J. Ind. Geophys. Union (October 2006)
Vol.10, No.4, pp.285-292

Studies on silt deposition in Gambhiram Reservoir – A Remote Sensing Approach

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ABSTRACT
The non-perennial Pedda Gedda, a minor watershed located in the hilly terrain of Eastern Ghats Mobile Belt (EGMB) region of Visakhapatnam District of Andhra Pradesh, has a drainage area of 184.9 sq.km with a reservoir called Ghambhiram in the middle of the basin. It is characterized by khondalite suite of rocks. Thematic information has been generated on the drainage pattern of the river, geological setting, geomorphological evolution of fluviatile landforms, lineament/structural trend and landuse/landcover. In this study, the Silt Yield Index (SYI) technique has been used to assess the effects of silt on the storage capacity of the reservoir. The study has been conducted at watershed level to understand the fluviatile activity of the river system. The study area is divided into 7 micro watersheds on the basis of drainage conditions. The micro watersheds 5 and 6 adjacent to the reservoir have rolling topography with moderate slopes contributing more silt to the reservoir. The micro watersheds 1 and 7 have no role in silt deposition to the reservoir. Sheet, gully and stream erosions are responsible for the reduction of the storage capacity of the reservoir to around 40% of its designed capacity. Mitigation measures like check-dam, afforestation and concrete have been suggested to arrest silt deposition.

INTRODUCTION

The Pedda Gedda watershed is located in Visakhapatnam District of Andhra Pradesh between 17^0 4′ and 17^0 55′ northern latitude and 83^0 10′ and 83^0 25′ eastern longitude. The Gambhiram Reservoir is constructed in 1962 across the Pedda Gedda with a gross storage capacity of 112.03 MC. Ft, and 40% of its storage capacity is lost owing to silt deposition. The problem of silt deposition occurs in all major and minor river basins eroding about 5333 million tones (16.35 T/H) of soil annually (Suresh *et al.,* 2004) in India creating severe environmental problems.

The Pedda Gedda is a minor category watershed (Rao 1975) with a drainage area of 184.9 sq km. The river has two tributaries, Marikavalasa Gedda and Chitta Gedda (Fig.1). Physiographically, the area is divisible into hilly terrain and plain areas. The process of silt deposition has been studied at watershed level to understand the fluviatile activity of the river system. In this study, IRS-IB-LISS-II of 1992 and IRS-IC-LISS-III of 1999 data have been used. Ground truth survey was carried out in November, 2003. Silt Yield Index (SYI) technique has been used to assess silt deposition in the Gambhiram reservoir.

MORPHOLOGICAL STUDIES

An empirical relationship has been developed for sediment yield estimation for 50 catchments by Garde & Kothari (1982) in India using catchment area, slope, drainage density, vegetation cover and annual precipitation. In the present investigation morphological features such as morphometry, geological setting and evolution of landforms in the river basin have been analysed. The basin is divided into 7 micro-watersheds. The drainage pattern of the river basin is mostly dendritic type. Other patterns encountered are sub-dendritic, parallel, rectangular and radial (Fig.1). Radial type of drainage is developed over the hilly terrain because of domal structure and dendritic type of drainage over the plains.

Morphometric analysis of the watershed is carried out from the Survey of India toposheets 65 O/5 & 65 O/1 on 1:50,000 scale. The linear and relief aspects are studied using the methods of Strahler (1957) and Chorely (1957). The estimated morphometric parameters are given in Table.1.

