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Design and Management Plan of a Village Pond for Multiple use in Eastern Coastal Zone of India in Odisha

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A study was undertaken in a pond, named Digi pokhari, in Garadpur village (Latitude 20° 23′ 1″ N and Longitude 86° 22′ 2″ E) situated under Garadpur block of Kendrapada district in south-eastern coastal plain zone of Odisha, India. The historical hydrological data were analyzed to find out the period in which the standard week wise rainfall is more than evaporation to store excess water in the pond. The pond was targeted for multiple use of water such as domestic, irrigation of crop as well as fishery, etc. The total inflow of water into the pond as well as peak rate of runoff was estimated. Different structures such as trapping mesh, sediment basin and gabion filters were designed for the pond to maintain the quality of water inflow into the pond. The design dimensions of the sediment basin with 40 m length, 1.5 m deep below the existing channel bottom with a trapezoidal shape of 4 m top width at the bottom of the existing channel which should be reduced to a bottom width of 2 m with 1 horizontal: 1.5 vertical side slope is recommended. It was found that with the recommended design, desilting of the sediment basin is required to be done once after two years. With the recommended design prescriptions of different structures required in a pond, it can be recommended that the similar approach can be taken up in different ponds located in south-eastern coastal plain zone of Odisha. The pond water can be used for multiple use including, domestic, irrigation and fishery activities.

(***Key words:*** *Gabion filter, Pond, Rainfall analysis, Sediment basin*)

Water is a very precious natural gift for sustaining life on earth. It is of primary need for human being, animals and all living organisms for survival and maintaining healthy ecosystem. In Odisha the safe drinking water availability, agriculture and sanitation largely depend on the river Mahanadi. It is the lifeline of both Chhattisgarh and Odisha states and drains into Bay of Bengal. The Mahanadi basin spread over an area of about 141,589 km^2, represents almost 4.3% of the total geographical area of the country with one of the largest deltas and densely populated areas in the eastern coast of India. In Odisha state, it spreads over a coastline of about 200 km long from mouth near Chilika in south up to Dhamra River in north. The Mahanadi Delta covers an area of nearly 95000 km^2 contributing about seven percent geographical area and one-third population of the state with a tropical hot and humid monsoonal climate (Hazra *et al*., 2016).

That area is more vulnerable to natural calamities like flood, cyclone, “drought,” etc. maximum part of which is being flooded during monsoon with saline groundwater due to sea water intrusion, thereby, rendering underground source very difficult for accessing potable water. Moreover, high intensity of rainfall combined with saucer shaped physiographic and flat land near the coastal area in deltaic alluvial region causes waterlogging, and there is no water for irrigation during post monsoon (Jena *et al*., 2011). Areas degraded due to hydrologic, social and economic reasons are to be reclaimed for arresting further deterioration in production. But due to insufficient yield of the top perched aquifer and the presence of saline water just below 6 to 10 m depth, the option of constructing open wells or bore wells are not possible in this area. Therefore, rivers and ponds are the only sources of getting fresh water.

The study area is situated in the Mahanadi delta where several management options are available at the farm scale to increase rainfall use efficiency. Construction of farm ponds for collection of excess rainfall flowing out from the farm area is the major option along with management of crop residues to

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improve infiltration and reduce sediment levels along with some other useful options of crop rotations and applications of soil amendments (Freebairn *et al*., 1986). Several researchers have shown that on-farm runoff collection into dugout farm ponds as sources of supplemental irrigation could increase and stabilize the crop production (Krishna *et al*., 1987). Hence, in that area the only way to obtain fresh water is the construction of conservation structure (farm pond) or renovation of existing ponds for storage of excess water during monsoon season followed by proper utilization of the stored water in the post monsoon season.

Multiple uses of water systems (MUS) can provide the more vulnerable users with low cost services for domestic water, water for agriculture (irrigation), homestead, garden, water for cattle, habitats for fish and other aquatic resources and rural water supplies (FAO, 2019). In the present study an attempt has been made for design of different components of a village pond based on hydrologic and other parameters. The basis of design is to reduce the inflow of sediments and other unwanted materials into the pond so that the pond water can be utilized for multiple purposes. The procedure and design dimensions obtained from this study would be a guideline in designing different components of farm ponds for efficient utilization of harvested rain water for domestic as well as agriculture purposes in the Mahanadi delta and elsewhere with similar situations.

