AQUA
Water Infrastructure, Ecosystems and Society

AQUA — Water Infrastructure, Ecosystems and Society Vol 72 No 5, 690 doi: 10.2166/aqua.2023.200

Assessment of wastewater treatment potential of sand beds of River Ganga at Varanasi, India

Anoop Narain Singh[a,*], Ankur Mudgal[b], Ravi Prakash Tripathi[c] and Padam Jee Omar[d]

[a] Department of Civil Engineering, Rajkiya Engineering College, Azamgarh, Uttar Pradesh 276201, India
[b] Department of Material Testing, CEG Test House and Research Centre, Jaipur 302001, India
[c] Department of Civil Engineering, Rajkiya Engineering College, Sonbhadra, Uttar Pradesh 231206, India
[d] Floodkon Consultants LLP, Noida 201304, India
*Corresponding author. E-mail: anoopnarain1407@gmail.com

ABSTRACT

Inadequate sewage treatment plant (STP) capacity, limited power supply, and discharge of partially treated and raw sewage create a significant sanitation problem in Varanasi city, India. This problem becomes severe during the lean period of the river. To reduce the burden on STPs, sewage can be treated and filtered in a naturally occurring sand bed at the convex bank side of the river. In the present study, a 7-km stretch of the sand bed of River Ganga at Varanasi has been selected. This stretch is divided into three zones: entrance, middle, and exit zones. The objective of this research is to assess the filtration potential of selected sections in respective zones and to find out the most suitable zone, out of the three, for wastewater filtration. Seven basic parameters such as dissolved oxygen, biological oxygen demand, electrical conductivity, total dissolved solids, salinity, pH, and temperature were measured before and after filtration, through the sand bed of the three zones of River Ganga. Of the three selected zones of the river bend, filtration length and the amount of available sand were found to be maximum in the middle zone. Experimental results and survey work show that the sand bed in the middle zone of the river bend is best suited for wastewater disposal and filtration.

Key words: disposal, filtration, lean period, river sand bed, STP, wastewater

HIGHLIGHTS

- Inadequate sewage treatment plant capacity creates significant sanitation problems.
- To reduce the burden on STPs, sewage can be treated and filtered in naturally occurring sand beds.
- Seven parameters such as DO, BOD, EC, TDS, salinity, pH, and temperature were measured before and after filtration.
- Experimental results and survey work show that the sand bed in the middle zone of the river bend is the best suited for wastewater disposal and filtration.

1. INTRODUCTION

One of the most acute problems of developing countries is the improper management of huge amounts of waste generated by various anthropogenic activities. Anthropogenic activities contribute impurities to surface water bodies in the form of domestic, agricultural, industrial, and chemical wastes (Gaur *et al.* 2021). River Ganga, which flows through Varanasi, is a typical example of a river with several waste-discharging activities (Omar *et al.* 2021b). A more challenging problem is the unsafe disposal of these wastes in the ambient environment (Omar *et al.* 2017; Shekhar *et al.* 2021). Water resources, especially freshwater bodies, are the most affected by this. This has often made these natural resources unsuitable for both primary and/or secondary usages (Omar *et al.* 2021a). However, industrial waste contamination of natural water bodies has emerged as a major challenge in developing and densely populated countries like India. River Ganga, which is the primary source of drinking water in Varanasi, is contaminated by the activities of the surrounding population and industrial establishments (Omar *et al.* 2020). River systems are the primary and easy means for the disposal of waste from industries, especially industries near the river. These effluents from industries change the physical, chemical, and biological nature of the receiving water body (Omar *et al.* 2022a). In the lean season of the river (February/March to June/July), this problem becomes more serious – because during this period, the dilution factor and dissolved oxygen (DO) are minimum, and the water level of the river becomes the lowest (Choudhary 1993; Jana *et al.* 2021; Tripathi & Pandey 2021, 2022a, 2022b). Hamner *et al.* have collected data and monitored the water quality of the Ganges River in Varanasi from 1993 to 2010. They demonstrated that the severely polluted nature of the Ganges in Varanasi is due to the release of raw sewage into the river (Hamner *et al.* 2013). Data collected during 2010 confirmed that the water quality of River Ganga along the Varanasi riverfront ranged from poor to exceptionally polluted. Of extreme concern are measurements of biochemical oxygen demand (BOD) and faecal coliform count (FCC), indicators of organic pollution and disease-causing bacteria, for which virtually no samples were compliant with standards set by the Central Pollution Control Board (CPCB), India. In the most polluted part of the river, the average BOD level exceeds 35 mg/l and the average FCC is greater than 10^7 MPN (Most Probable Number) per 100 ml. Due to this, people nearby the Ganga suffer from a high incidence of waterborne diseases, including cholera and dysentery (Hamner *et al.* 2006, 2013). There are six sewage treatment plants in Varanasi, out of which three are currently functional, while the other three are under construction. The capacity of currently functional sewage treatment plants (STPs) is 100 MLD (million litres per day) and the capacity of STPs under construction is 310 MLD (CPCB 2013; Trombadore *et al.* 2020). The extremely high levels of total coliform (TC) and FCC in the water of River Ganga indicate the need for efficient functioning of STPs. This requires maintenance of functional units and repairing of non-functional units of the existing STPs. In all three functional STP plants, the high levels of BOD and COD (chemical oxygen demand) detected in the STP effluents indicate that these STPs may not always function properly in the treatment of wastewater. This may be attributed to the increased rate of power-cut problems existing in Varanasi, which would have resulted in the functional discontinuity of STPs (Trombadore *et al.* 2020; Mishra *et al.* 2023). In order to reduce the burden on STPs and to address the aforementioned issues, it is proposed that the treated/partially treated/untreated sewage should be treated and filtered in the naturally occurring sand bed (Choudhary 2008). Choudhary and Singh have done a case study on wastewater management of Varanasi city and reported that by changing the location of the outfall point of the effluent drain from the concave side to the convex side (sand bed side), pollutants can be managed in a better way (Choudhary & Singh 2010). In this wastewater management system, it is remarkable to note that, in the critical lean period, sand beds can be more helpful to manage the pollutant load because it is exposed maximum (Choudhary *et al.* 1998). Gross and Mitchell conducted a study on the filtration efficiency of river sand, and their study reported that no detectable viruses were found in the effluent from clean sand filters. Hence, from the study, it can be concluded that the sand itself must have some ability to retain or inactivate viruses in the secondary-treated effluent (Gross & Mitchell 1990). In addition, the rate of removal of TOC (total organic carbon) from septic tank effluent is higher at 25 than 15 °C, which means temperature shows a positive effect on the removal of the organic load. It indicates that in the lean period of the river, the capacity of the sand bed to remove pollutants from wastewater increases. Figure 1 shows the Google Satellite image, which presents the existence and deposition of a river sand bed in Varanasi (Google Earth 2011).

