Technical Report

Effect of Sand Mining on River and Groundwater Regime in Hard Rock Areas: A Case Study from Andhra Pradesh

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PREFACE

Many rivers in South India are under stress condition due to increased human interventions. Indiscriminate extraction of sand from river bed is one of the most disastrous one. Demand for construction grade sand is increasing in our country due to rapid growth of infrastructure build-ups. Mining of sand from in-stream and floodplains leads to irreversible damages to the riverine environment and aquifer systems sustained by the river. However, in our country scientific investigations and understanding of the environmental/ ecological impact of river sand mining are noticed to be at a nascent phase still. As a result of lack of appropriate scientific feedback, decision making processes are mostly intuitive and empirical in the case of granting permissions for sand extraction by authorities concerned in various states of the country.

In this context, the Andhra Pradesh State GW Dept. (APGWD) had proposed to initiate studies on the issue of sand mining in their state. It has been reported that excessive removal of sand beds in many rivers/ flood plains in AP is causing depletion in the surrounding aquifers. Besides, depletion of sand reserves, structural damages, river bank erosion, scouring, embankment failures, degradation of the river echo system etc. are being observed. Responding to the proposal of the APGWD and considering the gravity of the problem the HRRC of NIH at Belgaum has decided to proceed with a pilot study by selecting one of the potential sand mining sites in AP. As such, a study on the impact of in-stream sand mining on the river system as well as on the associated aquifer system has been initiated for River Manjira in Nizamabad District of Andhra Pradesh. The proposed investigations and study have been be carried out over a span of two years. The team of scientists along with officials of the state department have been monitoring the field conditions and gathering data/ information. Presented is the report of the investigations/ study compiled with relevant technical details on the subject and activities carried out. The study has been conducted by Dr Mathew K Jose as principal investigator, and Dr T. Chandramohan, Sh. C. P. Kumar and Dr K. Venugopal, B. Narendra, Sh. G. Praveen Kumar (Officials of erstwhile APGWD), as co-investigators and it is expected to throw light into the issue of river sand mining and procedures to evaluate the environmental impacts.

(DIRECTOR)

ABSTRACT

Because of increased human activities within the riverine environment, a number of rivers in India are under tremendous stress. Sand extraction from river bed and flood plains is in an ever increasing phase due to burgeoning demand for construction grade sand. The consequences of continuous sand removal from river bed are of serious nature to the river as well as the environment.

In stream mining of sand can lead to irreversible damages to the river as well as the adjoining aquifer systems. However, it is noted that scientific studies pertaining to various aspects of the issue of sand mining are still meager. Impact of river sand mining on the aquifer systems are to be investigated as groundwater is an important source of drinking water and irrigation in the country. In the presented report an effort has been made towards this goal by considering a case study from erstwhile Andhra Pradesh. Excessive sand mining activities and environmental degradations have been reported by farmers as well as public in many rivers/ flood plains in erstwhile AP (presently, Telengana and Seemandhra). Therefore, a case study has been presented on the impact of stream sand mining on river-aquifer system for the chosen stretch of the River Manjira (Godavari River Basin) in Nizamabad District of Telangana. River-aquifer interaction aspects have been investigated by formulating a three dimensional groundwater model of the region of interest covering some of the existing sand mining reaches on the river.

Also, the effects of sand mining on river system have been studied by employing a methodology consisting of field investigations, laboratory analyses, and river modeling. Profiles of cross-sections at various locations along the river stretch have been taken. Water and sediment samples have been collected and analysed. The HEC River Analysis System has been used to model the river channel processes for steady and quasi-unsteady state situations. Flows and sediment transport for different return periods have been generated as part of the analyses. Various scenarios due to sand mining activities have been envisaged to assess the effects of different intensities of river degradation. Detailed analyses and results of the study are presented.

CONTENT

1. INTRODUCTION

In India, as a result of faster rates of development, creation of infrastructural facilities is rapidly growing. Construction grade sand is one of the pre-requisites for such activities. This causes undue stress on many river systems due to increased rates of sand extraction. It is, however, known that large-scale extraction of sand and pebbles from river beds is one of the most serious stresses on the river environment (Rovira et al. 2005; Kondolf 1994). It can lead to irreversible damage to the river environment (Weeks et al. 2003; Hemalatha et al. 2005). Studies have been carried out in the past in various parts of the world regarding river sand mining (Bull and Scott 1974; Collins and Dunne 1987; Sandecki 1989; Kondolf and Swanson 1993; Poulin et al. 1994; Kondolf 1997; Rinaldi et al. 2005; Jia and Luo 2007; Erskine 2008, Sreebha and Padmalal 2011). Excessive sand mining activities can destroy riverine vegetation, cause erosion, pollute water sources and reduce the diversity of animals supported by these woodlands habitats (Ashraf et al. 2011; Erskine et al.1985; Rinaldi et al. 2005). There are cases reported by investigators highlighting adverse effects of sand mining on the river ecosystems as well as adjoining aquifer systems (Padmalal et al. 2008, APGWD 2009). It is now well established that indiscriminate sand mining activities could be responsible for considerable environmental damage to aquifer systems besides the river ecosystem itself (Kondolf 1997; Leeuw et al. 2010). Nevertheless, in India such kind of investigations is yet to gather momentum. Want of appropriate scientific feedback and results on the subject in our country, decision making processes related to sand mining are mostly empirical in nature. Therefore, site-specific scientific investigations on the impact of river sand mining are to be carried out to facilitate sustainable levels of sand extraction from river systems (Malaysian Dep of Irrigation & Drainage 2009). In this context, mining of sand from the beds and flood plains of many rivers in the Andhra/ Telangana region is reported to have been causing environmental damages including depletion in the surrounding aquifer systems. This paper presents a case study from Nizamabad district of Telangana state wherein the interaction aspects of river-aquifer system (Sanz et al., 2011) is investigated visa-a-vis impact of sand mining on groundwater levels.

2. OBJECTIVES

The major objectives of the study are to investigate

- To understand the interaction aspects between river Manjira and adjoining aquifer system for various stress conditions in order to assess impact of sand mining on the groundwater regime due to removal of in stream bed material at selected reaches of the river using groundwater modelling.
- To investigate the impact of sand mining on riverine system through river analysis and hydraulic simulations

3. DESCRIPTION OF STUDY AREA

The study area falls within the catchment of River Manjira in Nizamabad district of Telangana state. Contained within the Godavari river system, Manjira river basin has a catchment area of about 11,000 sq km. Two sand mining reaches have been identified along the left and right banks of River Manjira at Birukur and Pulkal respectively (Ref: SI Toposheet No. 56F/15). The selected river stretches are located at downstream of a reservoir (Nizam Sagar) bound by latitudes 18^{o} 05' N & 19^{o} 00' N and longitudes 77^{o} 40' & 78^{o} 37' E respectively. Forest cover in the region is about 22%. The area receives a normal annual rainfall of about 1036 mm of which 74% received during the SW monsoon season (June-October). The annual potential evapotranspiration (PET) is about 1591 mm.

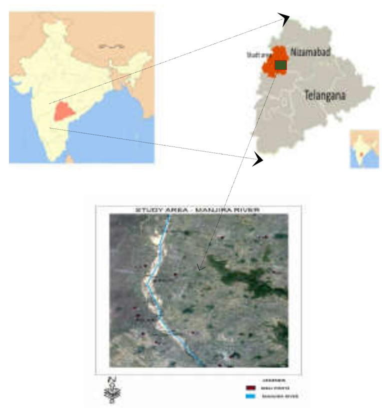


Figure 1: Location of Study area on River Manjira in Distric Nizamabad

Figure 2: Instream sand mining location on R Manjira at Nizamabad

Ground water occurs under various geological formations. Its occurrence and movement are governed by nature of geological formations, the porosity, fracturing and joint systems in rocks. It may be observed that 85% of state geographical area is covered by hard rocks, feasible for bore wells, 10% by sedimentary formations, which are generally semi consolidated in nature, suitable for dug wells and tube wells (APGWD 1976). About 5% area is alluvial formations, favorable for filter points and tube wells along the river reaches. The discharge of an open well may vary between 30,000 to 50,000 lpd in the area (APGWD 2011). In alluvial formations all along the river course, filter points (shallow bore-wells) and infiltration galleries are developed for irrigation and water supply respectively with very good yield.

Though alluvium occupies only about 5% of geographical area, these areas yield nearly 40% of ground water that is used chiefly to irrigate paddy fields (APGWD 2011). As there are no perennial streams in the region, groundwater is the dependent source for all water requirements. Clearly, these are compelling facts that lead to serious investigations regarding the impact of sand mining on groundwater resources, besides that on river system itself. With the reduction or absence of sand layers in these alluvial areas due to sand mining, storage has been observed to be gradually reduced leading to increased runoff from the rainfall received. Further, analysis of water level data indicates that the base flow contribution from aquifer to river system has been on the rise as a result of reversal of flow gradients.