The stream order indicates the position of a stream in the hierarchy of the tributaries. The fifth order stream of Marikavalasa Gedda confluences with 5th

Table.1: Morphometric Parameters of Pedda Gedda Watershed

Area of the basin	184.9 sq.kms
Stream order	6th
Bifurcation ratio	4.813
Drainage density	1.89
Stream frequency	3.126
Relief ratio	0.01898

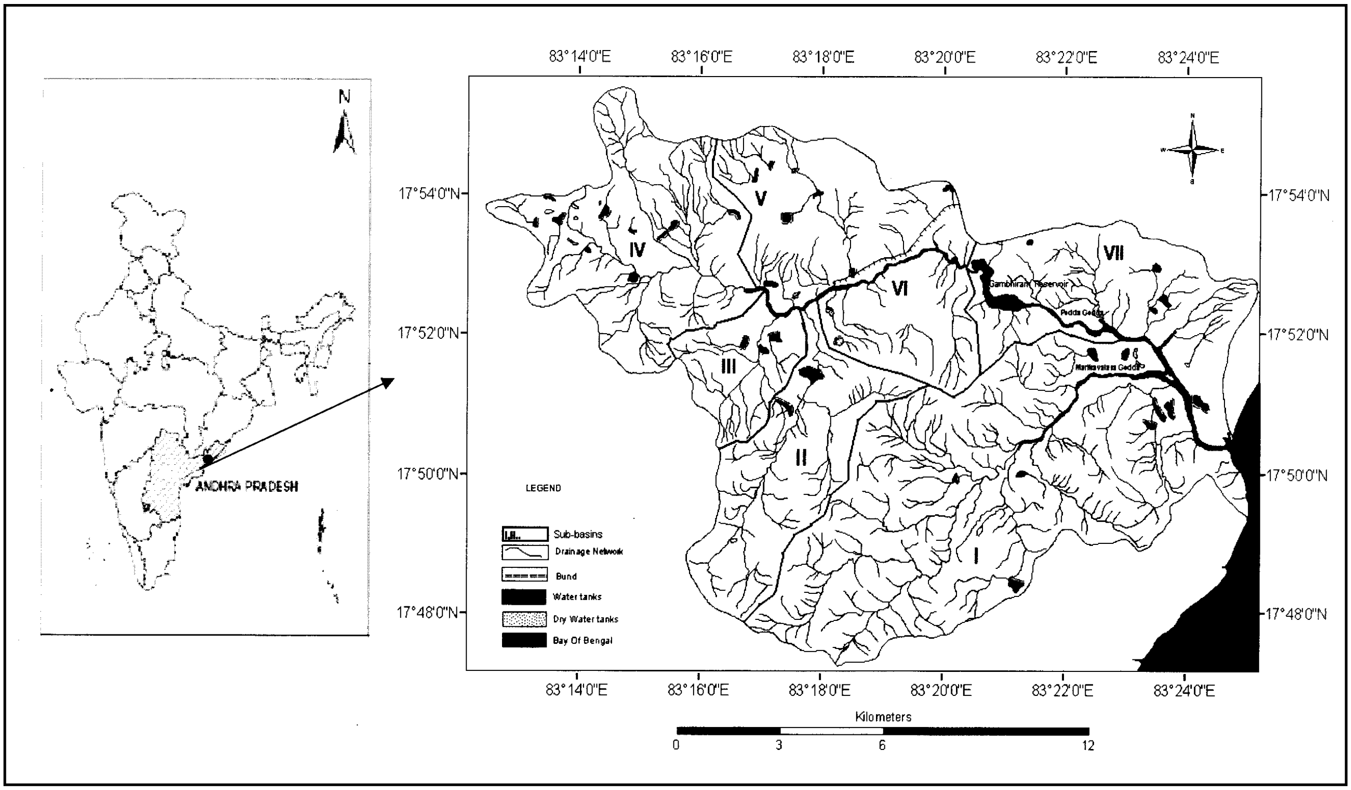

Figure 1. Location and Prioritisation map of the watershed

order stream of Pedda Gedda at Uppada village and forms 6th order which is the highest in the watershed (Fig.1). The drainage density reveals the closeness of spacing of drainage channels, thus providing a quantitative measure of the average length of stream channel for the basin.

The Bifurcation Ratio (Rb) is indicative of shape of the basin. An elongated basin may have a high Rb whereas a circular basin a low Rb (Nag and Surajit Chakraborty, 2003). The study area is elongated in shape as suggested by its mean bifurcation ratio (Table.1).