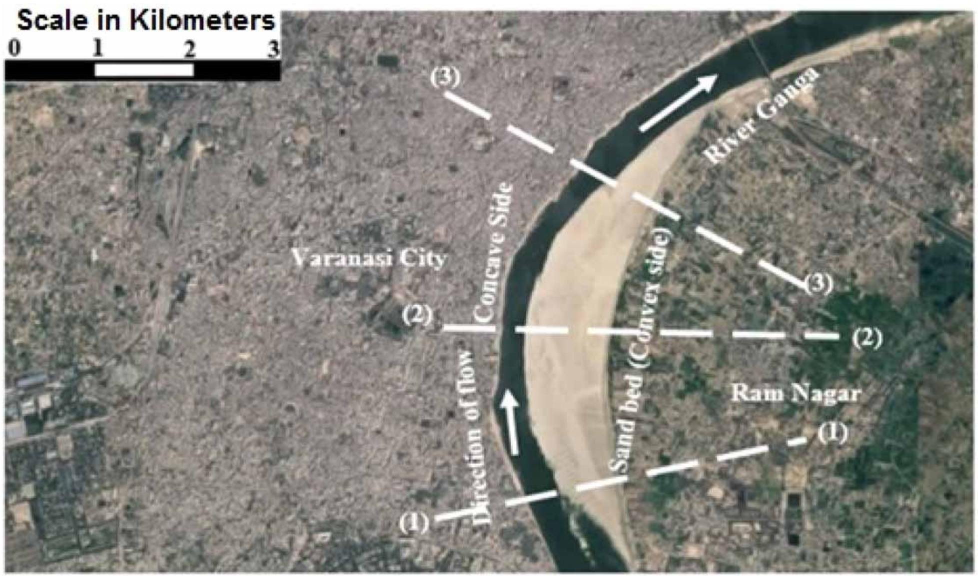

Figure 1 | Existence of sand beds at the convex side of River Ganga in front of Varanasi city.

The disposition of the sand bed at the convex side is not only in the case of Varanasi city, but has also been confirmed by other researchers for different river systems (Metcalf & Eddy 1979; Prasad *et al.* 2006; Alekseevskiy *et al.* 2008; Trombadore *et al.* 2020). The above studies show that a huge sand bed is available at the convex side of River Ganga, which can be utilised for wastewater filtration and management, especially in the lean period (discharge is very low and sand bed exposure is maximum). From the literature, it can be shown that the rate of filtration, size of sand particles, depth of filters, and temperature of sand have a considerable effect on wastewater filtration (Al-Adham 1989; Check *et al.* 1994; Ausland *et al.* 2002; Hua *et al.* 2003; Zahid 2003; Prasad *et al.* 2006; Kumar *et al.* 2021). In order to choose a better location for the disposal of wastewater in sand beds, it is necessary to find out the efficiency of lateral filtration. Therefore, the work done on lateral flow sand filters (LFSFs), which are close to the field conditions of river sand bed is studied and presented here.

Check *et al.* (1994) did an experiment on a lateral-flow sand filter (LFSF) system. Three full-size cross-sectional models of the LFSF system, each with a different sand fill, were constructed. The laboratory system represents a slice through the LFSF in the direction of flow (referred to here as the down slope length). The removal efficiencies (%) for different parameters are chloride: 14.0, orthophosphate (P): 39.7, ammonia (N): 99.9, TKN (total Kjeldahl nitrogen): 99.1, nitrogen (N): 22.9, suspended solids: 99.4, TOC: 88.3, BOD: >99.1, TC: 100, and faecal coliform: 100. The treatment differences resulting from the use of three separate sand fills were minimal. The use of a relatively coarser, more permeable sand fill can be recommended, as it allows good treatment as well as enhanced hydraulic functioning and system longevity. LFSF is closer to the structure of the river sand bed, which has a slope towards the river. The effects of the rate of loading and temperature need to be analysed for their effective application in the field. Havard *et al.* (2008) performed experiments on LFSFs for their treatment of septic tank effluent in Truro, Nova Scotia, Canada. This study also supports the idea of utilising the river sand bed, which has a slope towards the river, and which can be very useful in removing the BOD load.