4. REVIEW OF LITERATURE

4.1 Impact on groundwater/ aquifer system:

Stream channel and their flood plains are important sources of construction materials such as gravel, sand etc. River borne aggregates durability and sorting by fluvial action makes them suitable raw materials for construction activities (Kandolf et al., 2002). Increasing construction of infrastructure is responsible for more demand of sand (Tang M., 2011). Most of the rivers in India are over exploited to meet the resource requirement of human beings. One of the dangerous impact of in-stream mining is removal of sand more than it can be replenished naturally (DID Malaysia, 2009). Luo X. et al., (2007) studied the hydrology and morphology of the Pearl River Delta (PRD; South China) over the 20 years. They found that water levels in upstream of the PRD were decreased by 1.59–3.12 m. There are two sides to the effects of sand excavation. The positive effects are decreased chances of flooding damages, improved navigating conditions, and more water inputs to rapid economically growing regions. The negative effects include increased grade slope and instability of the riverbank, disruption of navigation in upstream dredging pits during dry seasons, and brackish-water intrusion.

Zhixian C. and Pender G., (2004) developed the numerical models for alluvial rivers subject to interactive sediment mining and feeding, within the context of shallow water hydrodynamics. Existing numerical river models have been developed for purely natural fluvial processes, and are not applicable where interactive sediment mining or feeding disturbances are exerted from the external. The major difference between the present and previous models is the presence of the sediment mining and feeding fluxes in the continuity equations, which are verified under idealized scenarios with known analytical features. The continuity and momentum equations also contain several terms due to mass exchange between the flow and the mobile bed, which though less known to the majority of the fluvial hydraulics community, can be important for fluvial systems with active sediment transport and morphological evolution. D. Padmalal et al., (2007) studied the environmental effects of river sand mining river on catchments of Vembanad lake, Southwest coast of India. They reveal that sand mining is taking place many folds higher than natural replenishments, which, in turn, led to severe environmental degradation and ecological disorders. Reduction in sediment supply from upstream reaches and erosion of its own channel during high flow regimes of monsoon season are common in many rivers in the southwest coast. This has led to channel incision and undermining of engineering structures like bridges, side protection walls, water intake structures constructed for rural water supplies, etc.

The potential impacts of gravel extraction are well known from literature (Kelly et al. 2005; Rinaldi et al. 2005) and include:

1. bed degradation and consequent effects on channel and bank stability
2. increased sediment loads, decreased water clarity and sedimentation
3. changes in channel morphology and disturbance of ecologically important roughness
4. elements in the river bed
5. ecological effects on bird nesting, fish migration, angling, etc.
6. modification of the riparian zone including bank erosion
7. direct destruction from heavy equipment operation
8. discharges from equipment and refuelling
9. reduction in groundwater elevations
10. impacts on structures and access
11. biosecurity and pest risks
12. impacts on coastal processes

In-stream and flood plain sand mining tends to increase in surface water temperature, groundwater level depletion, reduced dissolved oxygen, turbidity (Meador and Layher, 1998; Bork, 1999; Roell, 1999). These all characteristics have directly impact on aquatic habitat. Decrease in vegetative cove at flood plain due to sand mining effects riparian habitat (DID Malaysia, 2009)

The three prominent factors affecting environmental changes are population, standard of living and technology (Rubin, 2001). Standard of living or the level of affluence of the population is usually measured in terms of economics such as Gross Domestic Product (GDP) per capita. The more affluent the population, the more goods and services demanded, and the greater the resulting environmental impacts. Third critical factor is technology — the vehicle for delivering goods and services that people demand. These three factors are closely interrelated with each other. They are the principal drivers determining future land use patterns, natural resource requirements and pollutant emissions to air, water and land. However, the environmental impacts of human activities, including sand and gravel mining, depend directly on the number of people inhabiting in the area. Ehrlich and Ehrlich (1990) gave the following formula regarding the environmental impact of man: I = P x A x T, where P I Population, A = Per capita consumption of resources and T = Technology. A review of historical records shows that as standards of living improve, there is a concomitant increase in the use of natural resources for energy and raw materials (Rubin, 2001).

Set of recommendation are provided below (Padmalal D. et al., 2007; Sreedharan S. and Padmalal D., 2010) for improving overall environmental quality of sand mining prone areas.

1. An integrated environmental assessment, management and monitoring program should form part of the sand extraction processes.
2. Evaluate physical, chemical and biological effects of in stream mining on a river basin scale, so that cumulative effects of extraction on the aquatic and riparian resources can be recognised and addressed at various levels for proper remedial measures.
3. Examine and encourage alternatives to river sand for construction purposes. Immediate steps are to be taken to intensify research activities leading to the finding of a suitable, low cost and easily available alternative to river sand.
4. Evaluate control measures such as bank stabilisation, revegetation of buffer strips, influences of connected floodplain pits etc. Restoration efforts should concentrate on techniques that will optimise fish production, promote aquatic diversity and restore biotic integrity.
5. Separate legislations are to be enacted for river conservation and aggregate management in the area.
6. Mining should be done with care and with utmost environmental safeguards.
7. There is an urgent need for strengthening multidisciplinary studies on the rivers for providing adequate scientific information to river restoration and management activities.
8. The abandoned pits left after floodplain mining of sand should be reclaimed by land filling.
9. Awareness campaign should be conducted among people about the various impacts of river sand mining, present state of river environment, finite character of river sand, use of alternatives to sand and immediate need for control measures.
10. Limit the extraction of sand to meet indigenous demand alone.

4.2 Impact on River system:

The river morphology are used to describe the shapes of river channels and how they change over time. The morphology of a river channel is a function of the composition and erodibility of the bed and banks (e.g., sand, clay, bedrock), vegetation and the rate of plant growth, the availability of sediment, the size and composition of the sediment moving through the channel, the rate of sediment transport through the channel and the rate of deposition on the floodplain, banks, and bed, and regional aggradation or degradation due to subsidence or uplift.

Sand mining refers to the actual process of removal of sand from a place of their occurrence (oceans, rivers, streams etc.). Sand is removed from the flood plain and the river bed by hungry construction industry. The sand hungry construction industry uses the material to mix with concrete and for making bricks and all of this mining is happening without licenses because the demand is unbridled. Indiscriminate and unregulated sand mining causes erosion of the river bank, deepening & widening of the river channel, lowering of the ground water table, formation of bluff & lumps and damages biodiversity.

Sand and gravel have long been used as aggregate for construction of roads and building. Today, the demand for these materials continues to rise. The main source of sand is from in-stream mining. In-stream sand mining is a common practice because the mining locations are usually near the markets or along the transportation route, hence reducing transportation costs. In-stream sand mining can damage private and public properties as well as aquatic habitats. Excessive removal of sand may significantly distort the natural equilibrium of a stream channel. By removing sediment from the active channel bed, in-stream mines interrupt the continuity of sediment transport through the river system, disrupting the sediment mass balance in the river downstream and inducing channel adjustments (usually incision) extending considerable distances (commonly 1 km or more) beyond the extraction site itself. The magnitude of the impact basically depends on the magnitudes of the extraction relative to bed load sediment supply and transport through the reach (Kondolf et al., 2001).

Collins et al. (1990) summarised the effects of sand and gravel mining as listed below:

a) Extraction of bed material in excess of replenishment by transport from upstream.
b) Causes the bed to lower (degrade) upstream and downstream of the site of removal.
c) Bed degradation can undermine bridge supports, pipe lines or other structures.
d) Degradation may change the morphology of the river bed, which constitutes one aspect of the aquatic habitat.
e) Degradation can deplete the entire depth of gravelly bed material, exposing other substrates that may underlie the gravel, which could in turn affect the quality of aquatic habitat.
f) If a floodplain aquifer drains to the stream, groundwater levels can be lowered as a result of bed degradation.
g) Lowering of the water table can destroy riparian vegetation.
h) Flooding is reduced as bed elevations and flood heights decrease, reducing hazard for human occupancy of floodplains and the possibility of damage to engineering works.

The loose boundary (consisting of movable material) of an alluvial channel deforms under the action of flowing water and the deformed bed with its changing roughness (bed forms) interacts with the flow. A dynamic equilibrium state of the boundary may be expected when a steady and uniform flow has developed (Nalluri & Featherstone, 2001).The resulting movement of the bed material (sediment) in the direction of flow is called sediment transport and a critical bed shear stress (τ_c) must be exceeded to start the particle movement. Such a critical shear stress is referred as incipient (threshold) motion condition, below which the particles will be at rest and the flow is similar to that on a rigid boundary.

Shield (Yang, 1996) introduced the concept of the dimensionless entrainment function, $F_{rd}^2(= \tau_o/ \rho g\Delta d)$ as a function of shear Reynolds number, Re* (= U*d/ν) where is ρ density of the fluid and Δ is the relative density of sediment in the fluid, d the diameter of sediment, g the acceleration due to gravity, U* is the shear velocity (= $\sqrt{\tau\ o/\rho}$) and ν the kinematic viscosity of the fluid, and published a curve defining the threshold or incipient motion condition. The mode of transport of the material depends on the sediment characteristics such as its size and shape, density ρs and movability parameter U*/Ws where Ws is the fall velocity of the sediment particle.

