaluation procedure can produce a complete ranking (A > B > C > D), the best alternative (A > (B,C,D)), a set of acceptable alternatives ((A,B,C) > D), an incomplete ranking of alternatives (A > (B,C,D) or (A,B) > (C, D)). Weighted summation is a straightforward evaluation method where an appraisal score is calculated for each alternative by first multiplying each value by its appropriate weight followed by summing of the weighted scores for all criteria. This information is sometimes in monetary units but in many cases cannot be priced or measured quantitatively. Most problems therefore contain a mixture of monetary, quantitative and qualitative information. Sensitivity analysis could be made to test the validity of weights.

6.2 Data Collection and Analysis

In this analysis DEFINITE, a multi-objective decision support system (Janssen et al., 2001), has been used. The system supports the whole decision process from problem definition to report generation. In DEFINITE, the focus is on methods to support the choice phase. The results are sensitive to the evaluation method, uncertainties in scores, weights and prices used.

The evaluation framework was based on an effects table which included management alternatives in the columns, effects/criteria in the rows and scores in the cells. The criteria were divided according to the four policy objectives: ecological, social, economic and technical.

The data were gathered in two different ways. First, using a survey that was mailed to environmental NGOs, a set of alternatives was identified. Then these were evaluated by the field engineers attached to GSMB. These officers have a fairly good understanding of present resource extraction activities, government regulations and ongoing damage to the environment. They scored based on the experts' judgments on the relative performance of the alternatives as displayed by their effects. The focus group discussions further revealed that they had interacted with local politicians, village level officers and miners.

A number of studies have used expert opinion. Gilbert and Janssen (1998) and Janssen and Padilla (1999) used MCA to evaluate alternative management strategies for mangroves in the Philippines. Expert judgment was used in these cases to define the range of relevant management options. The effects on shore protection, biodiversity and ecotourism linked to alternatives could not be quantified. They invited a forestry expert, a marine biology expert and a zoology expert to provide expert judgment on the relative performance of the alternatives with regard to the three effects. Kangas et al. (2001) used a similar approach for the strategic planning of forestry on state-owned lands in Finland. In another study, Munasinghe (1993) illustrated that MCA could be used to improve the quality of environmental decision making in the power sector in Sri Lanka, with special emphasis on biodiversity conservation and the cost of electricity.

An inventory was made of all the possible management alternatives, although not all of the alternatives are feasible for all the study sites. Therefore, management alternatives considered for a particular river site are the options that are practiced at present or will be implemented in the near future.

During the interviews, the experts were asked to rank the criteria within each objective according to the importance of the criteria (expert weight). Then each of the management alternatives were evaluated based on the four criteria indicated (Table 6). The alternatives were ranked for each objective using the expert weights only. Also, an overall ranking was produced using a combination of expert and stakeholder weights. The management alternatives (existing and proposed) are described below.

Complete ban: As a consequence of environmental concerns raised by NGOs and the media, sand mining has been completely banned in certain rivers in Sri Lanka by the Supreme Court thanks to public interest litigation. Some institutions, such as National Water Supply and the Drainage Board, believe that there should be stricter regulation of some rivers, with a complete ban on sand mining needed considering its impact on water intake levels.

Restrict access to vulnerable sites: This is based on technical classification of sites. At present all the sites along the Ma Oya River have been technically evaluated by the GSMB. This approach could be extended to mining sites at other rivers and then mining in potentially vulnerable sites would not be allowed.

Do nothing: Currently, although the mining licenses are issued by the GSMB and a certain level of monitoring is conducted by local government, illegal mining takes place. Therefore, the “do nothing” option represents a continuation of present practices.

Environmental trust fund: With a reduction in sand supply caused by the restriction of access to vulnerable sites, the construction industry would face a serious sand shortage which would further escalate prices. The current supply cannot be sustained if damage to the environment is not dealt with. An environmental trust fund could be used to rehabilitate the environment. Moreover a trust fund could finance other environmental protection and natural resource management programs and promote the use of innovative solutions. Also, it could be used to support education and training programs related to the protection of the environment.

***Community-based sand mining*:** The draft Act on sand mining prepared by the Ministry of Environment and Natural Resources has identified this option. Permits would be provided to registered community-based organizations whose membership comprises existing river sand extractors. These community-based organizations would be assigned single extraction rights for specified extraction zones in those rivers for which harvest limits are introduced. Each mining zone would be supported with a single landing site and would be awarded to the community-based organization for a period of five years, within which an annual extractable quota would be assigned.

Four criteria, namely social, economic, environmental and technical, were used to evaluate the management options. Under the social criterion, a number of effects were considered. The “effect on livelihood” measures the loss of employment opportunities by the peripheral community due to a complete ban on, or restriction of sand mining. "Effect on health" represents the possibility of contracting mosquito-borne diseases in the dry season from the pits made due to mining the middle of the river. Some houses may be located adjacent to the river and heavy mining may cause damage to the structure of these dwellings – this is measured by "loss of residences". Usually, rural people rear cattle so livestock is released on nearby riverbanks for grazing and river water is used to bathe animals. "Effect on cattle rearing" therefore represents the loss of these activities. Sand mining leaves deep pits in the river masked by a thin layer of sand, making bathing extremely dangerous as there is a high risk of drowning. This is represented by "loss of bathing water". Sand mining creates turbid water and some rural people use river water for drinking. "Pollution of drinking water" measures this loss of resource.

A number of effects were considered under the economic criteria. One was the cost of repairing infrastructure where direct impacts have been observed in many river basins such as the Deduru Oya, Ma Oya and Kelani rivers (Kamaladasa 2008). The impact of sand mining on crop production is more severe in low-lying areas where the lowering of the water table affects perennials, and in some locations where river water is used to irrigate crops. "Impact on mine owners' income" is the cost of the direct loss of income from sand mining. The impact on the income of laborers and transporters is the same direct loss. The "income of vendors of off-shore sand and river sand suppliers" measures the direct impact of a policy. In highly degraded areas, the riverbanks need to be rehabilitated and the cost for this under different policy options is measured by the cost of riverbank conservation. Some inhabitants depend on fishing from these rivers and the "impact on fishing yields has been measured as "effect on inland fisheries". The "price of river sand" measures the monetary value of of one cube of river sand.

Of the number of effects considered under the environmental criterion, "salt-water intrusion" represents the ability of salt water to enter the river through the river mouth. This is usually more prevalent where the river is close to the sea. "Loss of biodiversity" measures the influence of an action on riverine vegetation. The lowering of the water table and the associated impacts are quantified as "decline in groundwater levels". By deepening the river, mining usually disrupts its flow and this is represented by "imbalance in the natural flow system of rivers". This may temporally change the river's hydrology but the length of time this takes depends on the season, i.e. rainfall and the water flow. The "quality of soil" measures the level of degradation of a riverbank due to sand stockpiles and the destruction of the bank environment thanks to the activity of lorries and tractors.

Two effects were considered under the technical criteria; one was the "use of technology" and the other was the "scale of mining". Sand-mining technology, e.g. mechanical mining, generally has an adverse impact on a natural system. The scale of mining is partly related to this impact as mechanical mining is usually unsustainable.

In this study, three major rivers (the Ma Oya, Mahaweli and Deduru Oya rivers), which are all highly controversial with respect to sand mining, were considered. Each of these rivers have a substantial number of mining sites so, depending upon the geological location and the extraction plan and actions of the local people, the effects of the management alternatives were varied. Another limitation was the difficulty in quantifying most of the effects.