In the present research study, a 7-km stretch (measured along the bend) of River Ganga at Varanasi has been selected. This stretch has been divided into three zones: entry, middle, and exit zones. The three sections have been selected in the respective zones, i.e. Ravidas Ghat (section 1-1), Dashaswamedh Ghat (section 2-2), and Panchganga Ghat (section 3-3) as shown in Figure 1. The objective of this research is to assess the filtering potential of the selected sections and to find out the most suitable zone among the three zones for wastewater filtration. For fulfilling the objectives, studies were done to find out (a) the zone of the longest filtration length in the transverse direction of the sand bed and the maximum volume of sand available for wastewater filtration and (b) the difference in the filtration efficiency of the three different sand columns (filled with sand from the selected three zones) on the basis of their ability to vary the following parameters: DO, BOD, EC, TDS, temperature, and pH of the wastewater.

2. MATERIALS AND METHODS

To fulfill the first objective, a morphological survey and bathymetrical survey of the three zones were carried out and the methodology is presented in the first section. For the second objective, measurement of the physical characteristics of the sand samples and experimental work on the filtration of secondary-treated effluent through the three different vertical sand columns were done and presented in the second and third sections, respectively.

2.1. Field investigation

Selected sections of River Ganga and sand bed were thoroughly surveyed. The river section's depth, width, and RL (reduced level) of river water were determined. The width and RL of the sand bed, the longitudinal distance between the sections, and the distance of the sand bed's maximum elevation from the concave bank are determined and presented in Table 2. The data were collected for the month of April 2017 (a period of low discharge). The geographical coordinates of the sections were obtained from Google Earth's satellite image (presented in Table 1) and the locations of the sections are presented in Figure 1.

The survey work of the sections was performed with the help of a tacheometer, levelling staffs, ranging rods, and a tape of length 30 m. At each section, the depth of the river and the elevation of the sand bed were measured with respect to the water level. Before starting the measurement of the river depth and elevation of the sand bed, a line of sight is fixed approximately perpendicular to the direction of flow with the help of a ranging rod. To measure the river depth, a boat was taken and there were two people in it, one to handle the staff and the other to measure the depth. The measurement started from the convex bank and was carried out along the line of sight from the convex bank to the concave bank. After travelling by boat for some distance, the boat was stopped for taking measurements of depth and for staff reading. Staff intercept at that point gives the distance of that point from the instrument station and the depth is measured by the traditional method, i.e. a heavy stone piece

Table 1 | Geographical location of the sections and reduced elevations of the concave and convex banks

Sections	Geographical location	RL of concave bank (m)	RL of convex bank (m)
1-1	25°17′07.23″ N, 83°00′30.64″ E	69.2	60.9
2-2	25°18′27.08″ N, 83°00′38.68″ E	72.2	61.2
3-3	25°18′18.07″ N, 83°00′39.28″ E	71.6	62.5

Table 2 | Morphological characteristics of the sand bed at the selected sections

Locations	Max. height (m)	Width (m)	Avg. slope	Cross-sectional area (m^2)
Section 1-1	1.57	563	1 in 0.00654	453.55
Section 2-2	3.30	856	1 in 0.00825	1,404.4
Section 3-3	6.95	418	1 in 0.42038	1,313.8

was allowed to fall with the help of a rope. When the stone reached near the bottom (riverbed), the rope was tightened to ensure a satisfactory performance. The length of the rope was measured with the help of tape. Staff intercept and depth of the river were measured along the line of sight at least 10–15 points at a section, to make it easier to draw the graph between depth and distance (shown in Figure 2(a)–2(c)). Similarly, to measure the elevation of the sand bed, staff reading had been taken on the sand bed along the line of sight.