MATERIALS AND METHODS

Study area

The study was carried out at Digi pokhari (a village pond), located in Garadpur village (Latitude 20° 23′ 1″ N and Longitude 86° 22′ 2″ E), in Garadpur block of Kendrapada district of Odisha. Kendrapara is a coastal district which is more vulnerable to the natural calamities like flood, cyclones and drought. During monsoon season maximum part of the area remain covered by flood water and the groundwater is saline and contaminated by sea water intrusion, so it is very difficult to get drinking water from groundwater. The only way of getting good quality water is farm ponds. So, the design, construction and management of pond is very important to store water in those conditions. The selected site ‘Digi pokhari’ is with an area and perimeter of 42000 m^2 and 880 m respectively. Location map of the study area and Digi pokhari is shown in Fig.1.

The study area is located in ‘east and south eastern coastal plain’ agro climate zone of India. The principal source of the rainfall is the south-west monsoon with normal onset and withdrawal being 2nd week of June and 1st week of October respectively. The climate of the district is tropical monsoon climate (hot and humid in nature) with summer, winter and rainy seasons. The average rainfall of the district is 1521 mm, with 105 number of rainy days. The temperature varies from maximum 40°C in May to minimum 10°C in December (Jena *et al*., 2006).

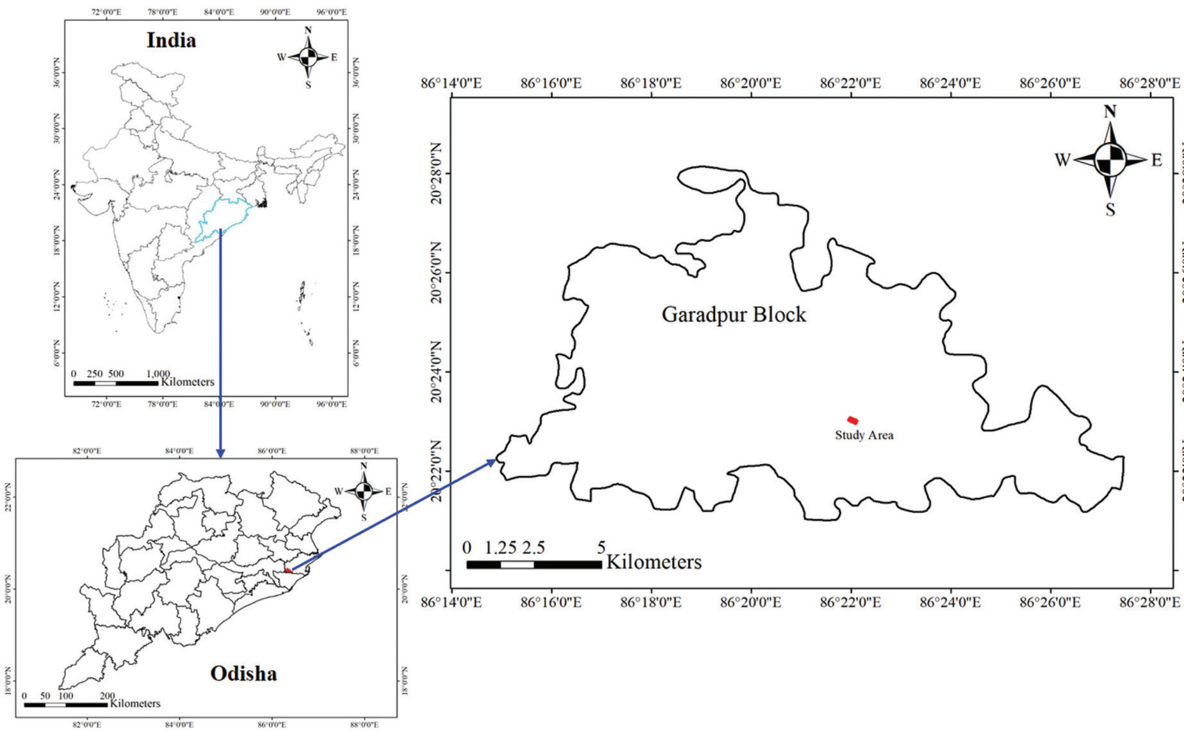
According to its physical and chemical characteristics, mode of origin and occurrence, the major group of the available soil in the study area is *Alfisols* which includes deltaic alluvial soils. The soil texture of the site is sandy loam to clay at different points. In catchment area soils are slightly acidic and pond soil is neutral. The pH and electrical conductivity (EC) of the pond water were 7 (neutral) and less than 1 dS m^{-1}, respectively throughout the year. The soils are not saline in all location and the availability of N, P and K is low to medium (Jena *et al*., 2006). The geology of the study area comes under upper delta deposit which are of middle to late Holocene age, consisting of clay with fine sand and silt and altering layers of sandy silt and silty clay respectively. The geomorphology of the study area comes under very gently sloping alluvial plains.