Some sediment particles roll or slide along the bed intermittently and some others hopping or bouncing along the bed. The material transported in one or both of these modes is called 'bed load'. Finer particles are entrained in suspension by the fluid turbulence and transported along the channel in suspension. This mode of transport is called 'suspended load'. Sometimes finer particles from upland catchment (sizes which are not present in the bed material), called 'wash load', are also transported in suspension. The combined bed material and wash load is called 'total load'(Nalluri & Featherstone, 2001).

Bed load ranges from a few percent of total load in lowland rivers to perhaps 15% in Mountain Rivers to over 60% in some arid catchments. Although a relatively small part of the total sediment load, the arrangement of bed load sediment constitutes the architecture of sand- and gravel-bed channels. The rate of sediment transport typically increases as a power function of flow; that is, a doubling of flow typically produces more than a doubling in sediment transport and most sediment transport occurs during floods (Kondolf, 1997).

5. METHODOLOGY

The aquifer modelling methodology has been used to assess the impact of sand mining on groundwater. Data concerning ground water levels, water quality, rainfall, stage-discharge as well as hydrogeological parameters were collected and processed to facilitate simulation of aquifer system for various stress conditions and sand removal options. The study has employed a methodology consisting of (i) field investigation methods, (ii) laboratory analyses of water samples and river bed load samples, (iii) river hydraulics modelling using HEC-RAS, and (iv) groundwater aquifer simulation techniques. A conceptual groundwater model for the river-aquifer system of the study area has been formulated, and simulations of scenarios under different stresses are generated using the MODFLOW code (McDonald and Harbaugh 1988).

The interaction characteristics have been analysed by simulating heads in the domain by employing the developed groundwater model for various stage conditions in the river. A few scenarios have been predefined depending upon the condition of the river based upon varying degrees of sand mining activity, land use practices in the surroundings and groundwater usage pattern in order to ascertain the river-aquifer interaction aspects. Thus, the following possibilities of the river channel arising out of sand mining activities have been considered, namely, widening of the river channel, deepened of the river channel, a combined effect of both widening plus deepening of the river channel as well as changes in groundwater pumping rates. Stress periods consisting of pre-monsoon, monsoon and post-monsoon periods have been considered for simulations.

The river simulation tools like HEC-RAS and BAGS were used to ascertain the impact on riverine system. Sediment and bed load samples were been collected from selected river sections along the stretch, and relevant laboratory analyses carried out. The HEC-RAS River Analysis System (Brunner, 2010) software was used to model the 1-D river channel processes. Profiling of cross-sections at various locations along the river stretch has been carried out to facilitate the river modeling. The methods from Bedload Assessment in Gravel-bed Streams by Pitlick et al (2009) has been used for computing bedload transport rates.

The environmental impact of in-stream/ flood plain sand mining may comprises of components like impact on fluvial system, impact on adjoining aquifer system, and impact on aquatic ecosystem. The major fluvial impact may be envisaged as the change in the rate of transport and accumulation of sediments in the river environment. As such, a few scenarios have been visualized to facilitate the assessment of such impacts on the riverine environment, like, widening of river channel; deepening of river channel; formation of river bluffs; formation of lumps; changes in sediment transport rates etc.

6. RESULTS AND ANALYSIS

A discussion on the results and inferences are presented based on field investigations and modelling studies using three dimensional groundwater model (MODFLOW), river analysis system (HEC RAS) as well as bed load assessment packages (BAGS). A number of simulations have been carried out for various cases and results analysed. For the sake of clarity, the two aspects which are considered for the assessment namely, the aquifer and the river environment have been dealt with in two separate sections below.

6.1 Impact on Aquifer System:

A three dimensional groundwater model (MODFLOW) has been calibrated for the study area and analyses performed using the simulation results.

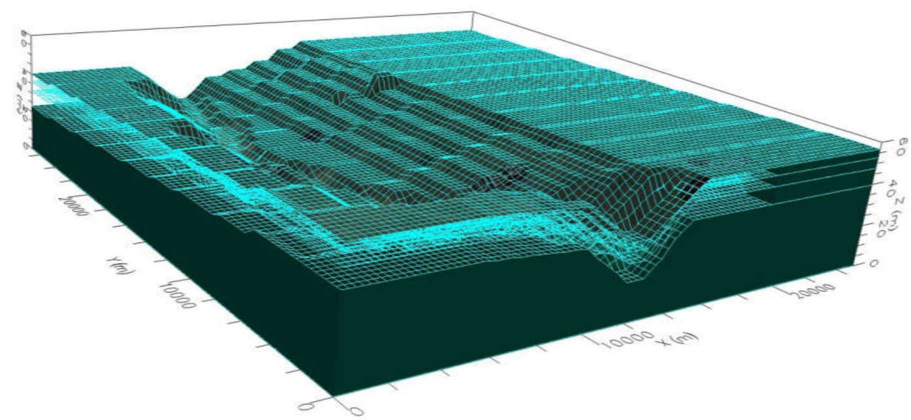


Figure 3: The three dimensional discretized model domain of the study area

6.2 Discretization and Boundary Conditions:

The discretised model has 90 rows, 95columns, and 4 layers for the finite difference grid. The grid dimesions are: 25 km along the columns, 27km along the rows with 60m depth. The study area is characterised by granite and patches of alluvial soil composed of sand and clay. Lateral extension of alluvium varies between 0.2 to 3 km from the river banks. Aquifer thickness is about 17 m.

Site map has georeferenced with known coordinates. Natural ridge line exist at the eastern boundary. Therefore, all the cells of eastern boundary are kept as inactive. Cells of fourth layer are inactive as it constitutes the impermeable strata and forms the lower boundary of the model.

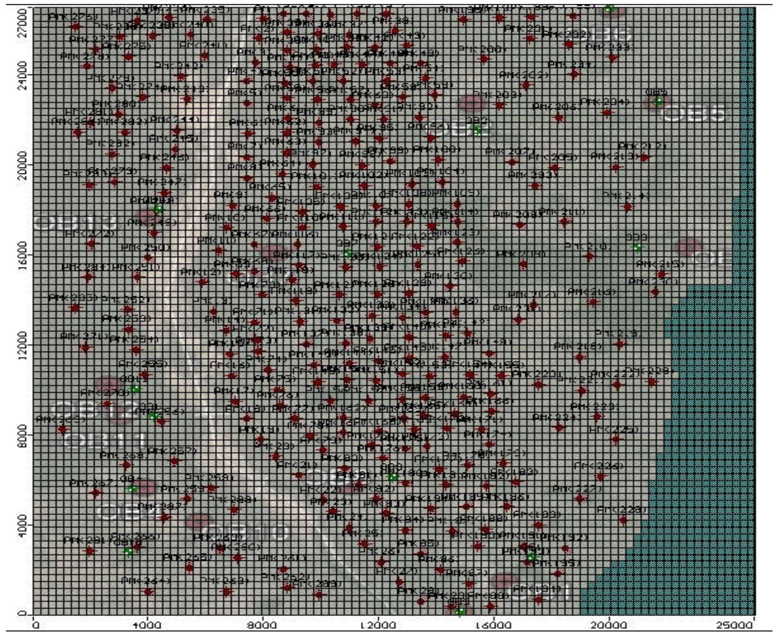


Figure 4: A planar view of the gridded domain of the study area with wells

The elevation goes on decreasing from south to north. Also, there is a slope towards the river channel from eastern and western boundaries. Longitudinal profile of Manjira River varies from 368 msl at upstream side to 348 msl at downstream side. Considering 328 msl as datum for the model domain, all other elevations have been reduced to model elevations to facilitate simulations. Observation data from 22 observation wells have been collected and used for calibration and validation of the model.

The calibration parameters like hydraulic conductivity, storage coefficient and rainfall recharge are given in Tables 6.1, 6.2 & 6.3 respectively.

Table 6.1: Calibrated conductivity

Soil Type	Initial Conductivity (m/s)			Calibrated Conductivity (m/s)		
	Kx	Ky	Kz	Kx	Ky	Kz
Sand	6.9E-4	6.9E-4	6.9E-4	6.9E-5	6.9E-5	6.9E-6
Clay	10E-10	10E-10	10E-6	10E-10	10E-10	10E-6
Granite	10E-8	10E-8	10E-8	10E-8	10E-8	10E-11

Table 6.2: Calibrated storage characteristics

Soil Type	Initial Storage Characteristics			Calibrated Storage Characteristics		
	Sy	Ss	n_{eff}	Sy	Ss	n_{eff}
Alluvium (sand/clay)	0.2	2.8E-5	0.15	0.2	2.8E-5	0.15
Granite	0.03	2.8E-5	0.15	0.003	2.8E-5	0.15

Table 6.3: Calibrated rainfall recharge

Soil Type	Initial rainfall recharge	Calibrated rainfall recharge
Alluvium (sand/clay)	22 % of precipitation	16 % of precipitation