The effects tables for these study sites were constructed using all the available information and are shown as Tables 6–8. In all cases, the respondents placed equal importance on the social, economic and environmental criteria but relatively less on the technical criterion. Accordingly, the weights were chosen for the social, economic, environmental and technical criteria. A sensitivity analysis was carried out (see Appendix 4).

Table 6. Effects table for the Ma Oya River

Evaluation Criteria	Complete ban	Restrict access to vulnerable sites	Make allowance for environmental trust fund	Do nothing
Social				
Effect on livelihood	- -	-	+	+ +
Effect on health	+ +	+ +	+	- -
Loss of residences	+ +	+	+	-
Water for cattle rearing	+	+	+	-
Loss of bathing water	+ +	+ +	+	-
Pollution of drinking water	+ + +	+	+	-
Economic				
Cost of repairing infrastructure	+ + +	+ + +	+	-
Effect on crop production	+ + +	+ +	0	-
Income of mine owners	- - -	- -	-	+ +
Income of laborers	- - -	- -	-	+ +
Income of sand transporters	- - -	- -	-	+ +
Income of building material suppliers (alternatives to sand)	+ + +	+ +	0	-
Income of building material suppliers (except alternatives to sand)	- -	-	0	+ +
Cost of riverbank conservation	+ +	+	+	-
Effect on inland fisheries	+ +	+	0	-
Price of sand	- -	-	0	+ +
Environmental				
Salt-water intrusion	+	+	0	-
Loss of bio-diversity	+ +	+	+	-
Loss of riverine vegetation	+ +	+	+	- -
Decline in groundwater levels	+ + +	+ +	0	-
Imbalance in the natural flow system of rivers	+ +	+	+	-
Quality of soil	+ + +	+ +	0	-
Technical				
Use of technology	+	+	--	-
Scale of mining	+ + +	+ +	--	-

Note: A scale of ---/0/ + + + was used.

Table 7. Effects table for the Mahaweli River

Evaluation Criteria	Do nothing	Restrict access to vulnerable sites	Introduce community-based sand mining	Make allowance for environmental trust fund
Social				
Effect on livelihood	+++	- -	+	+++
Effect on health	-	+	0	-
Loss of residences	-	+	0	-
Water for cattle rearing	-	0	+	-
Loss of bathing water	- -	+	+	- -
Economic				
Cost of repairing infrastructure	-	0	0	+
Effect on crop production	- -	+	++	-
Income of mine owners	+++	-	-	++
Income of laborers	+++	-	0	++
Income of sand transporters	+++	-	0	++
Income of building material suppers	+++	-	0	++
Sand supply	+	-	-	+
Cost of riverbank conservation	- -	0	0	-
Effect on inland fisheries	-	-	0	-
Environmental				
Loss of biodiversity and reverine vegetation	- -	0	0	- -
Decline in groundwater levels	- -	+	0	- -
Imbalance in the natural flow system of rivers	- -	0	0	- -
Water pollution	- -	0	0	- -
Quality of soil	- -	+	0	- -
Technical				
Use of technology	-	+	+	-
Scale of mining	- -	0	+	- - -

Note: A scale of ---/0/ + + + was used.

Table 8. Effects table for the Deduru Oya River

Evaluation Criteria	Do nothing	Complete ban	Restrict access to vulnerable sites	Introduce community-based sand mining	Make allowance for environmental trust fund
Social					
Effect on livelihood	+ + +	- - -	- -	+ +	+
Effect on health	-	+ +	+	0	- -
Loss of residences	-	+ +	+	+ +	-
Water for cattle rearing	-	+ +	+	+	- -
Loss of bathing water	- -	+ +	+	+	-
Economic					
Cost of repairing infrastructure	-	+ + +	+ +	0	- -
Effect on crop production	- -	+ + +	+	0	- -
Income of mine owners	+ + +	- - -	- -	-	+ + +
Income of laborers	+ + +	- - -	-	+	+ + +
Income of sand transporters	+ + +	- - -	-	+	+ + +
Income of building material suppliers	+ + +	- -	-	+	+ + +
Cost of riverbank conservation	- -	+ +	0	0	-
Effect on inland fisheries	-	+ +	+	+	- -
Price of sand to the end users	+ +	- - -	-	+	+
Environmental					
Loss of biodiversity and riverine vegetation	- -	+ +	+	0	- -
Decline in groundwater levels	- -	+ + +	+ +	0	- -
Imbalance in the natural flow system of rivers	- -	+ +	-	0	- -
Quality of soil	- -	+ + +	0	+	- -
Drinking water pollution	- -	+ + +	+	-	- -
Salt-water intrusion	-	+	+	0	- -
Technical					
Use of technology	-	+	+	0	+ +
Scale of mining	- -	+ + +	+ +	+	- -

Note: A scale of ---/0/+++ was used.

The effects tables were used as direct input of the analysis using DEFINITE, which yielded several graphical outputs. Of these, bar charts obtained (Figures 3–5) are used for the interpretation.

6.3 Results and Discussion

6.3.1 Management alternatives for the Ma Oya River

A high variation in the performance of management options under the economic, environmental and technical criteria was observed (Figure 3). “Do nothing” appeared to fare best under the economic criterion while it was the least preferred option of the social, environmental and technical criteria. As expected, a complete ban was the best option under the environmental criterion. Overall, it was found that continuing the current process with the restriction of mining at vulnerable sites was the best alternative, followed by the establishment of an environmental trust fund. The results of the sensitivity analysis are given in Appendix 4.

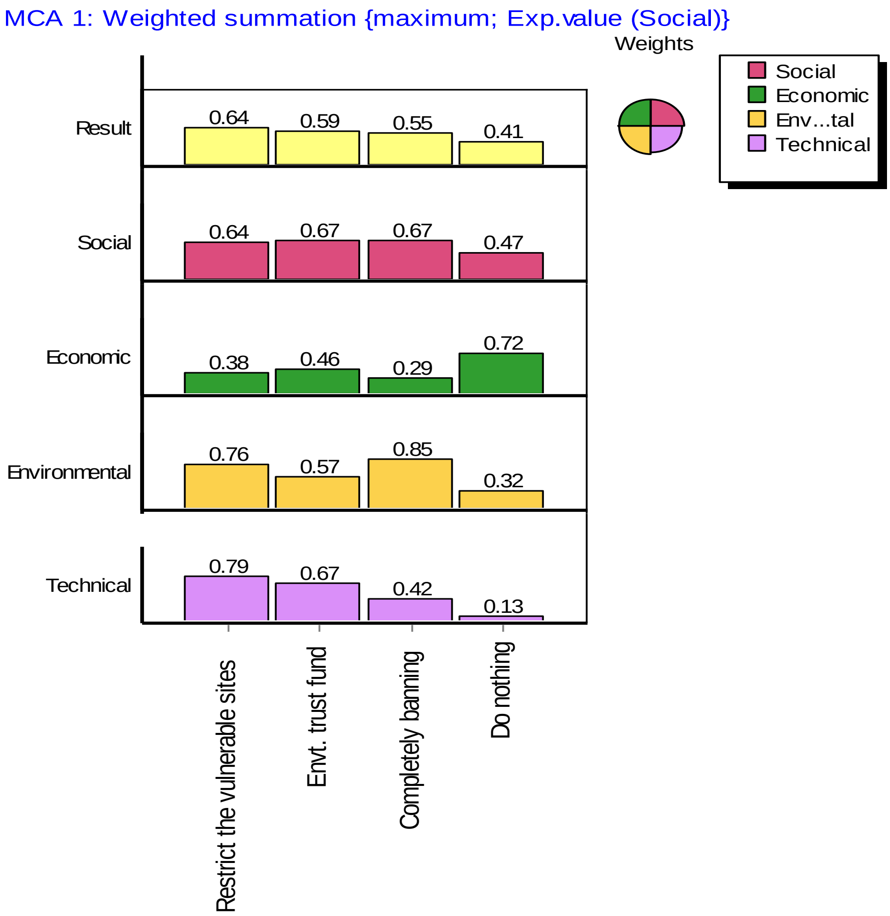

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Figure 3. Rank of management alternatives for the Ma Oya River