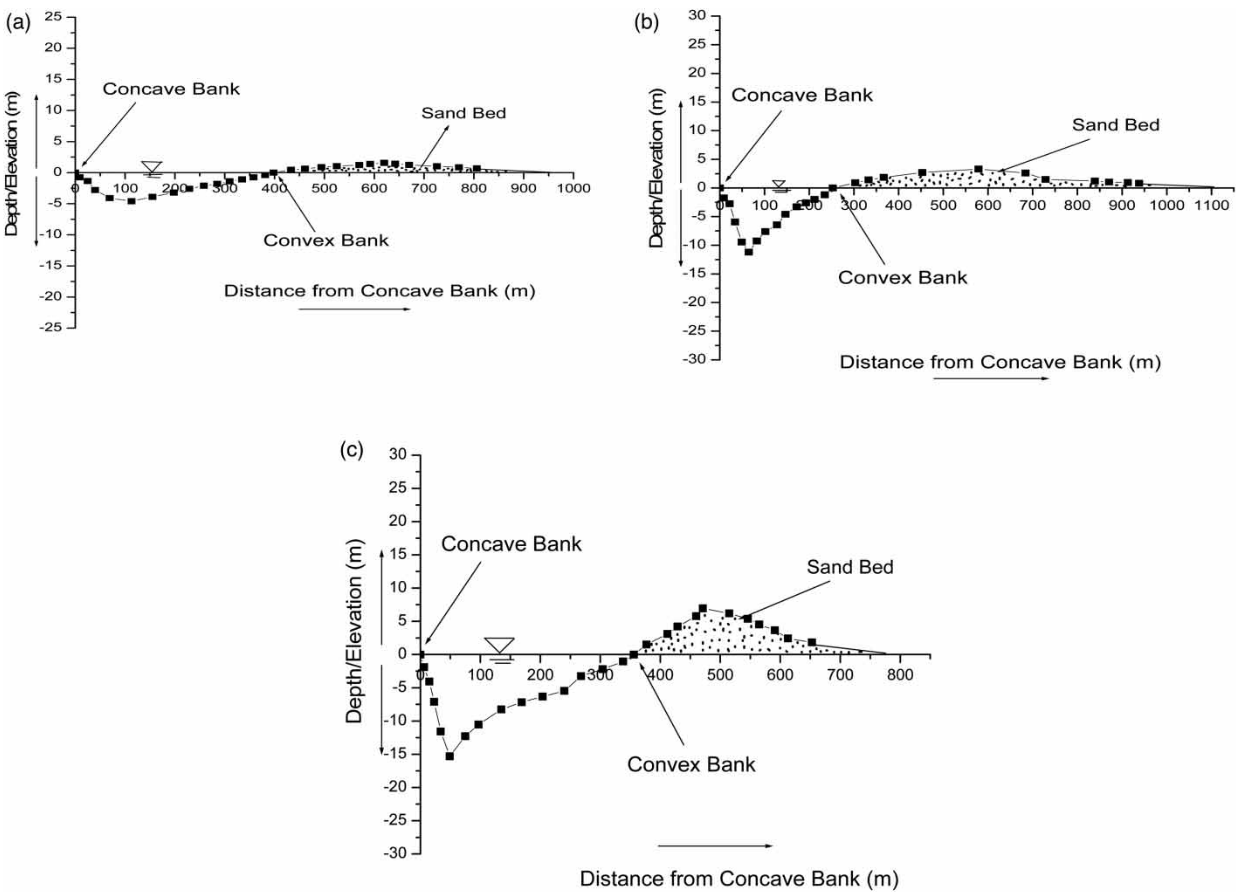

Figure 2 | (a) Cross-sectional profile of River Ganga at section 1-1, i.e. Ravidas Ghat. (b) Cross-sectional profile of River Ganga at section 2-2, i.e. Dashaswamegh Ghat. (c) Cross-sectional profile of River Ganga at section 3-3, i.e. Panchganga Ghat.

Measurement of the RL of the water level of the selected sections: the RL is marked on a permanent stable structure above the water level at Shiwala Ghat and at Vijay Nagar Ghat. These ghats are situated on the concave bank of River Ganga at Varanasi. At both ghats, the marked RL was transferred onto the water level with the help of theodolite and the staff. The distance between these two ghats was measured and the slope of the water surface was calculated. The RL of the concave side of the three sections (sections 1-1, 2-2, and 3-3) was calculated by calculating the distance of the section from Shiwala Ghat.

Measurement of physical characteristics of sand samples: Around 7 ft^3 of sand was collected from the central part of the sand bed of the three selected cross-sections. Sieve analysis was done, and the particle size distribution curves were obtained. Effective diameter (D10), coefficient of uniformity (Cu), and coefficient of curvature (Cc) were calculated. The coefficient of permeability was obtained by the falling head method. Experimental analysis was done in the soil mechanics laboratory of the Civil Engineering Department, IIT, BHU. The data are presented in Table 3. The filtration of secondary-treated effluent through the three different vertical sand columns was done, as shown in Figure 3.

3. EXPERIMENTAL SET-UP

To observe and compare the treatment performance of the collected sand samples from the three sections, three cylindrical filters of diameter 15 cm and height 45 cm were constructed. These filters have perforated bottoms to pass out the effluent. Sand samples were filled up to 30 cm height in each cylinder. The three cylindrical containers had conical funnels and containers to collect the filtered effluent. Figure 3 shows the schematic sketch of the filter.

4. EXPERIMENTAL PROCEDURE

Secondary-treated effluent was brought from the Bhagwanpur sewage treatment plant (STP) daily and dosed 2 l to each filter at the rate of 0.15 $m^3/m^2/h$ intermittently once in a day, for 45 days, to mature the filters. The time for the filters to stabilise

Table 3 | Physical characteristics of sand collected from the sections

Locations	Effective dia. D10 (mm)	Coefficient of uniformity Cu = D60/D10	Coefficient of permeability *K* (cm/s)
Section 1-1	0.137	1.817	3.75×10^{-2}
Section 2-2	0.097	2.11	1.27×10^{-2}
Section 3-3	0.129	1.751	3.369×10^{-2}

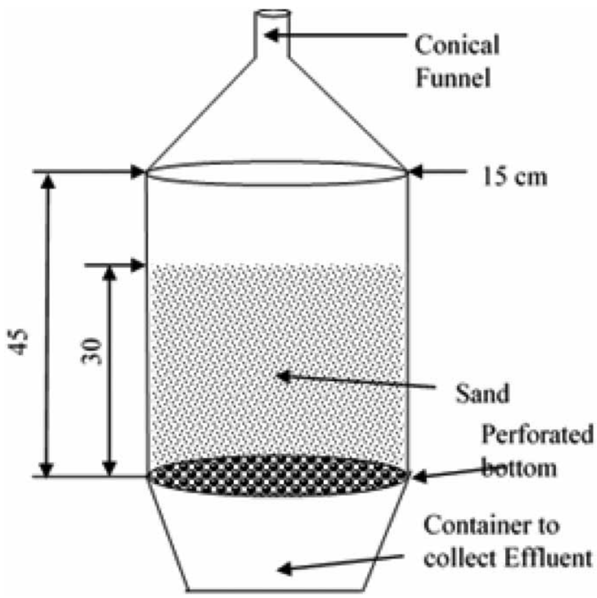

Figure 3 | Schematic sketch of filters.

and reach a constant performance (maturation) was found to be approximately 10 days, but progression to maturity up to 40 days was also observed (Bauer *et al.* 2011). From the experience of earlier published works, an initial 45-day period was utilised for the maturity of sand filters in the present work. The maturity of sand bed means sufficient growth of microbes, which is responsible for the organic matter removal. The same process continued and sampling of the treated effluent was started after 45 days of maturity. It took 45 min for the filtration of wastewater, after which, sand columns were kept as such in the open atmosphere for the rest of the day. Samples were collected for 50 days at a 5-day interval. DO, BOD, EC, TDS, salinity, pH, and temperature of the effluent were measured before and after the filtration through sand columns. DO, EC, TDS, salinity, and pH were measured with the digital probe of HACH, USA. BOD was measured by the standard method (APHA 1998) and temperature was measured by a glass thermometer.