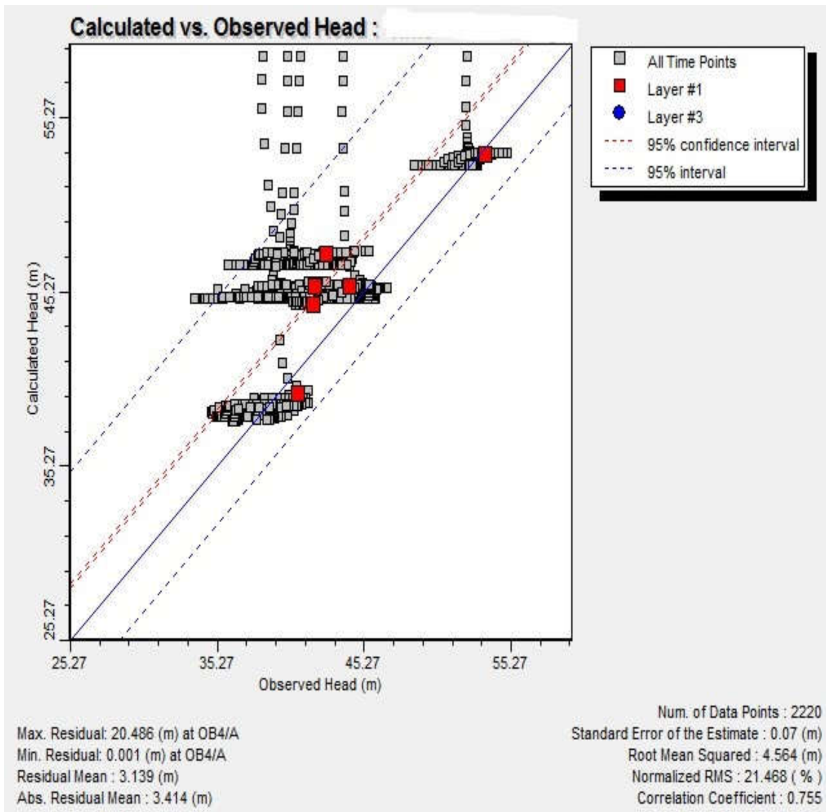


Figure 5: Calibration (Calculated vs. Observed head)

It is found that groundwater flow is generally in the south to north direction, and also towards river reaches. Analysis of seasonal variation in river-aquifer fluxes indicates gains to the aquifer system during the post and pre-monsoon periods while the aquifer is contributing during the wet season. The general nature of the river-aquifer interaction is clear from Table 6.4.

Table 6.4: Typical values fluxes indicating river-aquifer interaction in the study area

Months	River-aquifer Interaction fluxes	
	m^3/day	m^3/s
August 2010	-34220.4	-0.396
November 2010	-6666	-0.077
February 2011	+49476.1	+0.572
May 2011	+60134	+0.695

During the rainy season (monsoon) there is no irrigation, and agricultural activity (dominated by paddy) solely depends upon rainfall. The negative flux during this period indicates that aquifer is losing and river is gaining as the regional water table is elevated compared to the river stage. However, during the dry season (pre monsoon) water table tends to deplete and hydraulic gradients reverse. Thus, river starts contributing to the aquifer system and helps to sustain the availability of groundwater. It may be noticed that, indiscriminate mining of river bed can cause further lowering of the water table within the river channel and flood plains resulting in less flux or no contribution to the aquifer system.

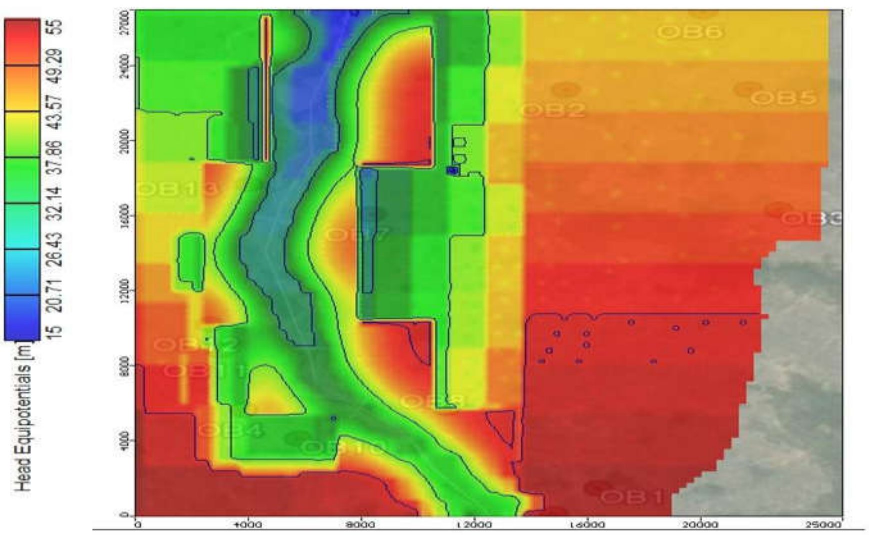


Figure 6: Contours of hydraulic head in the modelled domain

The calibrated model has been used to isolate effects of sand mining for various scenarios on groundwater levels at different river reaches. Four river reaches with sand mining activities namely, Wajidnagar, Pulkal, Birkur, and Pothangal have been considered for the investigations. The results of these different scenarios are tabulated in the tables 3.5, 3.6 and 3.7 respectively for three distinct cases of widening of river channel, deepening of river channel, and widening plus deepening of river along with increased groundwater extraction rate.

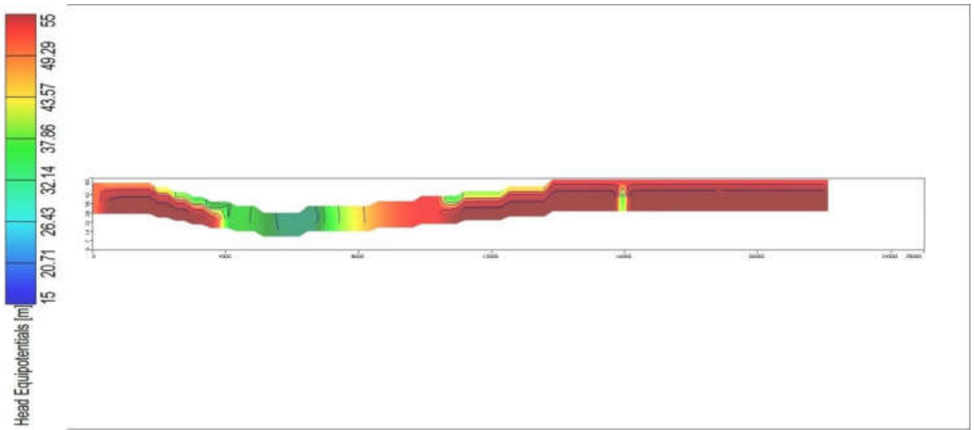
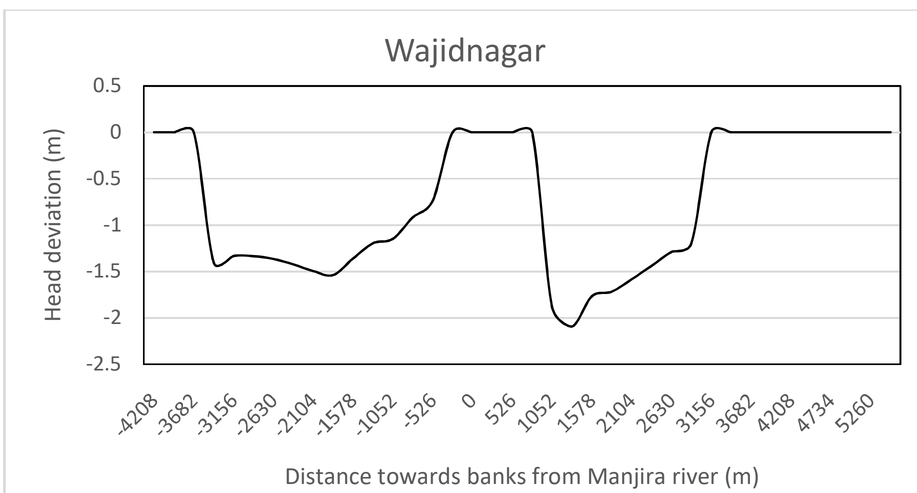


Figure 7: Hydraulic heads in Pilkal Cross section

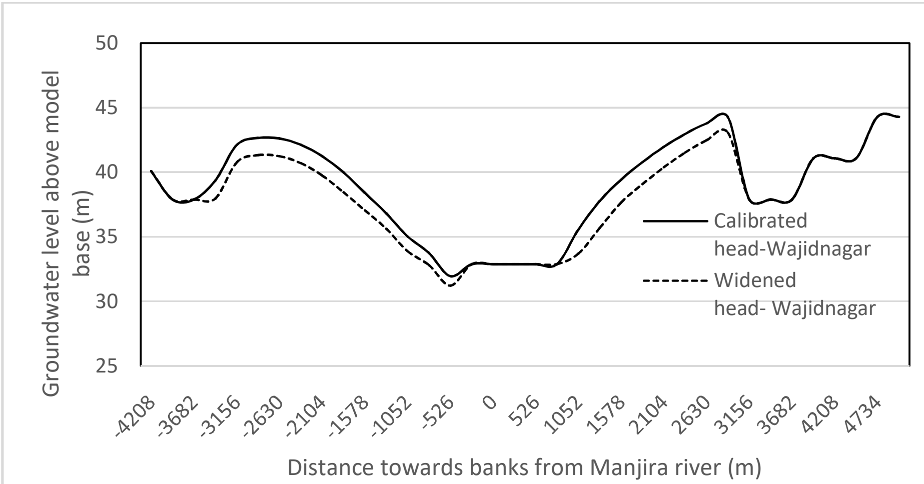
6.4 Analysis of different scenarios

1. Widening of a river channel:
In this case width of river channel is increased by 25 %. Hence there will be corresponding decrease in the river stage.