The basin relief of Pedda Gedda watershed varies between 128 to 484 meters. The relief measures corroborate with the inferences drawn from other parameters that the erosional development of the drainage basin has advanced well past maturity.

Integration of thematic maps

Thematic maps of drainage pattern, lineaments, geological setting and geomorphology have been generated and integrated to assess their cumulative affect on denudational process which influences the silt deposition in the reservoir (Fig.2).

Lineament studies

Linear features have been identified on the satellite False Color Composite (FCC) on 1:50,000 scale, and

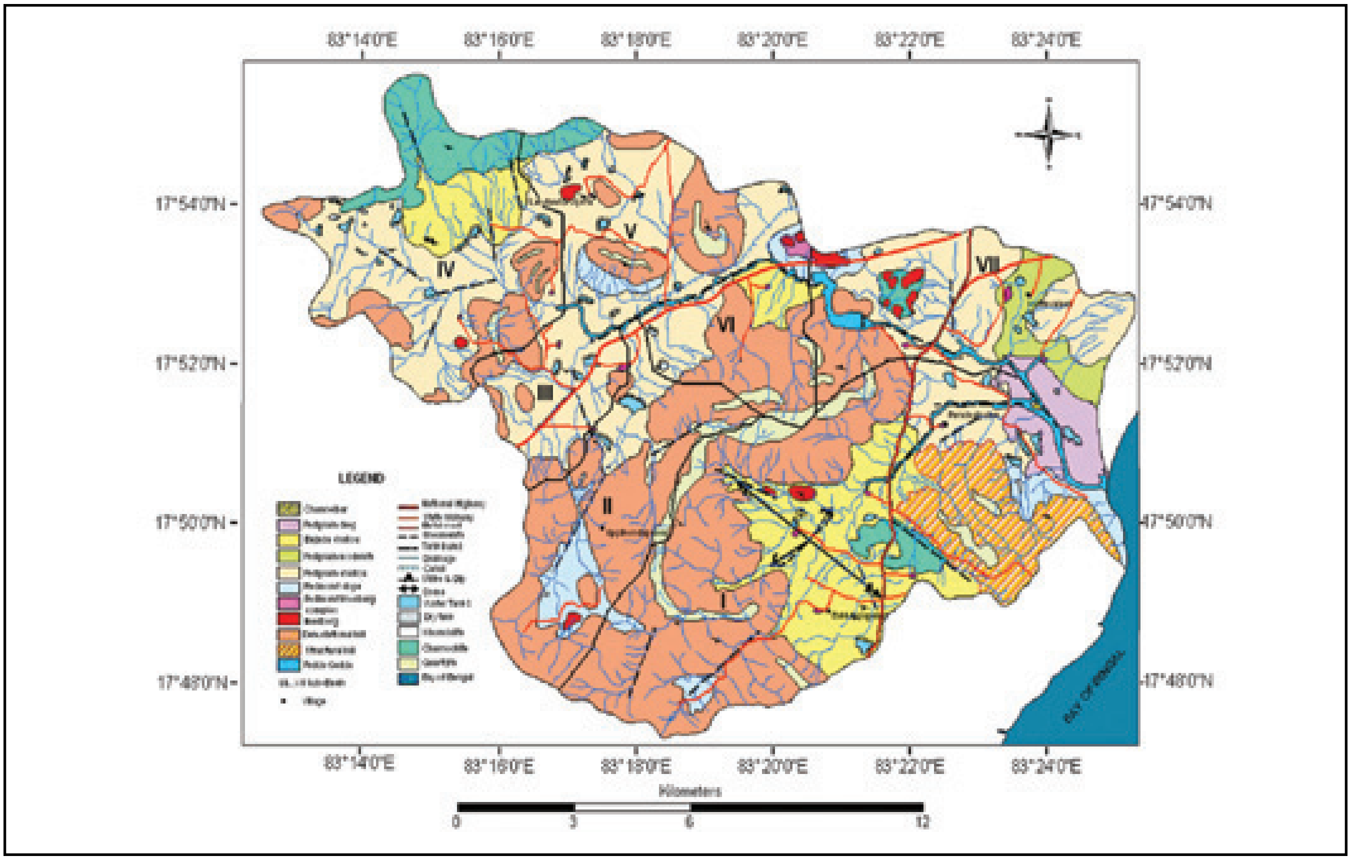

Figure 2. Integrated map of the watershed

traced out by visual interpretation (Fig.2). The major lineaments caused by linear streams, valleys, fractures, faults, linear vegetation growth, etc., have been covered (O'Leary & Friedman 1976). The hilly terrain, located in northwestern and southeastern parts has high lineament density. Moderate to low lineament density occurs over the plains. It is because the hills are structurally controlled and plains are formed by fluvial activity. Most of the drainage of the watershed is controlled by lineaments. These structurally weak zones promote landmass denudation (Venkatachalam *et al.*, 1991).

GEOLOGICAL STUDIES