5. RESULTS

The results are presented in three parts: (1) Results of morphological and bathymetrical surveys of the selected sections, which are (a) locations of sand beds; (b) width, maximum height, average slope, and cross-sectional area of sand beds of the three selected sections that give the zone of the longest filtration length and the maximum volume of sand available for wastewater filtration. (2) Results of the measurement of physical characteristics of the sand samples of the three sections, which are D10, Cu, and K that are used in further analysis of the effect of size and composition of sand on wastewater filtration. (3) Results of the measurement of filtration efficiency of three different sand columns, which give differences in the filtration potential of the sand columns.

5.1. Results of morphological and bathymetrical surveys

Survey with satellite imageries: The satellite imagery of the sand bed (Figure 1) of River Ganga clearly shows that the width of the sand bed is the maximum in the middle region of the bend. The data in Table 1 are taken from Google satellite imagery for the month of April 2017. The RL of the concave bank first increases from section 1-1 to section 2-2, and then, it decreases as one goes further downstream from section 2-2 to section 3-3. Figure 1 and Table 1 indicate that the river is curvilinear both in horizontal and vertical planes. The RL of the convex bank, i.e. sand bed increases continuously from section 1-1 to section 3-3. Table 2 shows the morphological characteristics (average slope, height, width, cross-sectional area) of the sand bed at the selected sections. The data indicate that the height of the sand bed increases as we move downstream in the bend.

5.2. Results of measurement of physical characteristics of the sand samples

As per Indian Standard (IS) code 383:1970, natural sand can be defined as a fine aggregate (particle size is less than 4.75 mm) produced by the natural disintegration of rock and which has been deposited by streams or glacial agencies. Sieve analysis results suggested that the sand deposited in all three sections is fine sand with an effective diameter (D10) of 0.137, 0.097, and 0.129 for sections 1-1, 2-2, and 3-3, respectively. The characteristics of fine sand in these sections are almost similar. Fine sand is hard and durable in nature, very clean, and free from adhering coatings and organic matter. The coefficient of permeability (K) for all three classes has been calculated from a constant head permeability test. The value of the coefficient of permeability (K) for section 1-1 is the highest (3.75×10^{-2} cm/s), while for section 2-2, it is the lowest (1.27×10^{-2} cm/s) as shown in Table 3.

5.3. Results of measurement of filtration efficiency of the sand samples

In order to find out the filtration efficiency of sand in these three sections, the effluent is taken out through three cylindrical filters of the same size (diameter as well as height) containing sand samples from sections 1-1, 2-2, and 3-3. About 2 l of secondary-treated effluent was dosed intermittently through filters once in a day for 45 days and the filtered sample was collected and analysed at a 5-day interval. An intermittent loading rate of 2.67 l/h (0.15 $m^3/m^2/h$) is maintained for all three sand samples throughout the experiment. Table 4 shows the mean, median, maximum, minimum, and standard deviation values of the parameters before and after filtration. Treatment performance (% increase and removal) of filters is calculated using mean values of the parameters.

Table 4 | Summary of treatment performance (percentage increase and/or removal) and parameters after filtration. Bolded values signifies the % Increase or % Removal in the values of tested parameters after the filtration.

Parameter	Before filtration		After Filtration	Filter Section 1-1	Section 2-2	Section 3-3
DO (mg/l)	Mean	3.87		4.9	5.3	5.6
	Median	3.97		4.74	5.1	5.4
	Maximum	5.10		6.33	6.5	6.7
	Minimum	2.78		3.72	4.5	4.5
	Standard deviation	0.76		0.97	0.74	0.76
			% Increase	**25.6**	**35.9**	**43.6**
BOD (mg/l)	Mean	18.08	After Filtration	1.42	1.15	1.09
	Median	18.00		1.32	1.08	1.10
	Maximum	19.4		1.92	1.85	1.49
	Minimum	16.5		1.14	0.77	0.54
	Standard deviation	1.00		0.27	0.34	0.30
			% Removal	**91.2**	**93.7**	**94.0**
EC (μS/cm)	Mean	738.9	After Filtration	702.7	714.1	722
	Median	742		672	742	716
	Maximum	767		931	903	966
	Minimum	707		561	534	587
	Standard deviation	19.2		115.8	102.9	120.6
			% Removal	**4.9**	**3.4**	**2.3**
TDS (mg/l)	Mean	360.8	After Filtration	342.9	348.6	352.6
	Median	362		327.5	361.5	349.5
	Maximum	375		458	448	476
	Minimum	345		272	259	285
	Standard deviation	9.68		58.5	52.5	60.5
			% Removal	**4.9**	**3.4**	**2.3**
pH	Mean	6.8	After Filtration	7.38	7.39	7.47
	Median	6.7		7.4	7.35	7.6
	Maximum	7.7		7.8	7.9	7.8
	Minimum	6.4		7	7.1	7.1
	Standard deviation	0.49		**0.24**	**0.25**	**0.33**
			% Increase	8.8	8.8	10.3
Temperature (°C)	Mean	26.18	After Filtration	30.26	30.5	29.64
	Median	24.4		29.5	29.7	28.7
	Maximum	33.5		36.7	37.8	37.8
	Minimum	21.5		23.5	23	24.3
	Standard deviation	4.1		4.6	5.09	5.00
			% Increase	**15.2**	**16.3**	**12.1**

6. DISCUSSION

6.1. Tacheometric survey

Cross-sectional details of the selected sections are presented in plots between depths of river/elevation of sand bed vs. transverse distance at three selected sections of River Ganga at Varanasi in Figure 2(a)–2(c) and in Table 2. These data are obtained by field observations through tacheometry.