Catchment area delineation

Using dumpy level and GPS, survey was conducted at micro level for precise contour elevation data. The surrounding of the pond was surveyed using dumpy level. From different elevation points, elevation contours were generated with 0.50 m contour interval. The elevation at pond is 9 m above mean sea level. The catchment area of the pond was delineated from contour map. The catchment of the pond was found to be 29.2 ha, out of which the pond is 4.2 ha. The rest 25 ha contributes runoff water to the pond.

Rainfall analysis

Daily rainfall data was collected from Bhubaneswar for the period 1975-2018. Since the study area and Bhubaneswar both fall in the same south eastern coastal plain agro-ecological zone of Odisha and the aerial distance between the two places are less than 60 km, the observatory at Bhubaneswar (Latitude 20° 15′ 57″ N and Longitude 85° 48′ 39″ E), was considered as



(*India map and Odisha map are not to scale*)

[*The dark circle indicates the location of the Digi pokhari pond (Latitude 20° 23' 1"N and Longitude 86° 22' 2" E)*]

Fig. 1. *Location map of the study area*

representative for the study area as recommended by Murty and Jha (2018). Amount of rainfall (annual as well as during monsoon or crop growing season) was calculated from daily data. Daily evaporation data was also collected from the same station. Statistical analysis (such as mean, median, maximum, minimum, annual and weekly, etc.) of rainfall and evaporation data was done and results were analysed for design and layout of different structures required for pond management.

For the estimation of onset of effective monsoon (OEM) and cessation of effective monsoon (CEM), the methodology used for characterizing the rainfall pattern at Umiam, Meghalaya by Satapathy *et al*. (1998) was followed.

Hydrological balance analysis

The excess runoff from the catchment to be ponded was estimated using hydrologic components. The standard week wise average rainfall and evaporation was calculated. From those values the period in which rainfall is more than evaporation was found out. The total number of days in which the rainfall is continuously higher than evaporation was noted. The total rainfall during that period was calculated. The total evaporation during that period was also calculated. The value of percolation and deep percolation losses for that period were also considered following the values computed by Jena *et al*. (2006). The sum total of evaporation and other losses were deducted from the total rainfall value. The depth of water required for field preparation was also deducted. With those calculations excess water available in the catchment to be stored in the pond was estimated. As there is better chance of getting those data for most of the places in the agro ecological zone of the study area, this procedure can be followed for calculation at other locations.

Peak runoff rate of the catchment area is important for the hydrologic design of the structures. The peak rate of runoff was estimated using rational method (Murty and Jha, 2018). The formula used for estimation is given below:

$$Q_{peak} = \frac{CIA}{360} \quad \text{.... (1)}$$

Where Q_{peak} = peak rate of runoff ($m^3 s^{-1}$)

C = runoff coefficient

I = intensity of rainfall ($mm\ h^{-1}$) of a given frequency for the duration equal to the time of concentration

A= area of the catchment (ha)

The sediment yield from the catchment was estimated considering the soil, vegetation and other field condition. For calculation of sediment yield the storms needed to be selected was based on the criteria and guidelines given by Ajward (1996). However, annual sediment yield was considered for designing the size of the sediment basin.

Design of different components of the pond system

Different components such as inlet channel, sediment or silt basin, trapping mesh and gabion filters were proposed for the pond. An emergency spillway was also required for safe disposal of water from the pond. The layout and location of different structures are proposed in this paper. However, considering the site condition, existing hydrologic, soil, vegetation parameters, etc. and easiness of construction, the design dimensions of those structures are presented under the next section. Only the design of inlet components is discussed in this paper.