6.3.2 Management alternatives for the Mahaweli River

In the evaluation of options for the Mahaweli River, a complete ban was not included. This is because the Mahaweli is the longest river in Sri Lanka and it flows across a steep enough and big enough land area for there to be no major environmental problems other than over-extraction, compared to other rivers.

Therefore, community-based sand mining was introduced into the analysis, which is one of the alternatives included in the draft act on sand mining. As shown in Figure 4, this particular management option performed well under all the criteria (except for economic) and was found to be the best option overall. Identification of vulnerable sites and the restriction of mining at these sites appeared to be environmentally more attractive.

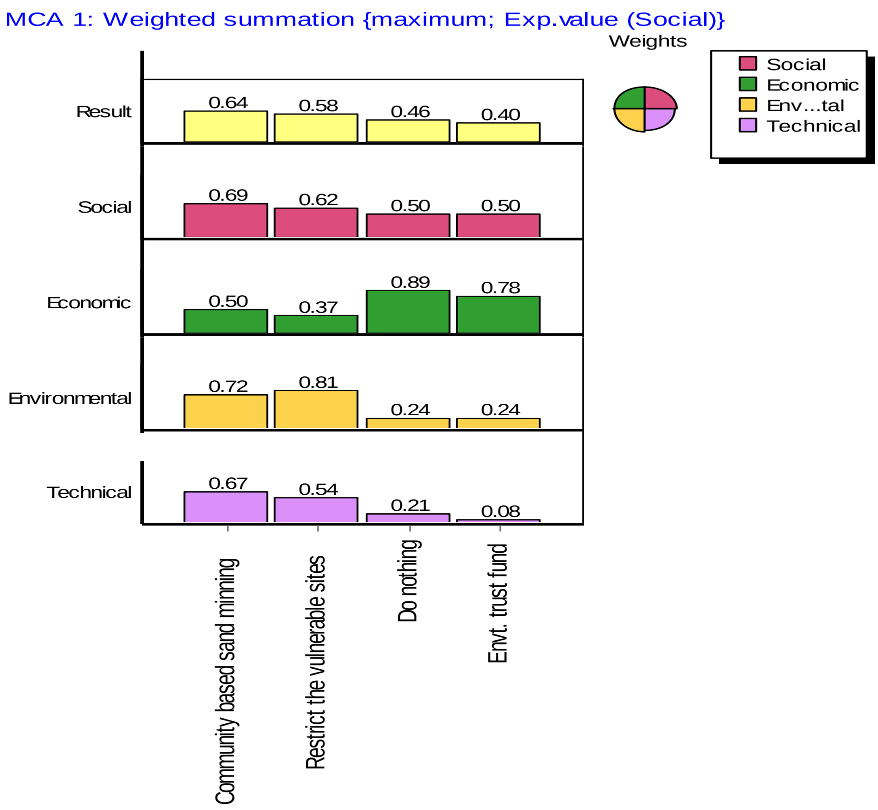

Figure 4. Rank of management alternatives for the Mahaweli River

6.3.4 Evaluation of policy options for the Deduru Oya River

As shown in Figure 5, there was a high variation in performance between the management alternatives for sand mining sites in the Deduru Oya River. Currently sand mining is banned in this river by the government, mainly due to environmental concerns (this is consistent with results). A complete ban is obviously not economically attractive, so it did not receive a better social preference, mainly due to the loss of livelihood it would entail. Although analysis ranked community-based sand mining as the best alternative, there was not a substantial variation among the management options.

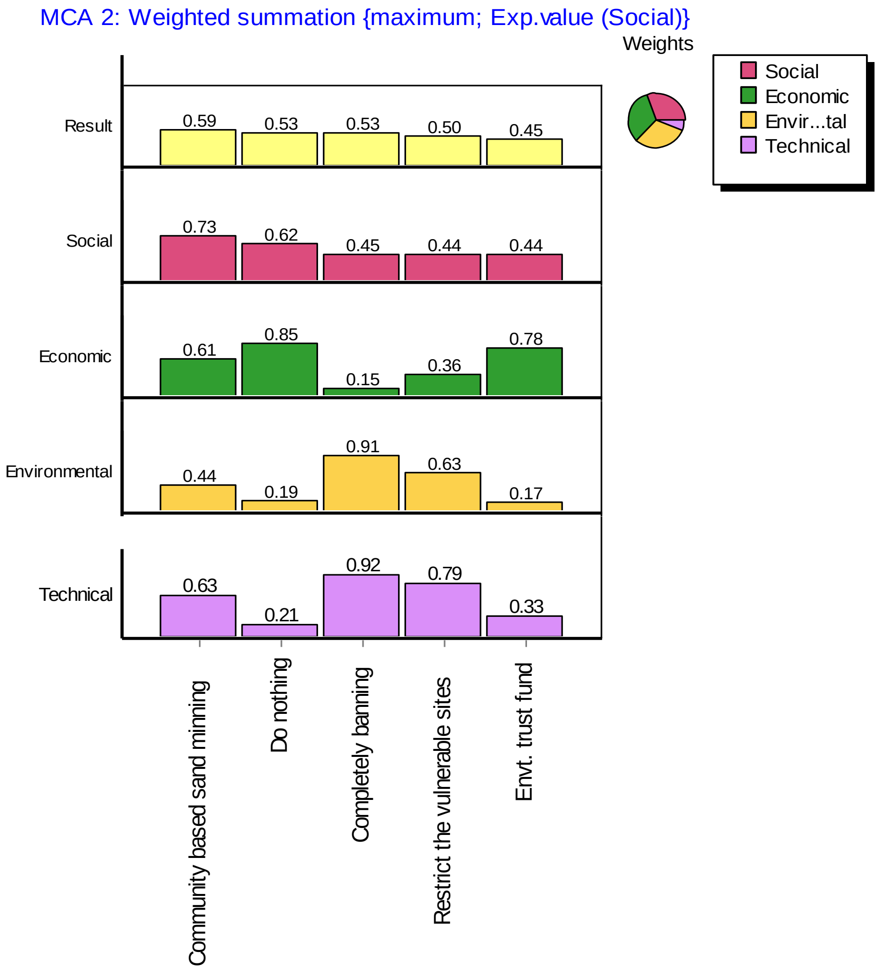

Figure 5. Rank of management alternatives for the Deduru Oya River

The multi-criteria analysis was capable of accommodating all the dimensions of the issue (social, economic, environmental and technical) and evaluating all the possible management options. Scores were obtained from experts and from a group of people who had environmental concerns and were aware of the issues. Therefore, the results of the analysis can be treated as a holistic evaluation of potential policies for each of the rivers studied. Analysis found that there is wide variation among the alternatives so a single criteria evaluation may fail at field level. A sensitivity analysis was carried out and can be seen in Appendix 4.