The study area located in the northern part of Eastern Ghats Mobile Belt (EGMB) is composed of high-grade metamorphic rocks and igneous intrusive bodies. The order of abundance of rocks is khondalite, charnockite and quartzite. The khondalites are whitish to brick red, easily susceptible to weathering and well defined to gneissic banding (Krishna Rao 1962). The structural trend of these rocks is N-NE to S-SW and it coincides with the general trend of the Eastern Ghats. However, local variations are identified at certain places (Chetty *et al.*, 2002). Madhurawada dome is formed in the Marikavalasa Gedda catchment with NE-SW trend. The area has undergone subaerial erosion is covered by denudational hills. The geological formations and their structural trends are shown in Fig.2.

Geomorphological studies

The geomorphological studies of the basin deal with fluviatile activity of the river system. Attempts have been made by earlier workers to quantify sediment yield on the basis of geomorphological parameters (Jose & Das 1982 and Misra, Suryanarayana & Mukherjee 1984). Eleven landforms have been delineated by visual interpretation from IRS-IB-LISS-II data (Fig.2). Denudational hills and pediplains have a significant role in silt transportation and deposition. Hills are prominently exposed in the NW and SE part. These are composed of khondalite rock, which is prone to weathering and contributing sediment to the lower reaches.

The pediplain shallow areas are proximal to the hilly terrain. The soil cover is less than 10 meters thick with gentle slopes (RGNDWM 2000). Pediplain