RESULTS AND DISCUSSION

In contour survey it was found that the total catchment area is 25 ha and the pond area is 4.2 ha with perimeter of 880 m. The contour drawn from dumpy level survey is at the scale of 1:3000. Contour map of the catchment of Digi pokhari (Garadpur) is shown in Fig. 2.

Analysis of rainfall and evaporation data

Analysis of 44 years (1975-2018) of daily rainfall data, revealed that the annual rainfall varied from minimum value of 951.6 mm (in the year 1996) to maximum 2218.7 mm (in the year 2001) and 55% of all values were below normal. It was also found that 84.1% of the total annual rainfall received between June to October. Normal annual rainy days were 105 days with maximum 129 days (1983) and minimum 86 days (1979). OEM generally started from 15 June, the earliest at 7 June and in latest it comes at 23 June, calculated from both mean and median. The CEM based on mean calculation was 8 October, earliest on 26 September and latest on 20 October. Similarly, in median calculation, CEM is on 10 October, earliest on 28 September and latest on 22 October. The average weekly rainfall and evaporation data were analyzed. The average annual rainfall is 1521 mm. In case of water storage in the pond, it is important that during rainy days, to store excess rainwater, the rainfall should be more than evaporation. In the Fig. 3, it is observed that, from standard 24th week to 41st week (*i.e.* 2nd week of June to 1st week of October) rainfall is higher than the evaporation, in this period the water can be stored in the water storage structures like farm ponds, water harvesting structures, etc.

Estimation of surplus water which needs to be stored

In this study area, rain is surplus during 24th week to 41st week (total 18 weeks *i.e.* 126 days). Rainfall during 24th week till 41st week is 1183 mm, evaporation during that period is 490 mm, therefore, the surplus rain (rainfall – evaporation) is 693 mm. Percolation during 18 weeks, assuming 2 mm day^{-1} is ≥ 252 mm (Jena *et al*., 2006). Therefore, water which will be available in pond (surplus rain – percolation) is 441 mm. Surplus water in rice field will be 321 mm, assuming 120 mm is required for field preparation (Jena *et al*., 2006).

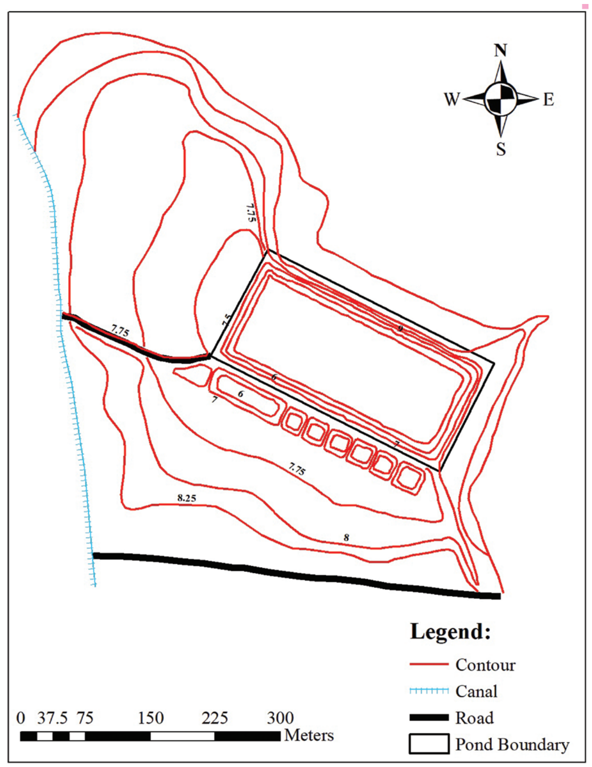
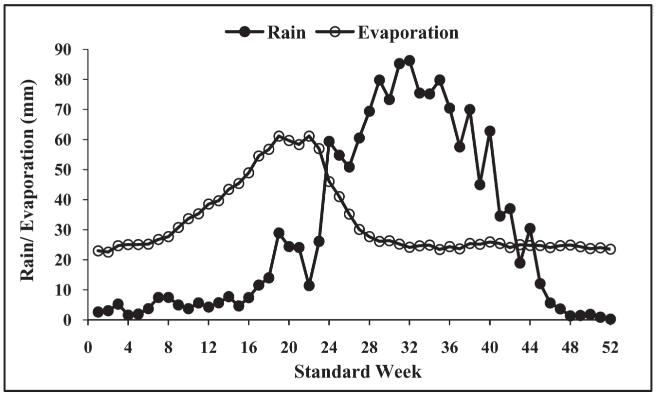