7.0 EVALUATION OF ALTERNATIVES TO RIVER SAND

7.1 Potential Alternatives to River Sand

If the demand for sand is partly absorbed by other means, subsequent environmental issues could be mitigated. Therefore, in line with objective (d) of this report, appropriate alternatives are evaluated in this chapter. The price of alternatives at the end user level were compared despite the fact that social and environmental costs are not embedded in market prices.

Four major alternatives to river sand have been identified in Sri Lanka; off-shore sand, land-based sand, dune sand, and quarry dust. Table 9 shows the availability of sand alternatives in Sri Lanka (Dias et al. 1999).

Table 9. Alternatives to sand mining

Type of sand	Annual availability (approx.)
Off-shore sand	31.5 million cu.m
Land-based sand	9.6 million cu.m
Dune sand	0.3 million cu.m.
Quarry dust	9.96 million cu.m

Source: (Dias et al. 1999)

Of these, land-based sand has already been used as an alternative to river sand in landfilling for road construction. A considerable amount of land with sandy soil is currently cut for property development, so there is potential to use fine and aggregate land-based sand. However, land-based sand cannot be considered as a successful alternative to river sand for a number of reasons. For instance, yield depends on the type of soil and the washing method. Also, the nature of the aggregate is usually coarse, so land-based sand cannot be used for plastering. In addition, the environmental impact of using land-based sand has not been assessed and there is the possibility that huge pits would be left after digging, creating environmental hazards similar to that of clay mining. However, studies carried out at the University of Moratuwa, Sri Lanka, revealed that land-based sand could be introduced on a project scale, where the unit cost depends on the scale of operation (Nanayakkara 1999). The cost computation based on a proposed project that included the cutting and washing of soil found that the price would range between LKR 1,230–1,500 per cubic meter.

Dune sand is available in Sri Lanka along the North-west coast between Chilaw and Kalpitiya, across Mannar Island and the Pooneryn Peninsula, along the North-east coast between Pulmoddai and Point Pedro and on the South-east coast from east of Ambalanthota to Trincomalee (Nanayakkara 1999). According to a study by NARESA (1991), an area of 7,500 ha of dune sand is available on the island. Although dune sand was found to be an appropriate substitute for river sand, the wider application of dune sand cannot be recommended due to its role in storm protection, as experienced during the Tsunami of 2004. Also, the quantity of dune sand available is insignificant in relation to the demand for sand.

Quarry dust is the only non-sand option being considered as a realistic alternative to river sand. Studies have shown that quarry dust in Sri Lanka is usually obtained as a by-product of aggregate production and is widely used for the production of cement blocks. Siriwardena (1992) showed that quarry dust could be successfully used in making concrete. Although no specific operations are needed other than crushing, quarry sand is not available at present in significant amounts. The computation, based on a proposed project, revealed that the end price ranges between LKR 2,280 and 3,000 per cubic meter, depending upon bulk density (Nanayakkara 1999).

Off-shore sand also has potential as an alternative to river sand. Large sand reserves in the sea, north of Colombo have been identified and could supply sand for the foreseeable future. Although off-shore sand mining is a new technology for Sri Lanka, it has been practiced for decades in many other countries such as India and the United Kingdom. However, this type of sand is less popular with the construction industry due to the presence of salt and shells. Previous investigations of the technology required have shown that the salt content can be altered, leaving the presence of shells as the only slightly negative factor for the construction industry.

Three major processes are involved with off-shore sand mining as far as cost component identification is concerned. They are: investigation and monitoring costs; the dredging cost; and the cost at the discharge point. The analysis used secondary data available at the Sri Lanka Land Reclamation and Development Corporation (SLLRDC) and the University of Moratuwa, Sri Lanka.

7.2 Off-shore Sand Mining Process

The economics of off-shore sand mining depend on the scale of the dredging operation in the sand mining locality. As the economy of scale is increased, the cost of the operation eventually declines, thus large-scale operations can reduce the unit cost of sand supplied at the stockpile. Trailing Suction Hopper Dredgers (TSHDs) have dredging capacities that range from several hundred cubic meters of sand per day to more than Sri Lanka’s annual requirement of sand in a few weeks. However, economical rates can only be achieved when the usage time of the machine is maximized. Therefore, round-the-clock operation of the dredger is usually preferred. In this analysis, it was assumed that a TSHD with a relatively small capacity would be operated in Sri Lanka. Moreover, two-week shifts have been assumed in order to increase the usage time. Since there is evidence that unprocessed, sea-dredged and well-drained fine aggregates with coarse aggregates have been successfully used in concrete preparation, this analysis assumes that the off-shore sand, after being pumped into discharging bays, would be allowed to drain for sufficient time and then moved to the stockpiles. It is also assumed that the drying of the sand is mainly due to draining out the seawater and not due to evaporation. However, previous experiences also show that there are cases where processing aggregates has been carried out before usage.

A project on off-shore sand dredging should follow a proper seabed investigation. This investigation should include a bathymetric survey and seabed sampling to understand the topography and material characteristics of the ocean floor, and to identify possible borrow areas. An EIA would also have to be carried out.

Table 10. Description of off-shore sand mining costs

Description	Rs. per cube
Capital payments	767.81
VAT	38.39
ICTAD levy	7.68
GSMB loyalty	7.68
License fee	10.60
EIA report	1.88
Opportunity cost of SLRDC 20 land	30.32
Opportunity cost of SLRDC 45 land	2.30
Financial cost	620.24
Administration and security cost	175.00
Loading cost	140.00
Other payments	60.00
Total cost per cube of sea sand	3,447.86
Add profit	352.14
Selling price	3,800.00

Note: Calculations are based on the records available at the Sri Lanka Land Reclamation and Development Corporation (SLLRDC). Capital payments represent the payments made to a foreign firm hired by the SLLRDC. The payments include hire charges for the THSD.

The current tender prices of off-shore sand are shown in Table 11. The price in Colombo without the transport cost is in the range of LKR 3,900–4,900 per cube. With a reasonable (depending on the distance) transport cost, the off-shore sand price at a construction site is in the range of LKR 5,900 and 7,900 per cube. The price of the sand at the river sites varies from about LKR 1,200 to 2,100 per cube[7] during the dry season while the price at the construction site with the transportation cost ranges between LKR 6,000 and 7,000 per cube depending upon the season. Since the difference is marginal, off-shore sand appears to be the best alternative to river sand. Currently off-shore sand is mainly available in the suburbs of Colombo (Western Province) so a reasonable fraction of the total sand requirement could be replaced by off-shore sand. (Currently 40% of the sand demand is created by the construction

[7] One cube = 2.8 cubic meters

boom in Western Province.) Increased use of off-shore sand would reduce the pressures on the Kelani and Ma Oya rivers, which are the main suppliers of sand to Western Province.

Table 11. Off-Shore sand tender prices without transportation (per cube)

Places	Prices
Wattala and Ja-Ela (Muthurajawela)	3,900.00
Kelaniya, Kiribathgoda	4,600.00
Colombo and sub-urban	4,900.00
Average price	4,466.67

Source: Paper advertisement by Sri Lanka Land Reclamation and Development Corporation, August 2009.