A) Wajidnagar river reach



(a)



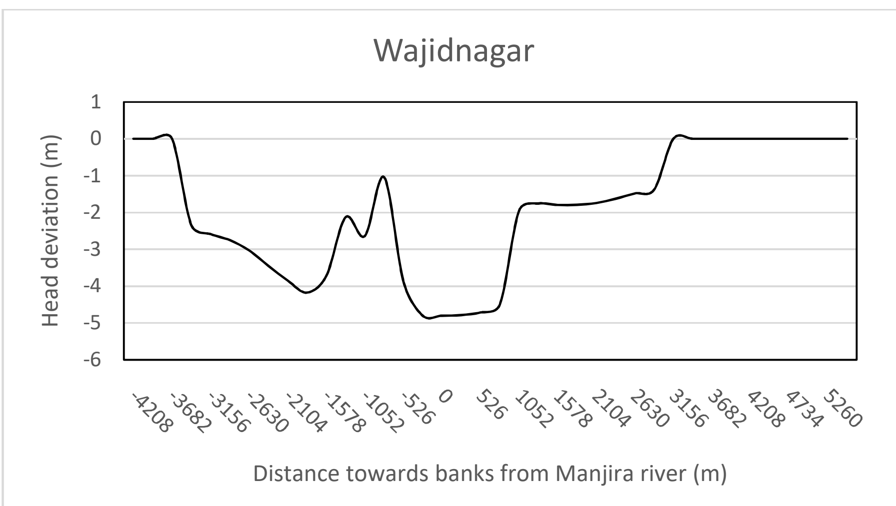
(b)

Figure 8: Effects of widening of river channel at Wajidnagar

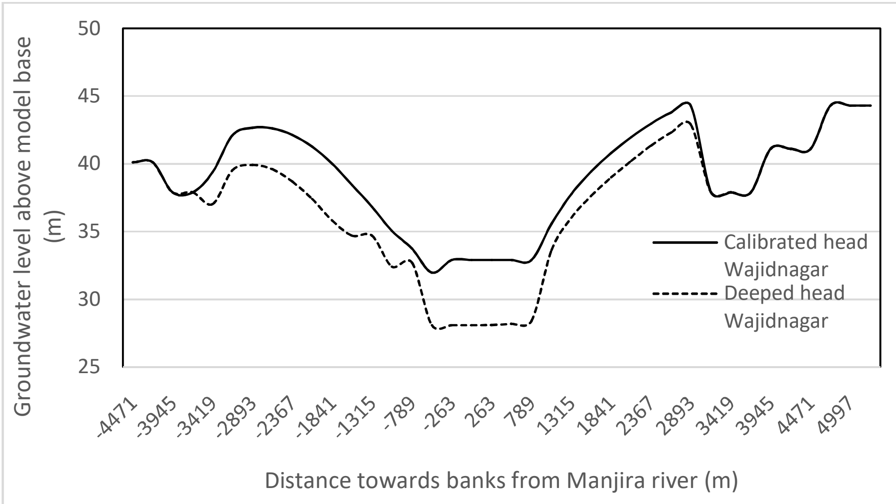
Deepening of river channel

The scenario is carried out to check what if whole sand layer is removed of river channel. Thus 4 m deep sand layer is removed.

A) Wajidnagar river channel



(a)

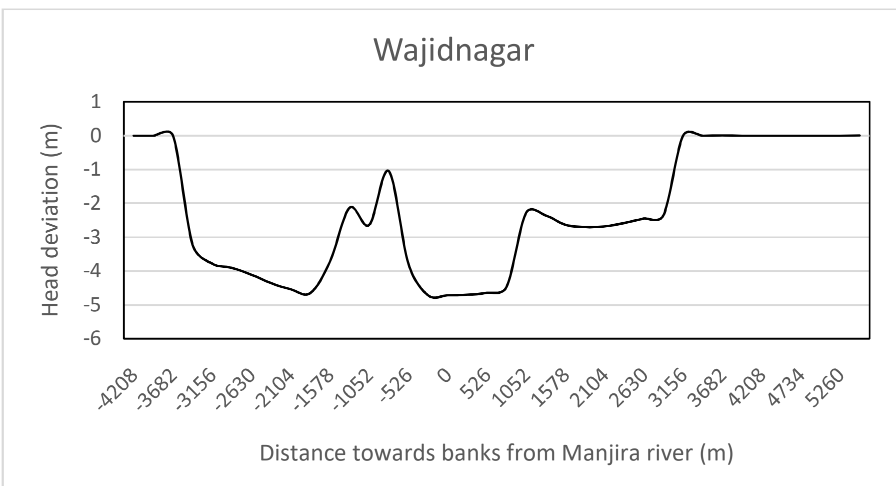


(b)

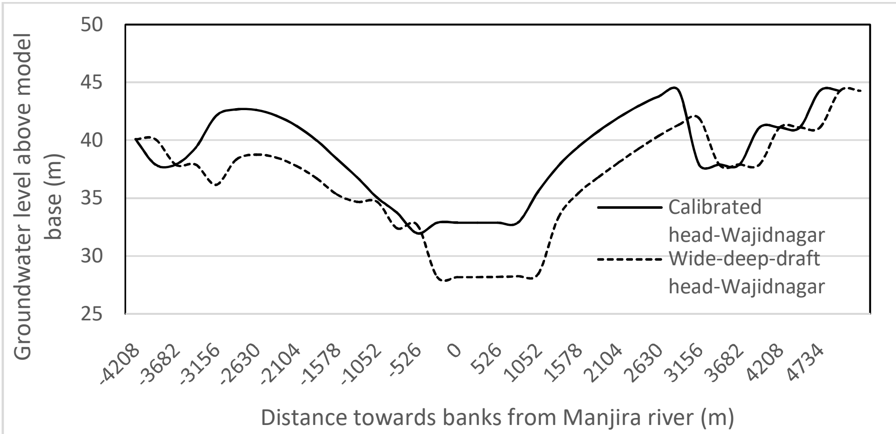
Figure 9: Effects of deepening of river channel at Wajidnagar

Widening, deepening of river channel and increase in groundwater extraction by 25 %
This is case of worst scenario where river channel is widened, deepened and groundwater extraction rate is increased by 25 %.

A) Wajidnagar river reach



(a)



(b)

Figure 10: Effects of widening, deepening of river channel and increase in groundwater extraction rate at Wajidnagar

Table 6.5: Case1: Widening of river channel

River reach	Effect on left bank of river		Effect in right bank of river	
	Extension (km)	Maximum groundwater level depletion (m)	Extension (km)	Maximum groundwater level depletion (m)
Wajidnagar	3.6	1.53	3.1	2.1
Pulkal	2.3	2.5	4.2	1.5
Birkur	-	-	3.4	2.2
Pothangal	2.3	1.67	3.6	3.5

In the first scenario width of river channel is increased by 25 %. There is depletion in groundwater levels right from upstream Wajidnagar to downstream Pothangal. Maximum groundwater depletion found to be 3.5 m at right bank of Pothangal and effect extends up to 3.6 km. There is no groundwater depletion at left bank of Birkur.

Table 6.6: Case2: Deepening of river channel

River reach	Effect on left bank of river		Effect in right bank of river	
	Extension (km)	Maximum groundwater level depletion (m)	Extension (km)	Maximum groundwater level depletion (m)
Wajidnagar	3.6	4.1	3.1	4.7
Pulkal	2.3	5.8	4.2	5.1
Birkur	0.5	4.7	3.4	4.6
Pothangal	2.3	6.8	3.6	6.5

River channel is deepened by 4m in the second scenario. Groundwater level depletion is more as compare to widening. Groundwater level depletion found to be in left bank of Birkur as it was not the case in widening scenario. Maximum groundwater level depletion is found to be 6.8 m at left bank of Pothangal.

Table 6.7: Case3: Widening plus deepening of riverl & increased groundwater extraction rate

River reach	Effect on left bank of river		Effect in right bank of river	
	Extension (km)	Maximum groundwater level depletion (m)	Extension (km)	Maximum groundwater level depletion (m)
Wajidnagar	3.6	4.6	3.1	4.7
Pulkal	2.3	7.1	4.4	5.1
Birkur	2.6	4.8	3.4	4.6
Pothangal	2.6	6.8	3.6	6.5

In the third case, a combination different conditions is applied, where river channel is widened, deepened and groundwater extraction rate is increased by 25 %. Groundwater level depletion is marginally higher as compared to both widening and deepening scenarios. However, it may be observed that deepening of river channel by means of sand mining has greater impact. Overall, it is found that there is not much variation as far as case 2 (channel deepening) and case 3 (combined effect) are concerned. Therefore, marginal increment in channel widening and extraction of groundwater in the adjoining aquifer (of the tune of 25%) has not apparently influenced considerable depletion of groundwater levels in the aquifer system in comparison to the channel deepening situation. It is further observed that there is an increase in groundwater depletion rate in the upstream to downstream direction.