Fig. 2. Contour map of the catchment of Digi pokhari (Garadpur) generated from dumpy level and GPS survey



(Rainfall is more than evaporation during 24th week (2nd week of June) till 41st week (1st week of October)

***Fig. 3.** Average weekly rainfall and evaporation of Bhubaneswar*

Total volume of runoff generated from the catchment area

$$= 250000 \times \frac{321}{1000} = 80250 \text{ m}^3$$

The maximum capacity of the pond to store water safely is 12600 m^3 as found from the survey of the pond cross section. The pond can be filled more than six times with the incoming water from the catchment. But the losses such as evaporation, percolation, deep percolation, etc. occur continuously. So, the pond will remain full to its capacity till mid-October. If there is any dry spell or any irrigation is required at the critical stage of the crop, one can irrigate crops during *kharif* season, it can be very easily done using the pond water. During summer the water depth reduced to 1.5 m. Therefore, it was observed that the depth of water available in the pond throughout the year varies between 1.5 m to 3.0 m. Hence, aquaculture activities can be easily carried out throughout the year as minimum depth of water to carryout fishery activities is available in the pond. If inflow water quality can be maintained in good condition, then the water stored in the pond can also be used for domestic purposes. Provision of other structures such as trapping mesh, sediment basin, and gabion filters were designed for the inlet of the pond. Therefore, multiple use of pond water is possible if the pond water quality is good for domestic use. The pond water can be used for aquaculture as the water depth available through the year is between 1.5 m during summer to 3.0 m during monsoon. Since the catchment produces more runoff than the capacity of the pond, so if water is used for irrigation during critical dry spells for *kharif* crops, it can be refilled to its full capacity by first week of October.

Peak runoff rate

Peak runoff rate of the catchment area was calculated by rational method as explained under previous section. For the calculation of peak rate of runoff, total catchment area (A) considered was 25 ha and runoff coefficient C for arable land and below 5% slope with moderate infiltration soil was taken as 0.5 (Murty and Jha, 2018). Intensity of rainfall for 10 year return period for coastal Odisha region was taken as 80 mm h^{-1} (Murty and Jha, 2018).

$$Q_p = \frac{0.50\text{x}80\text{x}25}{360} = 2.78 \text{ m}^3 \text{ s}^{-1}$$

Hence, the peak rate of runoff expected in the inlet channel carrying water from the catchment to pond is calculated as 2.78 m^3 s^{-1}.

Inlet channel

In study area, there is an unlined inlet channel of trapezoidal shape, through which water is carried from the catchment area and transferred to the pond. The channel is having the top width = 4 m, bottom width = 2 m, side slope = 1:1, depth of the channel = 1 m. The cross section area of the channel is 3 m^2. During the peak flow, if the channel runs to its full capacity, then the velocity of flow would be = 2.78/3 = 0.93 m s^{-1}. This velocity is slightly higher than the recommended velocity of flow in an earthen channel (Murty and Jha, 2018). However, the peak flow occurs very occasionally. But the channel can handle a discharge of 3 x 0.7 = 2.10 m^3 s^{-1} without any scouring of the bottom of the channel (considering 0.7 m s^{-1} is the permissible velocity), which would not cause any scouring of bottom in the existing earthen channel depending upon the soil type (Murty and Jha, 2018). With those dimensions the channel bed would be stabilized over time.