However, stakeholder discussions revealed that there are a number of limitations to off-shore sand as an alternative to river sand. These include: the need for a large initial investment, so traditional industries may be reluctant to enter into the business; the traditional thinking of construction companies that believe that river sand is the best kind of sand; the possibility of the presence of chlorides and shells may affect workability, permeability and the durability of buildings; and high transportation costs to the interior from the shore. Moreover, the off-shore sand price is sensitive to the scale of operation so there needs to be an assured demand before the business can be undertaken by firms. This implies a need for policies and other awareness activities to promote the use of off-shore sand. If the government declares that all large development projects, (i.e., highway construction, airports, harbors etc.), must use off-shore sand, then the industry can be initially sustained. Also, the government could use regulation to persuade all large private sector construction projects to move from using river sand to using off-shore sand. Of the total sand demand, 88% comes from home building and other construction which is usually advised by architects and engineers. Therefore, effective awareness and promotional programs that have the support of existing organizations such as the Institute for Construction Training and Development (ICTAD), the Chamber of Construction, and the Sri Lanka Institute of Engineers could be launched to familiarize the marketplace with off-shore sand. Moreover, if necessary, the implementation of a subsidiary scheme at the beginning might be helpful to move constructors towards off-shore sand. Once off-shore sand has become widely accepted these campaigns and the reduced price level can be terminated. Off-shore sand can then be competitively supplied to the market.

7.3 Potential Negative Externalities Associated with Off-shore Sand Mining

A number of potential environmental impacts have been cited. One key impact is increased turbidity which has a negative effect on the marine ecosystem, fauna, and benthic colonies, partly due to the overflow from dredging canals. This could be minimized by filling hoppers to safe levels and monitoring the hoses to prevent leaks and restricting dredging operations during the inter monsoon and northern monsoon period, i.e. when the sea is calm.

A large number of fish species are present in the pelagic waters of the existing environment for off-shore sand mining. These commercially important fish species are commonly found in western coastal waters. However, on the west coast, where off-shore sand mining would be initiated, none of the phytoplankton or zooplankton species is endemic, threatened or endangered. There could be some biological impacts due to stockpiling, but this can be ignored because a huge area is still available as a conservation zone and an urban buffer zone.

A number of registered fisherman associations and cooperatives exist in the area. Marine and lagoon fishing and the fish processing industry provide a major income for a substantial segment of the population within this area. The major social impacts of off-shore sand mining are damage to fishing nets and fishing craft, a reduction in the fish population, obstructions to laying nets, and damage to prawn grounds. These impacts could be mitigated by completing dredging operations in the shortest possible time, and providing fishermen with information about the dredging period and the area of mining activities. There would be no substantial difficulty due to salinity or the turbidity of surface or ground water because it is not used for drinking and commercial purposes. The transportation of the sand could avoid the main periods of traffic in order to prevent congestion on roads.

Off-shore sand may contain approximately 12% shell content. At the dredging stage, sand should be monitored to remove particles larger than 10 mm in size. To reach the acceptable chlorine content (0.075%), the sand stockpile could be exposed to monsoon rains and would not need supplementary washing.

National Environmental Regulation No. 01 (1993) indicates that all off-shore mining and mineral extraction processes need to be environmentally screened. There are two methods of screening: an Initial Environmental Examination (IEE) or an Environmental Impact Assessment (EIA). As part of this procedure, the Project Proponent (PP) needs to submit preliminary information to a Project Approving Agency (PAA) such as the Central Environmental Authority (CEA). After submitting information to environmental scoping the PP should be given Terms of Reference (TOR) for an Environmental Impact Assessment Report (EIAR). In addition, approval from the GSMB is needed for an exploration license for off-shore mining and an industrial mining license is needed for the extraction of off-shore sand. Approval from the Coastal Conservation Department is required in order to lay pipelines through a defined coastal zone and also approval from the Marine Pollution Protection Agency is necessary for the removal of ship-generated waste. The authorities allow dredging at selected sites located 20 kilometers off-shore at a water depth of over 15 meters.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions and Recommendations

River sand is an open access resource and conventional attempts to convert this into private property by quotas and tariffs have not been effective, mainly due to institutional failures related to monitoring and regulation. In Sri Lanka, a third of the supply that caters for the current demand of sand is met by illegal means, thus creating environmental problems. In this context, in order to identify policy options for sustainable river sand mining, private and social costs were compared. Then the trade-offs between environmental conservation and sand extraction as perceived by miners were analyzed under a choice modeling framework. This was followed by the evaluation of management alternatives based on expert views. Finally, given that rivers alone cannot meet the demand for sand, alternatives were sought. Based on the findings of the study the following recommendations can be made.

The study revealed that in the study sites the social cost of river sand exceeds the private costs; however social benefits were found to be non-negative. Since the off-site costs (e.g. coastal erosion) are not included, the true social cost should be more than estimated. However market prices of river sand do not reflect any of the social costs. Therefore, it is suggested that the GSMB should take an active role in assessing sand availability, i.e. the preparation of a sand management plan for all potential sand sites. Moreover, using the rationale displayed in our analysis, a simple yardstick could be developed to classify the sites; then with the support of the law enforcement authorities mining of sand from vulnerable sites should be completely banned and monitored.

The royalty payments and land rent collected by GSMB and local government have remained at very low levels. However, during the last few years the price of sand has increased at least four-fold – this increase has not been passed on to the government. The increasing costs of environmental rehabilitation due to the over-exploitation of sand resources has been borne by government institutions. In analyzing the preferences, it was found that miners are willing to contribute more to the royalty given to the government in order to continue sand mining. The results of the discrete choice experiment further suggest that the negative effects associated with sand mining could be partly mitigated by increasing government revenue towards an environmental trust fund, with some level of co-management. Strict rules and regulation as well as awareness programs, as suggested by the media and environmental groups, may not be that productive, according to the perceptions of miners.

The evaluation of management alternatives based on expert views also gave consistent results. For the Ma Oya River, where there are more than 70 sand mining sites, the restriction of access to vulnerable sites was found to be the best option, followed by the establishment of an environmental trust fund. Community-based management was found to be the best option for the Mahaweli and Deduru Oya rivers.

Off-shore sand was found to be the best alternative to river sand. In Sri Lanka, the construction industry in Western Province is responsible for 40% of the total sand demand. If this river sand were to be replaced by a reasonable amount of off-shore sand, then the immediate pressures on rivers could be mitigated. However, there is less preference for off-shore sand and its price is slightly high. Action is needed to move the construction industry towards the use of off-shore sand, which would absorb part of the demand for river sand, especially in Western Province.

As shown in the analysis, at present the price of off-shore sand is slightly higher than that of river sand. Moreover, there is less preference for off-shore sand due to the possibility of the presence of shells and chlorides. Prices could be brought down by expanding the size of off-shore sand operations because off-shore dredging is sensitive to economy of scale. This could be achieved by the creation of demand for off-shore sand by increasing awareness of the benefits of off-shore sand with engineers, architects and other craftsmen. In other words, since only large-scale off-shore sand mining is worthwhile, there needs to be a satisfactory level of acceptance by the construction community to use off-shore sand. The existing Mines and Minerals Act No. 33 (1992) should be amended so that the use of off-shore sand is compulsory for large construction projects and landfilling.