The width of the river channel at Ravidas Ghat is 398 m. The formation of the sand bed has been well pronounced at the convex side. The width of the sand bed is 563 m. Slope and cross-sectional area are minimum at this section, among the selected three sections.

From the tacheometric survey and data of satellite imagery, we got similar results, which means, as we move downstream in a bend, the height of the sand bed increases. Among the three selected sections, the width and cross-sectional area of the sand bed are maximum at the middle region, i.e. at section 2-2 (Dashaswamedh Ghat). Therefore, at section 2-2, the maximum amount of sand is available for wastewater filtration. And the maximum filtration length is also available in this section.

At the entry region of the bend, the curvature of the bend is less; therefore, the centrifugal force is less, and secondary cells are less pronounced. This may be one of the reasons why the width of the sand bed is less here. As the flow moves downstream towards the middle region of the bend, centrifugal forces enhance and lead to well-developed secondary cells (Choudhary 1974). Enhancement in centrifugal forces may be one of the main causes for the increase in the width of the sand bed in the middle region of the bend. In the exit region again, centrifugal forces reduce and the width of the sand bed reduces. The height of sedimentation (sand bed) is maximum at section 3-3 and it reduces as we move upstream towards section 1-1. This is because of the formation of a separation zone in zone 3, which leads to the maximum height of sedimentation in this zone.

6.2. Physical characteristics of sand samples

From Table 3, it is clear that although all three sand samples are in the fine sand category, their D10 values vary from section to section. At the entry zone of the bend, coarser sand is deposited, as the flow moves further towards the central zone (section 2-2), the sand becomes finer. Again, the result of sieve analysis shows that the sand becomes coarser in the exit region as compared to that of the section in the middle region. However, it is observed by the naked eye that there is a mixture of sand and fine silt at section 3-3. So, maybe, the effective diameter D10 of the sand of section 3-3 by sieve analysis gives a little higher value than its actual value. This may be due to the loss of fine silt during sieve analysis.

As the flow traverses from an upstream bend to a downstream bend, the concave bank converts into the convex bank and vice-versa. It means that the bank where erosion occurs in the upstream bend is slowly converted to the bank where sedimentation happens in the downstream bend (Omar *et al.* 2022b). The orientation of secondary cells reverses. The residual effect of the upstream bend does not allow smaller sand particles to settle down in the entry region of the downstream bend. As the flow traverses towards the middle region of the downstream bend, centrifugal forces enhance and the residual effect of the upstream bend reduces. In this region, finer sand particles also deposit at the upper layer of the sand bed. In the exit region of the bend, streamlines diverge and a separation zone is formed at the convex side. Hence, silt and clay are also deposited with sand in this region.

6.3. Treatment performance of the vertical sand columns

To measure the treatment performance of the sand samples, the data of filtration through vertical sand filters are discussed here. Treatment performances of the three sand samples are compared under the same atmospheric conditions and loading rates. The height of the sand column is kept constant for all three sand samples throughout the experiment.

The percentage increase in the mean value of DO is the highest for the sand sample of section 3-3 and the lowest for section 1-1. It shows that the sand sample of section 3-3 is better than the other two in terms of DO increase.

Percentage removal in the mean value of BOD is the highest for the sand sample of section 3-3 and the lowest for section 1-1. The difference in the percentage removal for sections 2-2 and 3-3 is very small; therefore, BOD removal from the sand samples of sections 2-2 and 3-3 is nearly equal. The higher BOD removal from the sand of the central zone (zone 2) and the exit zone (zone 3) than the entry zone (zone 1) is attributed to finer sand deposition in the central zone, and silt along with sand in the exit zone. Table 4 also shows that the average removal of BOD from the sand of section 2-2 was 93.7% when the hydraulic loading rate was maintained at 0.15 m/h. Al-Adham did an experiment at a nearly equal hydraulic loading rate of 0.16 m/h and found the average removal of BOD to be 86% for a 20-day filtration run. The removal percentage is higher than Al-Adham's results, which may be because he performed the experiments in the winter season (at a lower temperature).

The value of percentage removal in the mean values of EC and TDS is 4.9, 3.4, and 2.3% for sections 1-1, 2-2, and 3-3, respectively. It shows that there is a very slight variation in the EC and TDS of secondary-treated effluent after sand filtration. This removal occurs due to the adsorption of sand particles.

The mean value of daywise variation in the pH of the influent and the effluent shows that it changes from slightly acidic to slightly alkaline after filtration for all sand filters.

Data of each day show that the temperature of the effluent after filtration is more than the temperature of the influent for all three filters, and the percentage increase in the mean value of temperature is nearly the same for all three filters.

Selection of the best section for the filtration of wastewater: Among the three sections, the width and approximate cross-sectional area of the sand bed at section 2-2 is maximum and their values are 856 m and 1,404.4 m^2, respectively, for the month of April 2017 (lean period). The maximum filtration length and the maximum volume of sand for the filtration of wastewater are available in zone 2.

Percentage BOD removal by vertical sand filters made by sands of sections 1-1, 2-2, and 3-3 are 91.2, 93.7, and 94.0, respectively. In terms of BOD removal, the sand of section 3-3 is slightly better than the other two sand samples. The reason may be the presence of silt along with the sand in zone 3 (section 3-3).