Inlet structures

The lay-out maps for installation of different inlet and emergency spillway structures are shown in Fig. 4. For multiple use water systems, the same water should be used for different purposes. Since the pond water is planned to be used for domestic, irrigation as well as fishery activities as discussed in the above section, the following components of the inlet system were

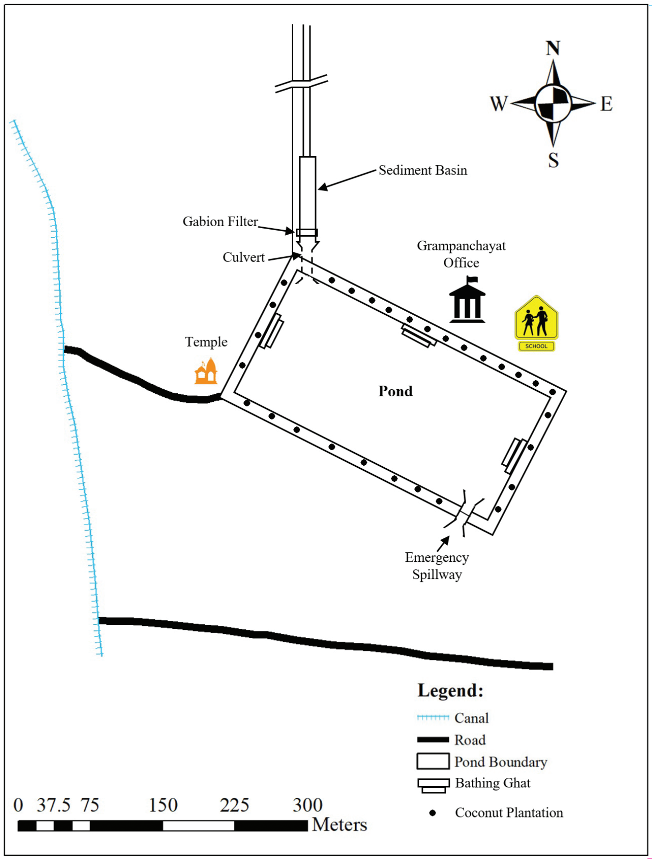


Fig. 4. *Lay-out map for installation of inlet and emergency spillway structures*

suggested. In the existing inlet channel, a sediment or silt basin was required, so that the inflow sediment would be deposited in the silt basin. In the upstream end of the silt basin, one trap mesh was designed to filter the inflow of floating materials including polythene, plastic bottles, coconut shell, etc. In the downstream end of the silt basin a gabion structure was proposed, so that any other lighter and small material which would pass through the mesh and silt basin, would be filtered there. In that process good quality water would flow into the pond. The design for different components is described in the following sections.

Design of trapping mesh

Trap mesh with screen size of 4 m × 1.25 m, height of screen above ground 1 m, foundation depth of 0.25 m and mesh size of 5 cm × 5 cm was necessary to stop and filter wastes like polythene, plastic bottle, coconut shell, cans, etc. at inlet channel entry, thereby quality of water and efficiency of the structures would increase. This has been suggested considering the field condition. The frame around the galvanized iron mesh was made of mild steel angle for its longevity.

Design of sediment basin

In the study area, the soil is sandy loam to sandy clay loam (Jena, 2019). Since the pond water was intended for multiple uses, the water should be clean and sediment free before entering into the pond, so a sediment basin would be designed to accumulate the silt or sediment and to reduce the turbidity of the water. Depending upon the soil and vegetation type, the erosion intensity class of the catchment was found to be low to medium (Sharma, 2010). Hence the soil erosion was considered as 10 t ha^{-1} yr^{-1}. Therefore, the total sediment eroded from the catchment area of 25 ha was 250 t ha^{-1} yr^{-1}. Since most part of the catchment is bunded paddy field, it was considered that the total amount of sediment to be eroded from all the fields would not come to the pond. Part of the eroded soil would be deposited in the catchment itself. Considering 50% of the eroded soil would enter into the pond and density of sandy loam soil of 1460 kg m^{-3} (Murty and Jha, 2018), the amount of sediment load per year is calculated as follows:

Total volume of expected sediment deposition in the sediment basin $= \dfrac{50\%\text{ of }250000}{1460} = 85.61\ \text{m}^3\ \text{yr}^{-1}$.