A river sand tax could be introduced in order to encourage the construction industry to move towards the use of off-shore sand. This could be easily computed using the Bill of Quantities (BOQs) prepared by architects and engineers. The payments could be collected at the BOQ approval stage by the relevant authority, i.e. municipal councils. Note that sand mining is neither taxed nor charged in line with its detrimental environmental costs. This tax should make off-shore sand cheaper than river sand.

8.2 Suggestions for Future Research

The study was limited by not using the spatial data related to the issue. This should be combined with the economic analysis to generate meaningful results. For instance, in representative sites estimation of the optimal rate of sand extraction is very useful. Then this could be compared with renewal and extraction rates.

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APPENDICES

Appendix 1. Sand mining locations

Name of river	Name of site	No. of recorded mining locations
Lunu Oya	Lunu Oya Site	20
Badulu Oya	Badulu Oya Site	21
Kothmale Ganga	Kothmale	23
Kuru Ganga	Kuru Ganga Site	23
Kukule Ganga	Kukule Ganga Site	25
Galwaturu Oya	Galwatura	30
Uma Oya	Uma Oya Site	30
Kuda oya	Kuda Oya Site	31
Kala Oya	Kalawewa	32
Attanagalu Oya	Attanagalla	33
Seethawaka Oya	Seethawaka	33
Hungamala Oya	Hungama	37
Veli Oya	Veli Oya Site	38
Bentara Ganga	Bentara	41
Kumbukkan Oya	Kumbukkan Oya Site	42
Dadugam Oya	Dadugama	45
Ambanganaga	Ambanganga Site	53
We Ganga	We Ganga Site	53
Menik Ganga	Menik Ganga Site	55
Kibulwana Oya	Kibulwana Oya Site	56
Yan Oya	Yan Oya Site	60
Menike Ela	Menike Ela Site	69
Kuda Ganga	Kuda Ganga Site	94
Maguru Oya	Maguru Oya Site	99
Walawe Ganga	Walawe	114
Gin Ganga	Gin Ganga Site	125
MahaWeli	Mahaweli Ganga Site	292
Ma Oya	Ma Oya	307
Kelani Ganga	Kelani Ganga Site	338
Kalu Ganga	Kalu Ganga Site	524

Source: Geological Survey and Mining Bureau, Sri Lanka

Appendix 2. Questionnaire

Identification and Evaluation of Policy Alternatives related to River Sand Mining in Sri Lanka

Department of Agricultural Economics and Business Management
Faculty of Agriculture
University of Peradeniya
Sri Lanka

Date of Enumeration:…………………………………………………………...
Time started:…………………………………………………………………
Time finished:…………………………………………………………...
DS Division:…………………………………………………………………..
GN Division:…………………………………………………………………

Location information
GPS Unit Number:……………………………………………………………
Way point:……………………………………………………………………….
GPS 3D (Y/N):…………………………………………………………………..
Location N ……………..
E ………………

1.1 Background information

1.1.1 Respondent name:…………………………………………………………
1.1.2 Name of the permit holder (if different from above)…………………
1.1.3 Involvement: miner/supervisor or manager/other (state)……………..
1.1.4 Respondent's address:………………………………………………………
1.1.5 Respondent's sex: 1.M/2.F

1.2 Personal details

Relationship to respondent	No. of years in formal education	Age (yrs)	Nature of other employment*	Monthly income from other sources (Rs)
Respondent				

*1. Farming 2. Hired labour 3. Home guard 4. Security force 5. Government service 6. Business and self 7. Carpentry 8. Professional 9. Mansonry 10. Unemployed 11. Other

1.3 *Mankada*/sand-mining related information

1.3.1 When did you or the owner get the permit?...
1.3.2 When did you start sand mining in this site?..
1.3.3 Were you involved in sand mining before? For how long?.....................
1.3.4 Where did you work earlier?..........……………………………………..

1.3.5 If not, what was your previous occupation?..
1.3.6 Membership of sand miners organization? (Y/N): 1.Y/2.N……………….
1.3.7 Distance from main road to *Mankada*: …………………………………
1.3.8 What made you enter the mining business? (please rank)

1. I have land adjacent to the river ☐
2. Because of neighbors/friends/relations ☐
3. Highly profitable ☐
4. Other (specify) ☐

1.3.9 Number of workers involved

Number of people	Outside the area	Within the area	Relationships (If any)
1			
2			
3			
4			
5			
6			
7			
8			

2. Mining costs and income

2.1 Mining costs (wages etc.)

Activity	Number of people employed	Payment basis	Payments (Rs)

2.2 Cost of activities (other costs)

Cost Components	Units	Unit cost	Comments
Land rent cost			
Mankada preparation and stage construction cost			
Tractor transport			
Opportunity cost of the above land			
Equipment			
Shovel			
Bucket			
Road			
Replacement costs			
Capital cost of boats			
Capital cost of tractors			
Other costs			

2.3 Returns

Number of cubes per month	Revenue from one cube

2.4 Institutional payments

Component	Period	Cost per period (Rs.)	To whom payment is made
Permit cost			
Transport permit cost			
Royalty			

3. Resource use questions

3.1 Attitudes to resource use

3.1.1 Awareness of current issues related to river sand mining
1. Not at all 2. A little concerned 3. Highly concerned

3.1.2 Concern about the sand generation rate and extraction rate
1. Not at all 2. A little concerned 3. Highly concerned

3.1.3 Opinion on conservation requirement by law
1. Not at all 2. A little concerned 3. Highly concerned

3.1.4 Attitudes to the reconstruction of damaged river sites by the sand mining community
1. Not at all 2. A little concerned 3. Highly concerned

3.1.5 Concern about future generations' requirements
1. Not at all 2. A little concerned 3. Highly concerned

3.1.6 Opinion on the severity of the environmental damage

1. Not at all 2. A little concerned 3. Highly concerned

3.2 Environmental Management questions

3.2.1 Attitude to the preservation of the environment and the development of infrastructure
1. Not at all 2. A little concerned 3. Highly concerned

3.2.2 Visited SMO meetings
1. Not at all 2. A little concerned 3. Highly concerned

3.2.3 Know the rules and regulations for building a *mankada*
1. Not at all 2. A little concerned 3. Highly concerned

3.3 Assessment of the environmental damage

3.3.1 Riverbank		Measures				
	Length					
	Height					
	Length of the slope					
	Damage level	1	2	3	4	5
3.3.2 Adjoining land						
	Land use					
	Damage level	1	2	3	4	5
3.3.3 Permanent structure						
	Presence/not	Y	N			
	Unit of damage if present	1	2	3	4	5
3.3.4 Sedimentation flow						
	Level	1	2	3	4	5

3.3.5 Other environmental impacts on the riverbank
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………

3.3.6 How much sand (number of cubes) would you like to mine per month?
1. 150 2. 180 3. 210 4. 240

3.3.8 WTP for road maintenance per month (Rs)

3.3.9 WTP to protect riverbed per month (Rs)

4. Any other comments
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

5. Site construction (*enumerator observations only)

Description/guidelines	Followed (1) or not (2)	Observations (Lickert's scale, 1-5) (5 is a high rating, based on appearance)
Use simple equipment to extract		
Load without approaching the river		
Minimum damage to riverbed		
Minimum damage to trees when constructing road		
Maximum two employed per boat		
Total of six employed per site		
Constructing roads parallel to the flow of the river		