The percentage of BOD removal is slightly more for the sand of section 3-3; however, due to the formation of a separation zone in the stream in this region, pollutants are likely to be stagnant and not easily dispersed in this region. Hence, section 3-3 is not suitable for wastewater disposal. Therefore, in view of the above results, section 2-2 seems to be the better section for wastewater disposal.

7. LIMITATIONS

Sand samples of River Ganga have been collected from three different zones and an attempt has been made to represent an entire zone (1, 2, and 3) from that sample. An experimental study can be carried out to select more suitable sites to obtain more useful results in real-field conditions. More laboratory tests can be conducted to simulate the actual morphology of the sand bed and to evaluate the effect of other hydraulic parameters that affect the flow of wastewater into the natural river sand bed.

8. CONCLUSIONS

The height of the sand bed continuously increases as the distance downstream increases and it attains the maximum at the end of the bend. Among the three selected zones in the river bend, the filtration length and the volume of the sand available are maximum in the central zone (zone 2) and their values are approximately 856 m and $14.04 \times 105\ m^3$, respectively. The effective diameter (D10) and the coefficient of permeability (K) of the sand at the central zone are the lowest among the three zones. Hence, out of the three selected zones, the middle zone of the sand bed has the best sand deposits. The sand sample of the exit zone (zone 3) shows that a small amount of silt is also deposited with the sand in this zone. The sand filters 1, 2, and 3 are quite efficient in organic load (BOD) removal with mean efficiencies of 91.2, 93.7, and 94.0%, respectively. The performance of sands of zones 2 and 3 is nearly equal and better than the sand of zone 1. The sand filters have lesser mean removal efficiencies of 2–5% for EC and TDS. The pH of wastewater slightly changes from acidic to alkaline with the values for sand filters 1, 2, and 3: it changes from 6.8 to 7.38, from 6.8 to 7.39, and from 6.8 to 7.47, respectively. The mean temperature of 26.18 °C of the wastewater increases to 30.3, 30.5, and 29.6 °C after the filtration from sand filters 1, 2, and 3, respectively. This suggests that the sand temperature is higher than that of the wastewater but this higher temperature is almost the same for all three filters. Although BOD removal is the function of the rise in the temperature of the sand bed, the rise in temperature is nearly the same for all three filters. Therefore, the observed differences in the sand filters in BOD removal are mainly due to the difference in the particle size of the sand. From the interpretation of the above conclusions, it is clear that the convex side of the sand bed of the central zone (zone 2) of the river bend is found to be the most suitable for the disposal and filtration of wastewater.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Al-Adham, S. S. 1989 *Tertiary Treatment of Municipal Sewage via Slow Sand Filtration*. MSc Thesis, Faculty of the College of Graduate Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.

Alekseevskiy, N. I., Berkovich, K. M. & Chalov, R. S. 2008 Erosion, sediment transportation and accumulation in rivers. *International Journal of Sediment Research* **23** (2), 93–105.

APHA 1998 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association, Washington, DC.

Ausland, G., Stevik, T. K., Hanssen, J. F., Kohler, J. C. & Jenssen, P. D. 2002 Intermittent filtration of wastewater – removal of fecal coliforms and fecal streptococci. *Water Research* **36** (2002), 3507–3516.

Bauer, R., Dizer, H., Graeber, I., Rosenwinkel, K. & López-Pila, J. M. 2011 Removal of bacterial fecal indicators, coliphages and enteric adenoviruses from waters with high fecal pollution by slow sand filtration. *Water Research* **45** (2), 439–452.

Check, G., Waller, D., Lee, S., Pak, D. & Mooers, J. 1994 The lateral-flow sand-filter system for septic effluent treatment. *Water Environment Research* **66** (7), 919–928.

Choudhary, U. K. 1974 *Experimental Investigation of Sub Critical Flow in Narrow and Wide 1800 Open Channel Bends*. PhD Thesis, I.I.T., Bombay.

Choudhary, U. K. 1993 Barriers in the Ganga pollution management project in Varanasi India Proceeding. In *3rd Stockholm Water*, 10–14 August, 1993, Stockhome, Sweden, pp. 199–206.

Choudhary, U. K. 2008 Utilization of Renewable River Energies for Cost Effective Pollution Abatement Abstract Volume. *Stockholm World Water Week*, 17–23 August, 212–213.

Choudhary, U. K. & Singh, A. N. 2010 Part to Whole Renewable Energy Utilization Concept: Integrated Pollution Prevention and Control' Stockholm World Water Week, 5–11 Sept 2010, Responding to global changes: The Water Quality Challenge-Prevention, Wise use and Abatement, Workshop no.1, Abstract Volume, 2010, Page no. 21–22, Stockholm, Sweden.

Choudhary, U. K., Srivastava, N. K. & Mohan, D. 1998 Convex bank potential of river for pollution management' Proceeding, Environmental Management, Australia, Vol. No.1, 609–614.

CPCB 2013 *Performance Evaluation of Sewage Treatment Plants Under NRDC*. Ministry of Environment and Forests, East Arjun Nagar, Delhi, Government of India.

Gaur, S., Johannet, A., Graillot, D. & Omar, P. J. 2021 Modeling of groundwater level using artificial neural network algorithm and WA-SVR Model. In: *Groundwater Resources Development and Planning in the Semi-Arid Region* (C. B. Pande & K. N. Moharir, eds.). Springer, Cham, pp. 129–150.

Google Earth 2011 Google Earth internet site. Satellite Imageries of River Ganga and in Plains. Available from: http:// www.googleearth.com (accessed 30 June 2011).

Gross, M. A. & Mitchell, D. 1990 Virus removal by sand filtration of septic tank effluent. *Journal of Environmental Engineering, ASCE* **116** (4), 711–720.