Determination of cross section and length of silt or sediment basin

The cross section of the existing channel which was converted to a silt/sediment basin was made as a rectangular one. Hence the top width is 4 m, bottom width is also 4 m and depth is 1 m. The cross section below the channel was made as trapezoidal and the dimensions were as follows. The top width is 4 m and bottom width is 2 m, the depth of the basin is kept as 1.5 m for easiness of excavation and stability, slope was provided to both sides of the silting basin (1.5 vertical to 1 horizontal). The cross-sectional area of channel was 4.5 m^2. To accommodate 85.61 m^3 of sediment, the length required for the sediment basin is 19.02 m. In case a provision of 19 m is kept for the sediment basin, then the silt basin would be filled each year and hence it is required to remove the silt every year. Therefore a provision of 40 m length was designed for the basin, so that in the worst case erosion scenario, there would be a need to remove the silt every two year. In normal condition it may be required to remove the silt once in a period of more than two years. The design dimension of the sediment basin is presented in Fig. 5.

Another consideration for length of the sediment basin to be longer is for water flowing through it would get more opportunity time to get settled in the basin. The cross section of the channel within the sediment basin above the channel bottom has been kept rectangular with a cross sectional area of 4 m^2 (4 m x 1 m), whereas the cross section of the inlet channel just in the upstream side of the sediment basin is 3 m^2 (trapezoidal section with 1:1 side slope). Therefore, when water would enter into the sediment basin having more cross sectional area than the inlet channel, the velocity of flow will be reduced, thus helping in settling of the silt or sediment in the basin. Also due to presence of a gabion structure in the downstream side of the channel, the flow velocity would also be reduced. All these factors would help in settling of sediments and silts in the sediment basin.

The bigger size garbage would be filtered by the wire mesh before the sediment and silt would be deposited in the sediment basin. However, there would be still some small floating material or sediment which may enter into the pond. To further reduce the inflow of sediments, floating material, etc. into the pond, a gabion filter would be provided in the downstream side of the sediment basin whose design dimensions are provided in the next section.

Design of gabion filter

Gabion filter is important for the cleaning of water before entering to the pond. So, the dimensions of the gabion should be well suitable for the inlet channel, where the gabion filter should be installed. Gabion filter which was designed to be installed at the outlet of the sediment basin is shown in Fig. 6. Top width of the gabion across the channel flow is 4 m, bottom width of the gabion across the channel flow is 2 m. The thickness of the gabion along the channel flow is 0.5 m. Side slope has been kept as 1:1, same as the existing side slope of the channel. The bottom and side of the channel where the gabion filter would be installed is lined or plastered with plain cement concrete of 100 mm thick (all three sides). This lining material has been kept inside the soil, which would help in stabilization of the gabion. All the water would flow through the gabion before entering into the pond.

With the provisions of the above structures, it would be ensured that good quality water would enter into the pond system. Since the pond water is under multiple use (domestic, irrigation as well as fishery) the results obtained from this study would help in efficient utilization of pond water for various purposes.

From the historical hydrologic data analysis which includes analysis of rainfall and evaporation it can be concluded that around 80000 m^3 of water can be contributed by the catchment to the pond during monsoon. Since all the losses such as evaporation,