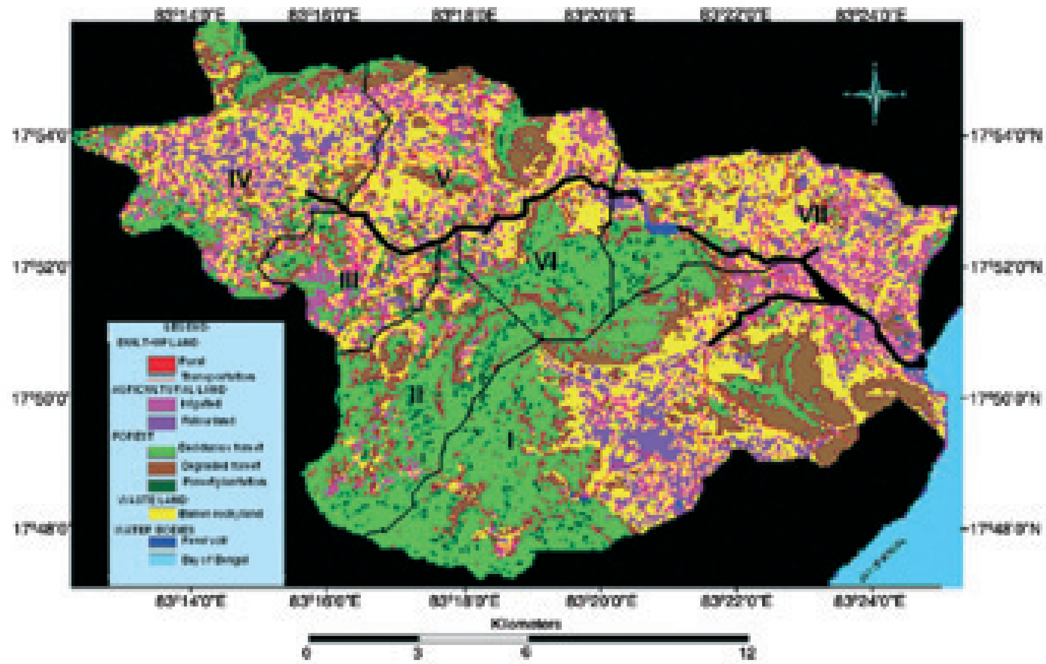

Figure 3. Land use/land cover map of the watershed

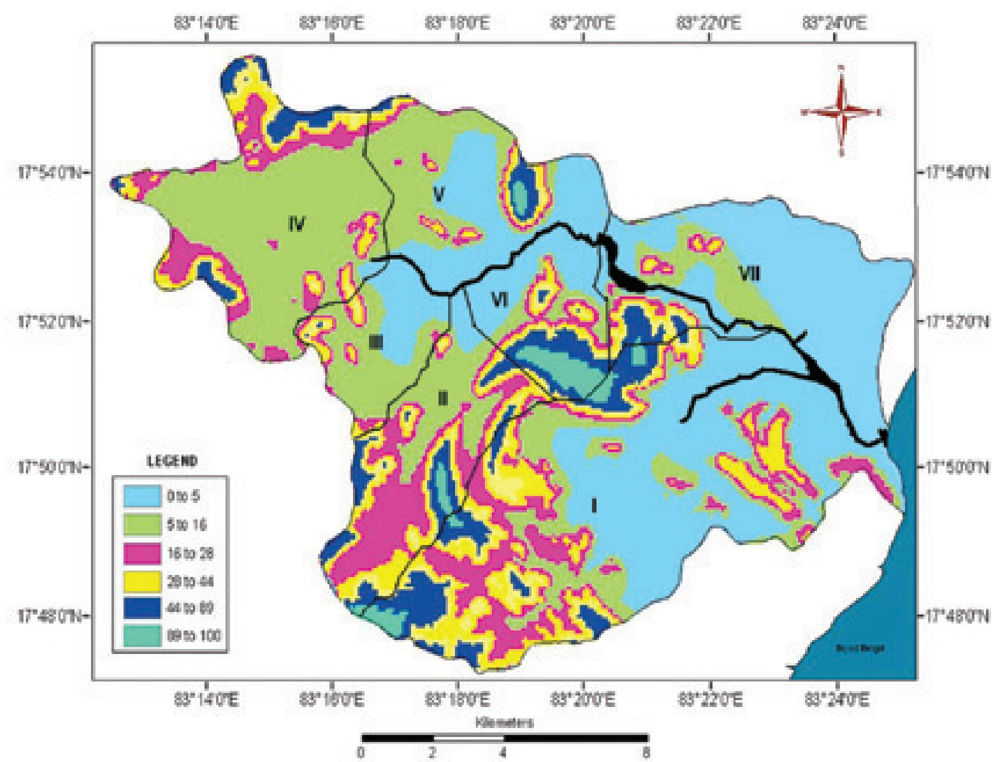

Figure 4. Slope map of the watershed

moderate, suitable for sediment deposition, is located over the plains and has sufficient soil cover (10-20 meters) at certain places. Pediplain deep is developed near the coastal area of the watershed by the deposition of river-transported material, more than 20 meters thick.

Landuse/landcover studies

The landuse/landcover analysis has been carried out on the digital data of IRS – IC – LISS–III, of March – 1999. Unsupervised classification technique is followed to study the changing landuse patterns of the area. Nine landuse/landcover classes have been identified in the area, they are built up land, irrigated land, unirrigated land, deciduous forests, scrub/ degraded forest, forest plantation, gullied land, upland with or without scrub and water bodies (Fig.3). Irrigation lands are located in the downstream of the reservoir. The microwatersheds 4, 5 and 6 have gullied lands. The surface features of these sub-watersheds escalate the erosion resulting in huge silt deposition to the reservoir.