Hamner, S., Tripathi, A., Mishra, R. K., Bouskill, N., Broadaway, S. C., Pyle, B. H. & Ford, T. E. 2006 The role of water use patterns and sewage pollution in incidence of water-borne/enteric diseases along the Ganges River in Varanasi, India. *International Journal of Environmental Health Research* **16**, 113–132.

Hamner, S., Pyke, D., Walker, M., Pandey, G., Mishra, R. K., Mishra, V. B., Porter, C. & Ford, T. E. 2013 Sewage pollution of the River Ganga: an ongoing case study in Varanasi, India. *River Systems* **20** (3–4), 157–167.

Havard, P., Jamieson, R., Cudmore, D., Boutilier, L. & Gordon, R. 2008 Performance and hydraulics of lateral flow sand filters for on-Site wastewater treatment. *Journal of Hydrologic Engineering, ASCE* **13** (8), 720–728.

Hua, J., An, P., Winter, J. & Gallert, C. 2003 Elimination of COD, microorganisms and pharmaceuticals from sewage by trickling through sandy soil below leaking sewers. *Water Research* **37** (2003), 4395–4404.

Jana, P., Pandey, R., Semeraro, T., Alatalo, J. M., Areteno, R., Todaria, N. P. & Tripathi, R. 2021 Community perspectives on conservation of water sources in Tarkeshwar sacred groves, Himalaya, India. *Water Supply* **21** (8), 4343–4354.

Kumar, V., Chaplot, B., Omar, P. J. & Mishra, S. 2021 Experimental study on infiltration pattern: opportunities for sustainable management in the Northern region of India. *Water Science and Technology* **84** (10–11), 2675–2685.

Metcalf and Eddy 1979 *Wastewater engineering: treatment, disposal, reuse*, 3rd edn. Tata McGraw-Hill. pp. 372–373.

Mishra, U., Mohapatra, A. K., Mandal, A. & Singh, A. 2023 Identification of potential artificial groundwater recharge sites in an alluvial setting: a coupled electrical resistivity tomography and sediment characterization study. *Groundwater for Sustainable Development* **20**, 100875.

Omar, P. J., Gupta, N., Tripathi, R. P. & Shekhar, S. 2017 A study of change in agricultural and forest land in Gwalior city using satellite imagery. *SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology* **9** (02), 109–112.

Omar, P. J., Dwivedi, S. B. & Dikshit, P. K. S. 2020 Sustainable development and management of groundwater in Varanasi, India. In: *Advances in Water Resources Engineering and Management* (R. AlKhadda, R. Singh, S. Dutta, M. Kumari, eds). Lecture Notes in Civil Engineering, Springer, Singapore, pp. 201–209.

Omar, P. J. 2021 Modeling of Groundwater Level Using Artificial Neural Network Algorithm and WA-SVR Model. In: *Groundwater Resources Development and Planning in the Semi-Arid Region* (C. B. Pande & K. N. Moharir, eds). Springer, Cham, pp. 129-150.

Omar, P. J., Gaur, S. & Dikshit, P. K. S. 2021a Conceptualization and development of multi-layered groundwater model in transient condition. *Applied Water Science* **11** (10), 1–10.

Omar, P. J., Gaur, S., Dwivedi, S. B. & Dikshit, P. K. S. 2021b Development and application of the integrated GIS-MODFLOW model. In: *Fate and Transport of Subsurface Pollutants*. *Microorganisms for Sustainability*, vol. 24 (P. K. Gupta & R. N. Bharagava, eds). Springer, Singapore, pp. 305–314.

Omar, P. J., Rai, S. P. & Tiwari, H. 2022a Study of morphological changes and socio-economic impact assessment: a case study of Koshi River. *Arabian Journal of Geosciences* **15** (17), 1–15.

Omar, P. J., Shivhare, N., Dwivedi, S. B. & Dikshit, P. K. S. 2022b Identification of soil erosion-prone zone utilizing geo-informatics techniques and WSPM model. *Sustainable Water Resources Management* **8** (3), 1–13.

Prasad, G., Rajput, R. & Chopra, A. K. 2006 Sand intermittent filtration technology for safer domestic sewage treatment. *Journal of Applied Sciences and Environmental Management* **10** (1), 73–77.

Shekhar, S., Chauhan, M. S., Omar, P. J. & Jha, M. 2021 River discharge study in river Ganga, Varanasi using conventional and modern techniques. In: *The Ganga River Basin: A Hydrometeorological Approach. Society of Earth Scientists Series* (M. S. Chauhan & C. S. P. Ojha, eds). Springer, Cham, pp. 101–113.

Tripathi, R. P. & Pandey, K. K. 2021 Experimental study of local scour around T-shaped spur dike in a meandering channel. *Water Supply* **21**, 542–552.

Tripathi, R. P. & Pandey, K. K. 2022a Numerical investigation of flow field around T-shaped spur dyke in a reverse-meandering channel. *Water Supply* **22** (1), 574–588.

Tripathi, R. P. & Pandey, K. K. 2022b Scour around spur dike in curved channel: a review. *Acta Geophysica* **70** (5), 2469–2485.

Trombadore, O., Nandi, I. & Shah, K. 2020 Effective data convergence, mapping, and pollution categorization of ghats at Ganga River Front in Varanasi. *Environmental Science and Pollution Research* **27**, 15912–15924.

Zahid, W. M. K. 2003 Tertiary filtration of wastewater using local sand. *Journal of King Saud University* **16** (1), 23–36.

First received 9 November 2022; accepted in revised form 20 April 2023. Available online 17 May 2023