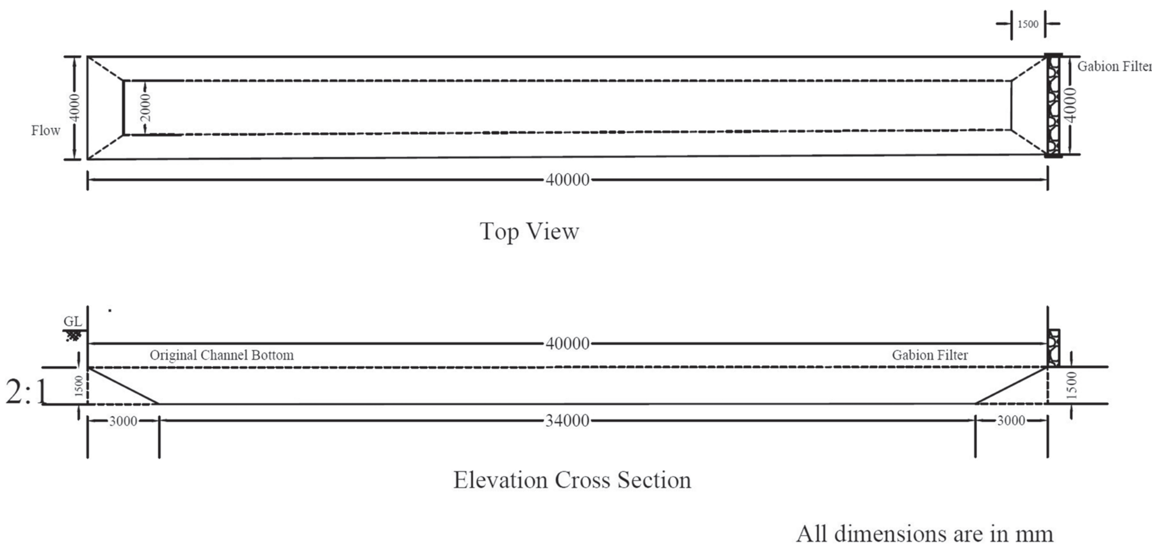


Fig. 5. Design dimensions of sediment basin

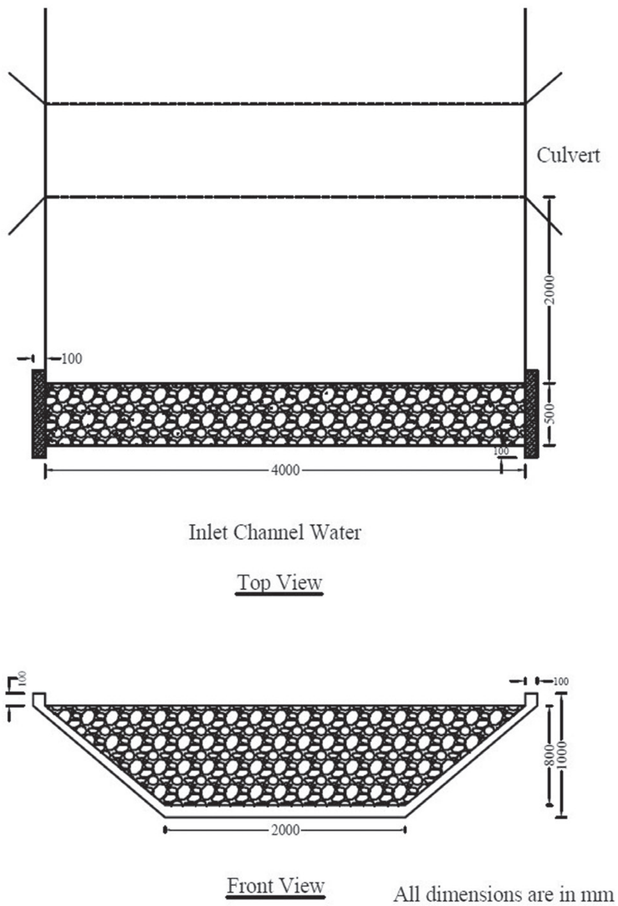


Fig. 6. *Design dimensions of gabion filter*

percolation, deep percolation, etc. happens continuously throughout the year, the excess water stored during July to October can be used for irrigating the crop if required without affecting the water filling up to the maximum capacity. The pond holds water to its full capacity till mid of October and reduces to 1.5 m in the peak summer (May - June). Fishery can be undertaken throughout the year as sufficient depth of water remains in the pond. The design which has been proposed in this study for trapping mesh would suitably remove the trashes and garbage. The design dimensions of the sediment basin with 40 m length, 1.5 m deep below the existing channel bottom with a trapezoidal shape of 4 m top width at the bottom of the existing channel which should be reduced to a bottom width of 2 m with 1 horizontal: 1.5 vertical side slope is recommended. The cross section of the existing channel for the sediment basin section has been modified to rectangular shape of 4 m width and 1 m depth. All these prescribed design dimensions would be of help in reducing the velocity of flow in the sediment basin section and settling of the sediment or silt in the basin. Desilting of the sediment basin is required to be done once in two years or beyond. The designed dimensions of the gabion filter are suitable to the location to further filter the smaller floating materials and sediments. These design prescriptions of different structures required in a pond located in south-eastern coastal plain zone of Odisha, would allow good quality water free from trashes, garbage and sediment to enter into the pond. The pond water can be used for multiple use including, domestic, irrigation and fishery activities.

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