Appendix 3. Detailed private costs

Detailed private costs of sand mining: Site 1 – Doluwa

Item	**Unit cost/price (LKR)**	**Cost for one month (LKR)**
Tender price	53040.00 for nine months	5,893
Royalty payments	150.00 per cube	195,000
Labor charges for mining	1200.00 per cube	1560,000
Labor charges for loading	300.00 per cube	390,000
Equipment – cane baskets	300.00 for 15 days	9,000
Equipment – shovel	800.00 for three months	4,000
Total cost (per month)		2,163,893

Detailed private costs of sand mining: Site 2 – Weragantota

Cost items	**Average cost per miner (LKR)**	**Total mining costs for the site (LKR)**
Payments to Pradeshiya Sabha and GSMB	172, 557 per year	6,384,609
Land rent	48,267 per year	1,785,879
Site preparation cost	63,652 per two years	1,177,192
Site maintenance cost	5,135 per year	189,995
Boat rent	51,750 per year	1,914,750
Tractor rent	63,210 per year	2,338,770
Labor cost for loading boat	1,374,227 per year	50,846,399
Labor cost for loading tractor	523,848 per year	19,382,376
Equipment (basket and shovel)	19,500 per year	721,500
Total	2,290,310 per year	84,741,470

Detailed private cost of sand mining: Site 3 – Alawwa

Cost of item	**Average unit cost**	**Total cost**
Permit/tender cost	13,020 per year	312,480
Royalty payment	150 per cube	608,4000
Land rent	3,000 per year	72,000
Labor	800 per cube	32,256,000
Equipment	7,200 per month	86,400
Total		38,810,880

Appendix 4. Sensitivity analysis of multi-criteria analysis

Ma Oya River

Sensitivity ranking for weight adjustments

Ranking is insensitive to weight changes under the social criterion as rank reversal was not observed.

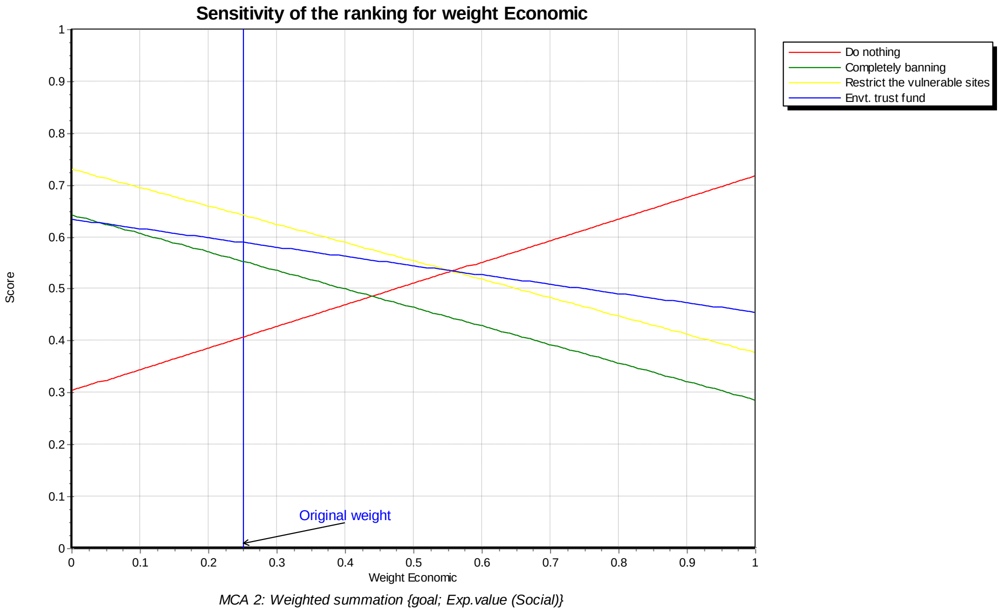

Figure 1. Rank reversal under the economic criterion

With a change in the original weight from 0.25 to 0.44 the “do nothing” option would be highly economical. (“Do nothing” vs “complete ban” 0.44, “do nothing vs environmental trust fund” 0.5581, “environmental trust fund” vs. “Restrict access to vulnerable Sites” 0.5531.)

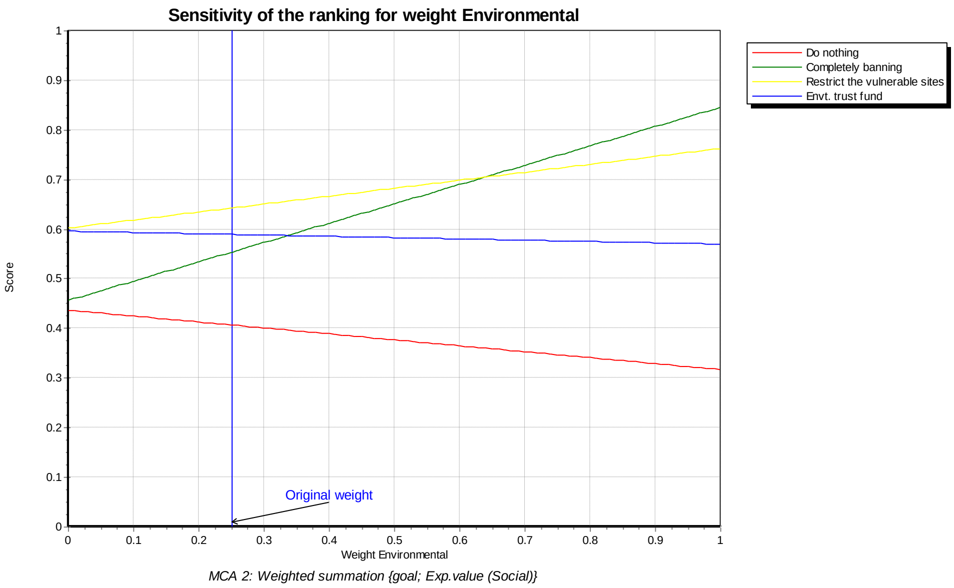

Figure 2. Rank reversal under environmental criterion

There is a tendency to reverse the rank of the environmental trust fund and a complete ban at the weight 0.3368.

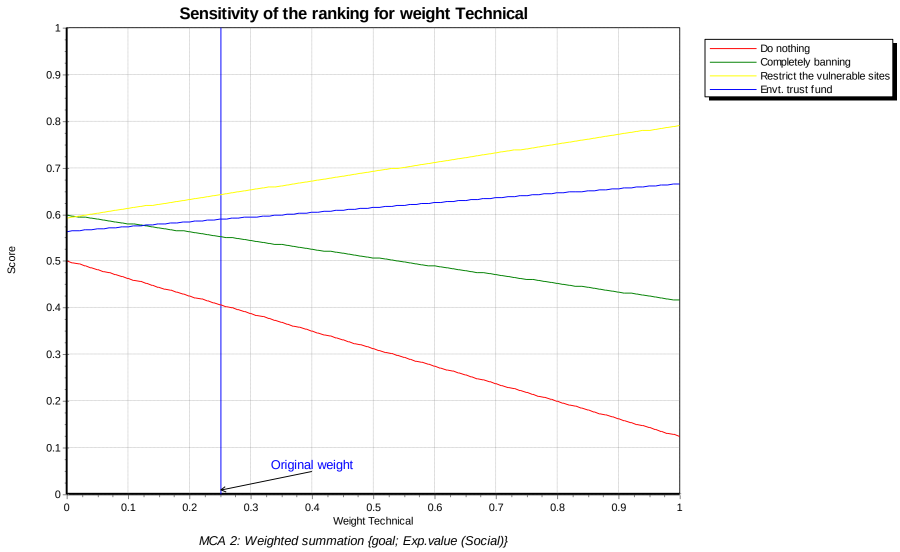

Figure 3: Rank reversal under technical criterion

An environmental trust fund would be the best alternative to a complete ban if the weight given to the technical criteria changes from 0.25 to 0.1206.