6.4 Impact on Riverine System

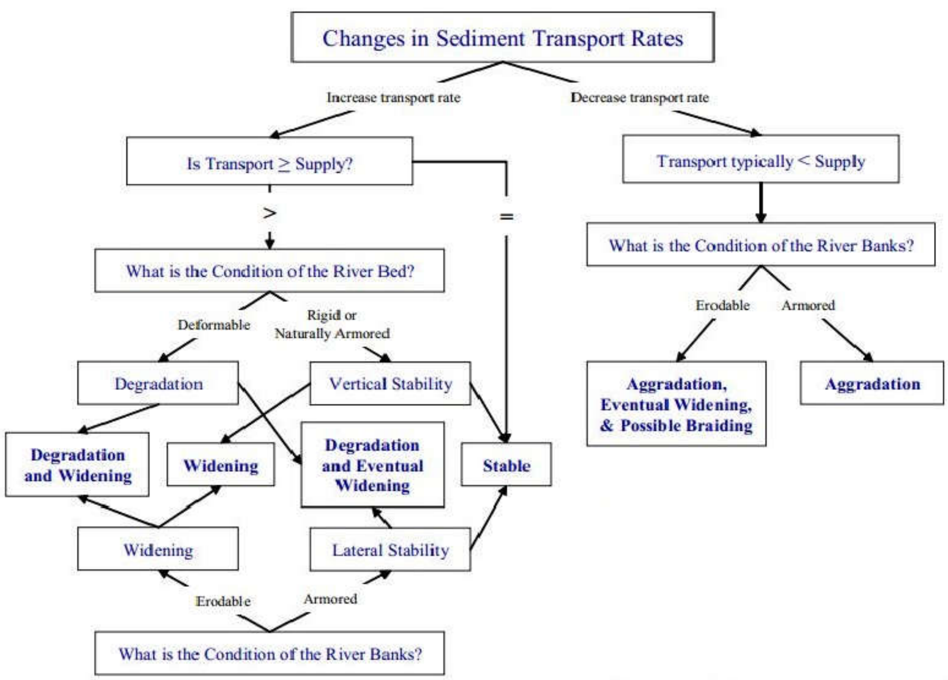


Figure 11: Effects of change in Sediment transport rate on the river channel

The environmental impacts of in-stream sand mining comprises of components like a) impact on fluvial system b) impact on adjoining aquifer systems c) impact on aquatic ecosystem. The major fluvial impact may be envisaged as the change in the rate of transport and accumulation of sediments in the river environment. As such the following scenarios have been visualized in the assessment of the impact of sand mining;

1) Widening of river channel;
2) Deepening of river channel;
3) Formation of river bluffs;
4) Formation of lumps;
5) Groundwater fluctuations/lowering/depletion
6) Groundwater contamination / water quality
7) Change in the vegetation cover / bank deformation
8) Changes in sediment transport rates
9) Changes in aquatic ecosystem / fish species

1) Widening of river channel:

The collapsing of the river bank widens the river channel. The collapsing of the river bank increase sediment load, magnitude of sedimentation and turbidity of the downstream of the collapsed banks (Kori, E, and Mathada, H, 2012).

2) Deepening of river channel:

During high floods (in case of sand mining); the volume of the bed material decreases which deepen the river channel (Kori, E, and Mathada, H, 2012).

3) Formation of river Bluff:

Due to continuous erosion of bed material, the contact between the sand materials loses; it causes the sudden collapsing of the bed material over the river bank (the river bank on both the sides lowers as compared to its initial position).

4) Formation of Lumps:

Lumps are formed due to rapid deposition of thick, localized masses of heavier sediments directly upon lighter material. Lumps caused the turbidity (Morgan, J, Coleman, J, and Gagliano, S, 1968).

5) Groundwater fluctuations/lowering/depletion:

Excessive pumping out of ground water during sand mining results in depletion of ground water level, which affects irrigation and potable water availability.

6) Groundwater contamination / water quality:

Sand mining reduces the thickness of natural filter material (sediments) infiltration through which ground water is recharged into the aquifer.

7) Change in the vegetation cover / bank deformation:

Vegetation cover controls erosion and provide nutrient into the stream and prevents intrusion of the pollutant in the stream through runoff.

8) Change in sediment transport rates:

Changes in sediment transport rates combined with the boundary conditions of the bed and banks ultimately determine channel stability (Figure 1.5). Activities that increase water conveyance often increase the channel's ability to transport sediment. If the size of erodable particle exceeds the critical threshold of the bed or bank material, increased erosion and deposition can occur. Long-term increases in channel erosion lead to removal of finer subthreshold particles and bed degradation. If sufficient large particles remain, the river bed may become naturally armored and stabilize, leaving just the banks still subject to erosion and channel widening. Reducing the river's ability to transport sediment by reducing its slope or diverting water (i.e., lowering water velocity) can lead to sediment deposition and channel aggradation.

The methodology adopted for the analysis of impact of sand mining on river system consists of application of river analysis software and computation of bedload transport within the stream. In order to envisage various possibilities a few scenarios have been visualized and analyzed for varying intensities of channel flow represented by different return periods. In order to carry out the analysis of fluvial system, the HEC-RAS (Brunner, G, CEIWR-HEC, 2010) software has been employed. The bedload Assessment in Gravel-bed Streams (BAGS) (Pitlick, J, Cui, Y, & Wilcock, P, 2009) has been used for computing bedload transport rates.

6.5 Conceptualization Of The System:

Figure 12: Scheme of the River Manjira between Wazid nagar and Pothangal reach

The stretch of the Manjira River system under investigation has been conceptualized with four cross sections / control-sections, namely Wazid nagar, Pulkal, Birkur, and Pothangal over a reach length of about 20 Km from upstream to downstream respectively. The cross sections / control-sections have been chosen to ascertain the impact in-stream sand removal from River Manjira, as Birkur and Pulkal are two potential sand mining spots and the other two sections as the control sections. The roughness parameters (Manning's coefficient) have been assigned based on the existing field conditions of the River environment. The flow in the River Manjira predominantly ephemeral, consisting of about five months starting from June to October during normal Monsoon years. During the remaining period of the year the river either sustains minimum flow or no flow. During the High flow periods, the stage in the river is four to six meters. Since Manjira river in the study area is not supported by discharge measurements, it is necessary to deduce discharge data using the stage-discharge data of nearby Lendi river at Degloor (one of the tributaries of Manjira river) to proceed with the analysis assuming hydrological homogeneity of the region.

6.6 Field Investigations

During field investigations; river cross sections have been mapped and bedload samples are collected and analysed. These data were used for developing the sediment model in HEC-

RAS software and Bedload transport model in BAGS software. Water samples were analysed in the laboratory and the results used to check out the water quality in the four selected stretches (Wazid nagar, Pulkal, Birkur and Pothangal).

6.7 Measurement of River cross sections

River cross sections of the four selected stretches of the Manjira river have been mapped in collaboration with the Andhra Pradesh Ground Water Board (APGWB), Nizamabad and those data are plotted in the following Figures.

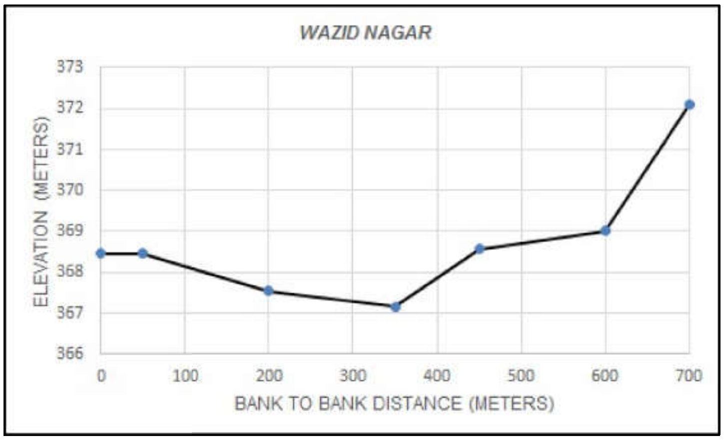


Figure 13: Plot of typical River cross section at Wazid nagar reach

Collection of Bedload sample data:

Medium sand is the bedload material in the Manjira river of the four selected stretches after performing sieve analysis test in the laboratory (Fig. 3.8 – 3.11).