Slope studies

Slope is an important parameter instigating run-off and the resultant erosion and higher rate of denudation. Digital Elevation Model (DEM) is generated in Arc/Info-8.5 environment to study the slope characters of the area (Fig.4). Steep slopes with sparse vegetation generate huge amount of silt material to the reservoir. Unidirectional general slope of the area promoting by sheet erosion is prominent over the plains with slope confined to the central and mouth areas of the watershed. The undulated topography with slopes of 16^0 to 89^0 is present in the study area. More than 60% area shows 0^0-16^0 slope category. The region experiences rill or gully erosion. The micro-watersheds 1 to 6 have developed gully erosion whereas the micro-watershed 7 has sheet erosion because of hilly and plain terrains respectively. Considering the slope, several mitigation measures have been suggested to allow silt free water into the reservoir and locate areas for artificial recharge of water (Nitin Bharadwaj and Bajpal, 2004).

Silt Yield Index (SYI)

The study area is composed of weathering-prone khondalite country rock, facilitating easy transport of fine silt material. The silt yield in the area has been calculated using the following relation (Vito A Vanani 1975. Bali & Karale 1977). Silt Yield Index (SYI) is calculated in percentage for all the micro-watersheds (Table.2).

$$SYI = \sum_{i=1}^{n} (A_{ei} * W_{ei} * DR_i)/A_w * 100$$

A_{ei} = Area of ith erosion intensity mapping unit
W_{ei} = Weightage value of ith mapping unit
DR_i = Delivery ratio of ith mapping unit
A_w = Total area of the watershed
n = Number of mapping units.

The delivery ratio is an important parameter for the estimation of Silt Yield Index of a reservoir (Table 2). This value ranges from 19.95 to 229.09 for different micro- watersheds. This can be ascribed to the area, which is inversely proportional to the delivery ratio.

Integrating the weightage values for the parameters such as topography, slope, vegetation cover and erosion have arrived at the weightage factors for each of the seven micro-watersheds. The weightage factors

Table .2: Parameters for calculation of Silt Yield Index of the study area

Basin No.	Weightage factor	Length (L) kms	Basin area (A) Km^2	Relief (R) Km	Delivery ratio (D)	Silt Yield Index (SYI)
I	13	11.5	64.45	0.356	28.84	130.65
II	12	8.5	16.33	0.232	58.88	62.41
III	13	3	8.93	0.092	199.53	125.28
IV	14	8	29.26	0.197	39.81	88.19
V	14	5	24.54	0.272	229.09	425.67
VI	14	7.5	18.39	0.169	199.53	277.83
VII	13	9	23.00	0.133	19.95	34.74

vary from 12 to 14 depending upon geomorphological features of the micro-watersheds. The lowest weightage factor is obtained for the micro-watershed 2, whereas the highest weightage factor that is 14 to the watersheds with nos' 4, 5, and 6 (Table 2). Active erosion is still occurs in the watershed reducing the storage capacity of the reservoir.

The micro-watershed 3, the smallest watershed covering an area of 8.93 sq. kms, is located in the upstream of the reservoir. It has irregular shape. Parallel and dendritic types of drainages are developed with 4th order stream in this micro-watershed. It shows that the area is structurally controlled with moderate slope. The area is covered with khondalite and traversed with piedmont slope and pediplain shallow. This has two major lineaments in NE-SW and NW-SE directions. The landuse/landcover categories are barren rocky land, degraded forest and irrigated types. Though, it covers limited area the micro-watershed contributes huge amount of silt material to the reservoir because of the above characteristics.