Mahaweli River

Sensitivity Analysis

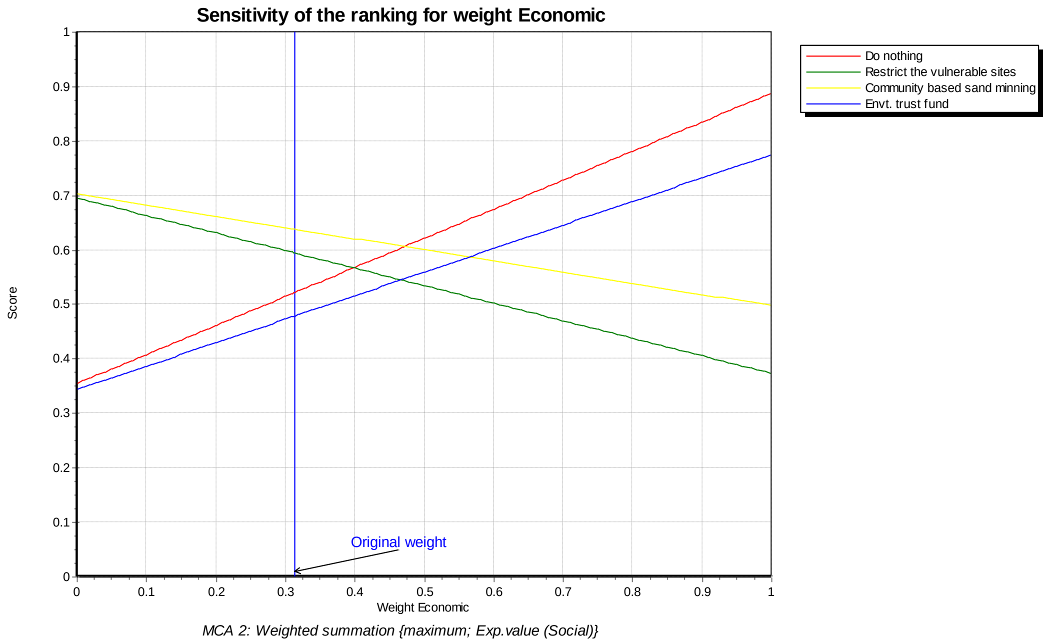

Figure 4. Rank reversal under economic criterion

The "do nothing" option exceeds the option of "restricting access to vulnerable sites" when the weight given for the economic criterion increased to 0.3988 and vice versa for a decline in the weight to 0.21 from 0.313 under the environment criterion.

The social and technical criterions are insensitive to the weights in the context of this study.

Deduru Oya River

Sensitivity Analysis

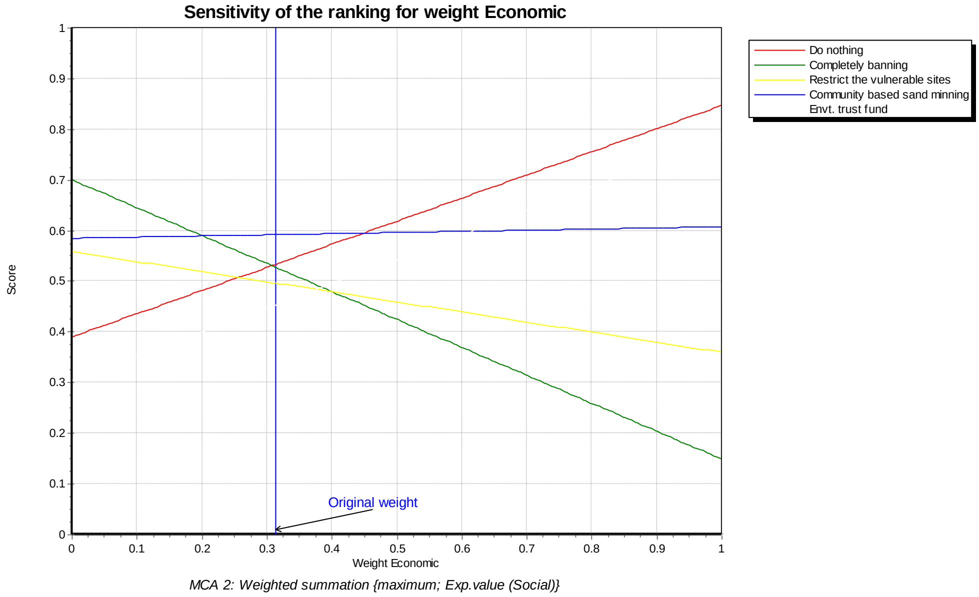

Figure 5. Rank reversal under economic criterion

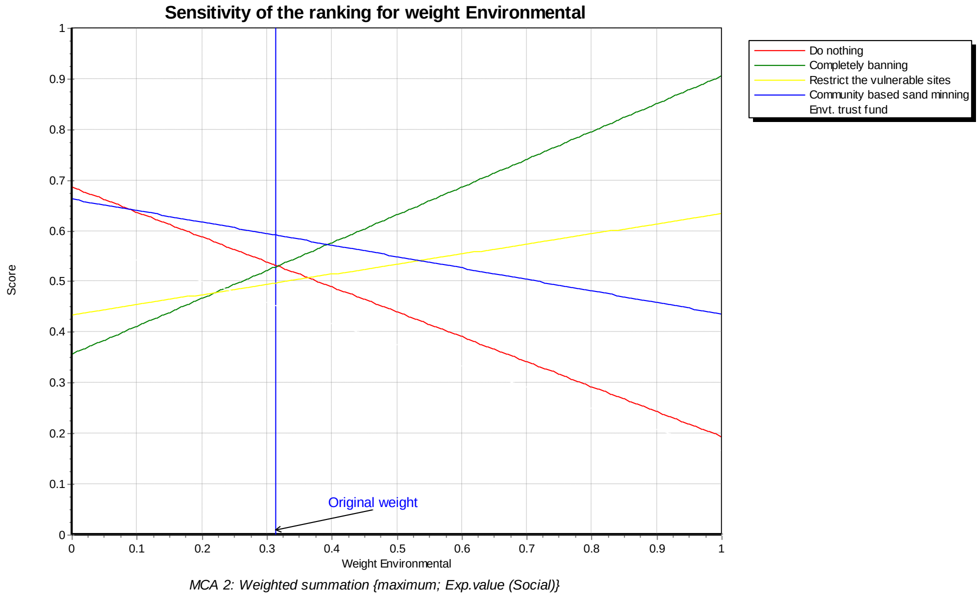

Figure 6. Rank reversal under environmental criterion

Unlike the other sites, at the Deduru Oya River site all the major criterions (social, economical, environmental and technical) were highly sensitive to the weight changes. For instance, “do nothing” and “complete ban” interchange ranks with slight weight changes under all the four major criterions, i.e. of the given weight 0.313 for social, economical and environmental deviations occur by changing the weights to 0.290, 0.308 and 0.317 respectively.