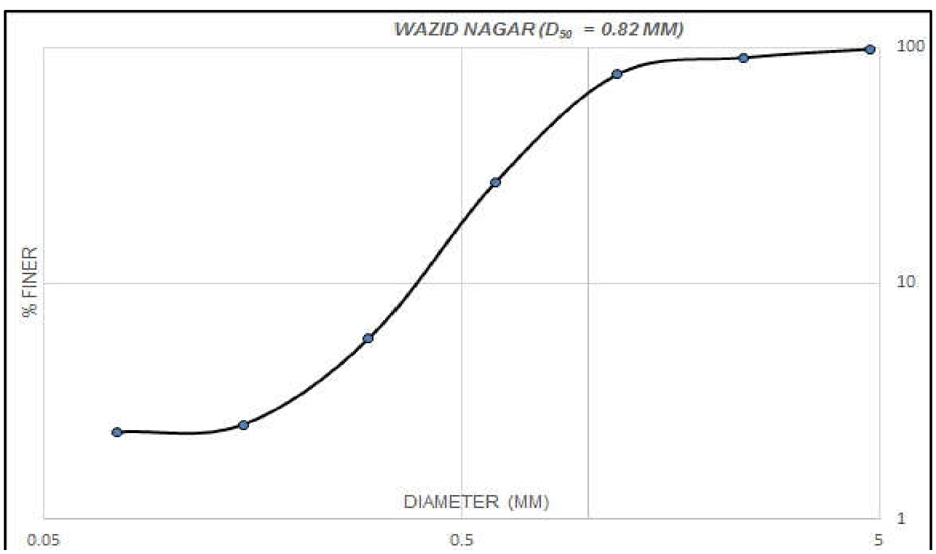


Figure 14: Grain size distribution curve for Wazid nagar cross section

6.9 Collection of River water sample:
Water samples were collected and analysed from the four selected stretches of the Manjira and results given in Table below:

Table : Water quality tests at different sites of River Manjira

Tests	Specific Conductivity (µS/cm)	Chloride content (mg/lit)	Hardness (mg/lit) as $CaCO_3$	Alkalinity (mg/lit) as $CaCO_3$	Total Dissolved Solids (mg/lit)	Turbidity (NTU)
Wazid nagar	220	18.5	134	138	136.4	0.5
Pulkal	240	30	40	124	148.8	5.3
Birkur	360	34.5	180	198	223.2	0.5
Pothangal	330	34.5	160	256	204.6	0.6

6.10 River Model Set Up With HEC-RAS

The U.S. Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) is a one-dimensional model, intended for hydraulic analysis of river channels. The model is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The system includes four river analysis components such as the steady flow water surface profile computations, unsteady flow simulation, sediment transport computations and water quality analysis. The steady flow component uses the standard step method for the solution of steady gradually varied flow. The unsteady flow component uses a numerical solution of the equations governing gradually varied unsteady flow in open channels. The movable boundary component uses the sediment continuity and one of several sediment transport equations to calculate river bed degradation. In HEC-RAS model, sediment transport computations is resulting from erosion and deposition rate over reasonable time periods. The HEC-RAS model is intended to simulate long term trends of erosion and deposition in a stream channel that might result from modifying the frequency and duration of the stage and discharge of the channel, or modifying the channel geometry. HEC-RAS applications include floodplain management studies, bridge and culvert analysis and design, and channel modification studies.

Following data have to be entered for developing sediment model in HEC-RAS:

1) Geometric data
2) Quasi-Unsteady flow data
3) Sediment data

Geometric data:
The geometric data develops by drawing the river system from upstream to downstream on a reach by reach basis. Geometric data consist of establishing the connectivity of the river system by entering cross-section data.

Table – Table showing distance between the selected reaches of the Manjira river used in HEC-RAS modelling

River station	Left of Bank (meters)	Channel (meters)	Right of Bank (meters)
Wazid Nagar	8630	8630	8630
Pulkal	7300	7300	7300
Birkur	3740	3740	3740
Pothangal	0	0	0

In HEC-RAS; cross section data consists of station and elevation points (Fig. 3.4 -3.7), downstream reach lengths (Table 3.3), Manning's roughness coefficients for main channel (0.04) and bank stations (0.06). The Manning's coefficients have been ascertained based on assessment of field conditions.

Quasi-Unsteady flow data:
The quasi-unsteady flow assumption approximates a continuous hydrograph with a series of discrete steady flow profiles. For each record in the flow series, flow remains constant over a specified time for transport. The steady flow profiles are easier to develop than a fully unsteady model. Each discrete steady flow profile is divided, and further subdivided, into shorter blocks of time for sediment transport computations; such as the flow duration, the computation increment and the bed mixing time step.

Here, threshold discharge (discharge considered greater than or equal to) is considered as two thousand Cumecs & Rainy season is considered for sediment transport analysis and water temperature is taken as 26°C, since fall velocity are sensitive to water temperature. Boundary conditions are considered as flow series data (1987-2011) at Wazid nagar station and stage series data (1987-2011) at Pothangal station.

Flow duration:
The flow duration is the coarsest time step (Fig. 3.12). It represents the length of time over which flow, stage, temperature, or sediment loads are assumed constant. Here the flow data was collected daily, therefore flow duration taken as twenty four hours.

Computational increment:
The flow duration is further sub-divided into a computational increment (Table 3.4). Although flow remains the same over the entire flow duration, the bed geometry and hydrodynamics are updated after each computational increment. Model stability can be sensitive to this time step, because the bed geometry can only change at the end of the time step. When the computational increment is too long, the bed geometry is not updated frequently enough and the model results can vary.

Bed mixing time step:
Computational increments are further subdivided into the bed mixing time step. During each mixing time step in a computation increment, bathymetry, hydraulic parameters, and transport potential for each grain size remains constant.

Table - Table showing the computational increment used in HEC-RAS for different flows

Q_{low} (Cumecs)	Q_{high} (Cumecs)	Computational Increment (hours)
2000	4000	1
4000	6000	0.5
6000	8000	0.25
8000	10000	0.2
10000	15000	0.1

The computations for sediment erosion and deposition take place during this time step and this can cause changes to the composition of the bed mixing layers (e.g. the active, cover and/or inactive layers). The vertical gradational profile is rearranged in response to the removal or addition of material. Since the active layer gradation changes during the bed mixing time step, the sediment transport capacity changes even when the hydrodynamics and, therefore, the transport potential remains constant.

6.11 Sediment data:
The sediment data has two conditions namely initial & boundary condition;

Initial conditions and Transport parameters:
In this the HEC-RAS model has to specify: sediment transport potential, sorting and armoring method, fall velocity method, sediment control volume, mobile cross section limits and the bed gradation associated with each cross section.

Sediment transport potential:
Sediment transport potential is the measure of how much material of a particular grain class a hydrodynamic condition can transport. Transport potential is computed with one of a number of sediment transport equations namely Ackers and White, England Hansen, Laursen-Copeland, Meyer-Peter Muller, Toffaleti, Yang and Wilcock. Among which only Ackers and White and England Hansen transport functions are used for the analysis of sediment transport in HEC-RAS software; since medium sand is a bedload material in the Manjira river.

6.12 Transport model set up with BAGS:
The BAGS (Bedload Assessment of Gravel-bed Streams) software implements six bedload transport equations developed specifically for gravel-bed rivers:

1) The surface based equation of Parker (1990),
2) The substrate based equation of Parker-Klingeman-McLean (1982),
3) The substrate based equation of Parker and Klingeman (1982),
4) The surface based two fraction equation of Wilcock (2001),

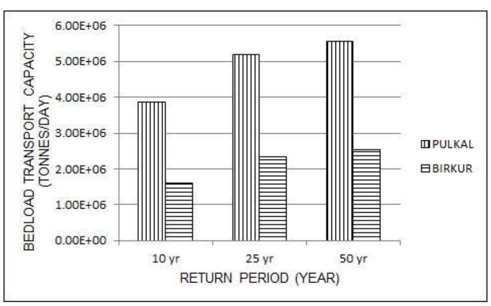
5) The surface based equation of Wilcock and Crowe (2003), and
6) The procedure of Bakke and others (1999).

All of the equations and procedures recognize the role of the armor layer in regulating bed load transport rates, thus the dynamics of transport are represented by the three components such as the surface layer, substrate, and bedload. The equations of Parker (1990), Wilcock (2001), and Wilcock and Crowe (2003) apply surface grain size characteristics as inputs, while the Parker Klingeman-McLean equation (1982) uses substrate grain sizes. The method of Bakke and others (1999) applies to either the surface or the substrate, depending on circumstances. Also, the methods of both Wilcock (2001) and Bakke and others (1982) use bed load measurements to calibrate certain coefficients in the transport equations and procedures.

Even though there are six method available in the software BAGS, only Parker, Klingeman and Mclean method has been employed to compute the Bedload transport for the present case as this is the only method applicable for the particle size distribution (Medium sand) of Manjira river bed as evident from the sieve analysis.

6.13 Analysis of Sand Mining Scenarios

In order to assess the impact of sand mining due to the activities at the chosen river sections, three different scenarios of the river reach were considered. Those are: (i) Widening of river channel due to sand removal, (ii) Deepening of the river channel due to sand removal, and (iii) Combination of Widening and Deepening of the River channel due to sand mining. These scenarios were compared with a no-sand mining situation. The sediment transport rates were computed by Ackers and White method and Engelund-Hansen method using HEC-RAS software for more than twenty year period during 1988-2010. A brief discussion on different scenarios is given below.