Table.3: Priortised Microwatersheds with Mitigation Measures

Micro watershed No	Description of the micro-watershed, Physiography and erosion intensity	Mitigation measures
I	This is a separate drainage basin namely Marikavalasa Gedda, which is the main tributary to the River Pedda Gedda. This watershed covers an area of 64.45sq.km. Steep slopes are confined to the hilly terrain. Higher rate of denudation and rolling topography are the characteristic features of this watershed. This tributary has no influence of silt deposition in the Gambhiram reservoir.	Tributary to the river. It has no influence of silt deposition in the reservoir
II	This micro-watershed has a feather like drainage pattern which is confined to steep slopes. Less denudation.	Afforestation, Check dam
III	This basin is located in the upper catchment of the river. Moderate slope with varied type of drainage patterns are observed in this micro-watershed.	Afforestation, Check dam
IV	The river Pedda Gedda originated in this micro-watershed. This micro-watershed is characterized by varied type of drainages, steep slope and higher rate of denudation.	Afforestation Checkdam
V	The charnockite is exposed at the boundary of this micro-watershed. This hillock may act as drainage divide and isolated hillocks are composed with quartzite rock to the khondalite country rock. It is moderate slope and denudation at places.	Afforestation, Check dam
VI	This basin is located adjacent to the Gambhiram reservoir. Highly denuded rocks with rolling topography with moderate slope are observed.	Afforestation, Check dam, Concrete slab
VII	This microwatershed is located near the mouth area of the river. A small tributary namely Chitta Gedda flows in this micro-watershed. Uneven drainages are developed over khondalite country rock with low slopes. The drainage disturbance is due to anthropogenic involvement in this watershed. Higher rate of deposition in this micro watershed yield silt deposition in the tanks. This micro watershed has no influence of silt deposition in Gambhiram reservoir. However, this has been analysed to know the fluviatile activity of the river system.	River mouth area. Down stream of the reservoir

The micro-watershed 6 located in the upstream and adjacent to the reservoir has irregular shape. The drainage pattern is similar to that of micro-watershed 3. Irrigated and barren rocky lands are the landuse/ landcover categories. Sparse vegetation and irrigation might be the reasons for higher rate of denudation contributing silt to the reservoir.

The reservoir was constructed in 1962 with the gross storage capacity of 112.03 MC.Ft. The storage capacity has been reduced to about 40% due to deposition of silt in the reservoir. The topography, denudation character and mitigation measures are given in Table.3.

SUMMARY AND CONCLUSIONS

Pedda Gedda watershed situated in Visakhapatnam District, Andhra Pradesh suffers a loss of 40% of its storage capacity of 112.3 MC.Ft. The watershed is covered by highly weathered khondalite rock, and hence it has deep weathered zones at places. High drainage density is observed over the hilly terrain with impermeable hard rock substratum and low drainage density over the highly permeable sub-soils and low relief areas. The dendritic type of drainage is predominant in the watershed. Eventhough undulating topography, the major area has under 0-16^0 category slope. But the remaining area has more than 16 is responsible for deposition of silt. Deforestation in the watershed is one of the reasons for the erosion of silt material. Weithtage factors 10-14 have been assigned to each of the themes depending upon the qualitative features in the micro watershed. An integrated weightage factor has been arrived at for each micro watershed. The integrated factor is one of the important parameter for SYI estimation. Higher rate of denudation and removal of silt are observed more in the micro watersheds 5 and 6. Afforestation, check dams and cover weak rocks with concrete slabs have suggested at suitable areas depending upon geology, drainage, slope and geomorphologic characteristics. SYI is the important method to arrive at silt deposition. The themes slope, geology, drainage, land use / land cover and geomorphology from satellite data played an important role in the determination of Silt Yield Index.

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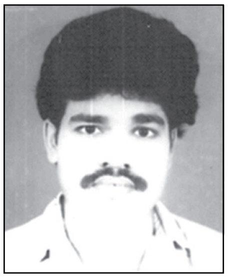
(Accepted 2006 July 2. Received 2006 June 24; in original form)



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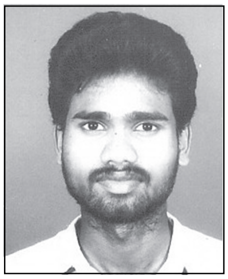

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