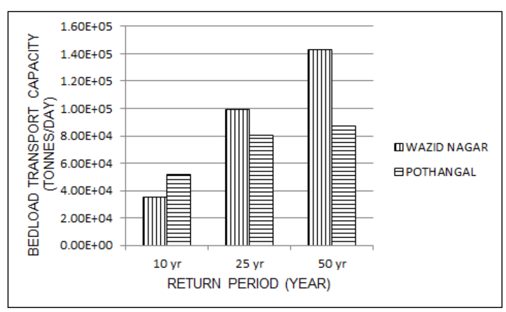


Figure 15: Plots of Bedload transport capacity for various Return periods for four cross-sectional locations

No Sand mining Scenario

A situation is visualized without sand mining within the river reach, and total sediment transport mass had been computed at four stretches using HEC-RAS software. The results are tabulated in Table 1, below. The results can be used as a base to compare other scenarios.

Table 1: Table showing total sediment transport mass computed by Engelund-Hansen and Ackers & White methods for Scenario 1 (no-sand mining situation) for duration 1987-2011

Location	*Total Sediment transport mass in tones using Engelund-Hansen methods*	*Total Sediment transport mass in tones using Ackers and White methods*
Wazid Nagar	5.11E+08	5.56E+08
Pulkal	1.73E+09	1.86E+09
Birkur	2.98E+09	3.12E+09
Pothangal	2.59E+09	2.30E+09

Widening of the river channel

Here, river width is increased by 20% in the model uniformly from both banks of the river channel and then total sediment transport mass calculated. Comparing widening of the river channel condition with no-sand mining condition, it has been found that total sediment transport mass at Wazid nagar stretch it is decreased by 0.18% , at Pulkal stretch it is decreased by 0.17% . However, at Birkur stretch it is decreased by 0.17%, and at Pothangal stretch it is decreased by 0.22%.

Deepening of the river channel

Here, Channel bed is lowered by 5 meter and then total sediment transport mass and total sediment supply mass have been calculated at four stretches. Comparing deepening of the river channel condition with no-sand mining condition, it has been found that total sediment transport mass by Ackers and White method at Wazid nagar stretch it is increased by 46.95%, at Pulkal stretch it is increased by 10.21% , at Birkur stretch it is decreased by 2.25%, and at Pothangal stretch it is increased by 3.04%. Also, total sediment transport mass by Engelund-Hansen method at Wazid nagar stretch it is increased by 35.03% , at Pulkal stretch it is increased by 20.23% , at Birkur stretch it is increased by 32.88%, and at Pothangal stretch it is increased by 46.72%.

Similarly, by Ackers and White method it has been found that total sediment supply mass at Wazid nagar stretch has no change, at Pulkal stretch it is increased by 46.94%, at Birkur stretch it is increased by 10.21%, and at Pothangal stretch it is increased by 2.24%. Also, by Engelund-Hansen method it has been found that , total sediment supply mass at Wazid nagar stretch has no change, at Pulkal stretch it is increased by 35.02% , at Birkur stretch it is increased by 20.23%, and at Pothangal stretch it is increased by 32.88%.

Combination of Widening and Deepening of the river channel

The scenario visualized here is just a combination of the previous two scenarios (Scenario 2 & Scenario 3). As such, river width is increased by 20% from both sides of the channel and also channel bed is lowered by 5 meter. Total sediment transport mass and total sediment supply mass have been calculated at four stretches. The result is presented in Table 2.

Comparing combination of widening and deepening of the river channel condition with without sand mining condition; it has been found that total sediment transport mass by Ackers and White method at Wazid nagar stretch it is increased by 46.95%, at Pulkal stretch it is increased by 10.21%, at Birkur stretch it is decreased by 2.25%, and at Pothangal stretch it is increased by 3.04%. Also, total sediment transport mass by Engelund-Hansen method at Wazid nagar stretch it is increased by 35.03% , at Pulkal stretch it is increased by 20.23% , at Birkur stretch it is increased by 32.88%, and at Pothangal stretch it is increased by 46.72%.

Table 2: Table showing total sediment transport mass computed by Engelund-Hansen and Ackers and White methods for Scenario 4 (widening and deepening) for duration 1987-2011

Location	*Total Sediment transport mass in tones using Engelund-Hansen methods*	*Total Sediment transport mass in tones using Ackers and White methods*
Wazid Nagar	8.43E+08	8.51E+08
Pulkal	3.81E+09	3.91E+09
Birkur	6.94E+09	6.17E+09
Pothangal	6.39E+09	4.67E+09

Similarly, it has been found that total sediment supply mass by Ackers and White method; at Wazid nagar stretch has no change, at Pulkal stretch it is increased by 46.94% , at Birkur stretch it is increased by 10.21%, and at Pothangal stretch it is increased by 2.24%. Also, it has been found that total sediment supply mass by Engelund-Hansen method at Wazid nagar stretch has no change, at Pulkal stretch it is increased by 35.02% , at Birkur stretch it is increased by 20.23%, and at Pothangal stretch it is increased by 32.88%.

CONCLUSION

Aquifer system

A river-aquifer interaction model is constructed for better understanding of groundwater system dynamics. Modelling carried out using the Visual MODFLOW. Salient features of work done are described below.

Model is calibrated for a period from June 2004 to October 2006 using trial and error method. Calibration is done by matching simulated heads with observed heads. Results are relatively good in accordance with availability of data.

An attempt is made to understand groundwater system dynamics by qualitative analysis of seasonal variation in river-aquifer fluxes. Indian water year June 2010 to May 2011 is considered as representative year.

Groundwater flow seems to be from south to north and also towards river reaches.

rainy season aquifer discharges into the river. As we move towards dry season (no rainfall) groundwater undergoes cone of depression due to groundwater pumping. This results in modification of river-aquifer relationship. Hydraulic gradients gets reversed and gaining river switches to losing. River stages starts depleting and soon river gets dried up.

Few scenarios are carried out to ascertain impacts of sand mining on groundwater regime by setting up synthetic simulation considering worst case scenario (i.e. groundwater levels to highest). This situation arrived in February 2011.

Deepening of river channel results in more groundwater level depletion than widening of river channel. Groundwater level depletion in third scenario (i.e. widening, deepening of river channel and increase in groundwater extraction rate) is more as compare to both widening and deepening scenarios. There is no much variation in sand mining effects extension towards river banks but rather in groundwater level depletion for different scenarios. Sand mining do have directly impact on groundwater regimes at different river reaches.

Groundwater level should be monitored at more number of locations on continuous basis so that model simulations can be improved. There is need of detailed hydrological, hydrogeological characteristics to carry out similar modelling exercises to yield exhaustive results.

River System

A study has been carried out with a view to assess the impact of in-stream sand mining on river environment and to simulate the transportation characteristics of sediments with a case of a selected river reach of Manjira river in Nizamabad district of Telangna. It is expected that the methodology adopted for the study may be emulated in similar investigations to evaluate impact of river sand mining on river systems. Different scenarios arising out of intense sand mining activities, like channel widening, deepening and erosion/deposition of channel were simulated using appropriate models and results analysed.

The inference from the study may be summarized as follows:

Scenario 1: Without sand mining

It has been found that Wazid nagar and Pulkal stretches are prone to erosion condition. However, Birkur and Pothangal stretches are prone to deposition condition. The maximum sediment transport mass occurred at Birkur stretch and maximum sediment supply mass occurred at Pothangal stretch.

Scenario 2: Widened river channel

Sediment transport mass and sediment supply mass has been decreased as compared to scenario 1. The maximum sediment transport mass occurred at Birkur stretch and maximum sediment supply mass occurred at Pothangal stretch.

Scenario 3: Deepened river channel

Sediment transport mass and sediment supply mass has been increased as compared to without sand mining condition. The maximum sediment transport mass occurred at Birkur stretch and maximum sediment supply mass occurred at Pothangal stretch.

Scenario 4: Combined effect of widening and deepening of river channel

Sediment transport mass and sediment supply mass has been increased as compared to without sand mining condition. The maximum sediment transport mass occurred at Birkur stretch and maximum sediment supply mass occurred at Pothangal stretch. Further, it is observed that Pulkal reach has maximum bedload transport capacity.

The study is expected to set out a precedence in establishing a scientific approach and a robust procedure, by integrating river channel hydraulics and aquifer system simulations to gather insights, for similar investigations of river sand mining elsewhere.

Results from a case study of river-aquifer interaction in the backdrop of in-stream sand mining activities on a stretch of river Manjira in the district of Nizamabad, Telangana has been presented. As mentioned earlier, the study employed (i) field investigation methods, (ii) laboratory analyses, (iii) river hydraulics modeling, and (iv) groundwater aquifer simulation techniques. The prognostic projections of various possible scenarios facilitate specific understanding of river aquifer interaction characteristics. Sustainability of the river as well as aquifer has to be maintained while removing bed load material from the river. Maintaining sustainable limits of groundwater levels in the adjoining aquifer system is important to ensure dependability on well discharges to support agriculture and domestic requirements. Site-specific guidelines based on the inferences of the study can be of use while framing policies for sustainable levels of sand mining and regulating such activities with a view to environmental protection.

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