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Hydro Science & Marine Engineering

Volume 3·Issue 2·October 2021 ISSN 2661-331X(Online)



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Volume 3 Issue 2 · October 2021 · 2661-311X(online)

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Contents

Editorial

- 18 Recent Development in Ice Engineering**
Li Zhou

Articles

- 1 Effects of Spur Dyke's Orientation on Bed Variation in Channel Bend**
Mohammad Athar TalibMansoor NishankAggarwal
- 10 Degree of Integrated Water Resources Management Implementation in Context of Climate Change in a Watershed: Case of Oueme Basin, Benin (West Africa)**
Femi. Cocker Eric A. Alamou Bernadin M. Elegbede Ismaïla I. Toko
- 20 Effect of Meander on Bridge Pier Scour**
M. Athar M.K. Sabiree H. Athar
- 32 Surface Water Quality Assessment of Panchagnaga River and Development of DO-BOD Relationship Using Empirical Approach**
Shilpa Yakkerimath Sanjaykumar Divekar Chidanand Patil Amruth A Purandara Bekal

ARTICLE

Effects of Spur Dyke's Orientation on Bed Variation in Channel Bend

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ARTICLE INFO

Article history

Received: 14 October 2021

Accepted: 21 October 2021

Published Online: 5 November 2021

Keywords:

Spur dykes

Inner bank

Outer bank

Bridge pier

Curved channel

Location

ABSTRACT

Spur dykes also known as Groynes are often used to either divert or attract the flow from the main structure to safeguard their life. Those structures may be bridge piers, abutments or any similar hydraulics structures. Spur dykes are also used to save the cutting of banks on concave side of stream. Lots of work have been done in recent past on spur dykes by many investigators in which various hydraulic and geometrical parameters of spur dykes such as discharge, sediment size, flow velocity, shear stress, spur dykes shape, size and submergence etc. are studied in detail. But mostly all the studies were pointed out in straight open channels. Very few studies were done in curved channel and only their similar effects were studied. In present thesis main emphasis is given to study the effect of orientation and location of spur dykes in meandering channel on the bed of downstream side. In the present study experimental work has been carried out in 80° bend and constant discharge ($Q = 4.5 \text{ l/s}$) is allowed to pass in channel without spur dyke. It is found that maximum scouring occurs at angular displacement $\theta = 60^\circ$ to 80° in the vicinity of outer bank. To minimize this scouring, spur dyke has been installed at angular displacement $\theta = 20^\circ$, 40° & 60° by changing the dyke angle $\alpha = 60^\circ$, 90° & 120° respectively. It is found that scouring at $\theta = 60^\circ$ is reduced by installing spur dyke at angular displacement $\theta = 40^\circ$ which is oriented at $\alpha = 60^\circ$ and scouring at $\theta = 80^\circ$ is reduced by installing spur dyke at angular displacement $\theta = 60^\circ$ which is oriented at $\alpha = 60^\circ$.

1. Introduction

Spur dykes or Groynes are hydraulic structures that project from the bank of streams or rivers at some angle or perpendicular to the main flow direction. They are used for two purposes, namely river training and erosion protection of the riverbank. With respect to river training,

the primary objective is to improve the navigability of a river by providing a sufficient depth of flow and a desirable channel alignment. Spur dykes also serve to increase the sediment transport rate through the dyked reach, which decreases channel dredging costs. With respect to erosion protection, spur dykes can be designed to protect both straight reaches and channel bends.

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DOI: <https://doi.org/10.30564/hsme.v3i2.3834>

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Compared with other methods, such as revetments, spur dykes are among the most economical structures that may be used for riverbank erosion protection.

Spur dikes have been used extensively in all parts of the world as river training structures to enhance navigation, improve flood control and protect erodible banks. Spur dike can be defined as an elongated obstruction having one end on the bank of a stream and the other end projecting into the current. It may be permeable, allowing water to pass through it at a reduced velocity; or it may be impermeable, completely blocking the current. Spur dikes may be constructed of permanent material such as masonry, concrete, or earth and stone; semi-permanent material such as steel or timber sheet piling, gabions or timber fencing or temporary material such as weighted brushwood fascines. Spur dikes may be built at right angles to the bank or current, or angled upstream or downstream. The effect of the spur dike is to reduce the current along the stream bank, thereby reducing the erosive capability of the stream and in some cases inducing sedimentation between dykes.

Few investigators carried out extensive work on flow behavior and scour around spur dykes in straight as well as curved reach of meandering channel. Amongst those are Garde et al. (1961) ^[7], Gill (1972) ^[8], Zaghoul et al. (1982) ^[9], Elawady, et al. (2001) ^[13], Kuhnle et al. (2002) ^[10], Zhang (2005) ^[12], Vaghefi et al. (2009) ^[16], Zhang et al. (2009) ^[5], Masjedi et al. (2010) ^[15], Yossef (2010) ^[3], Zhang et al. (2012) ^[2], Parashar et al. (2014) ^[14], Przedwojski (2015) ^[6], Pandey et al. (2017) ^[1], Karki et al. (2018) ^[4] etc. After reviewing their work it is concluded that lot of work on spur dyke have been done. But the effect of spur dyke's orientation on bed variation is not available in literature.

This report is concerned with the use of impermeable spur dikes as a bank protection technique in a concave bend of a meandering stream. Although the use of spur dikes is extensive, no definitive hydraulic design criteria have been developed. Design continues to be based primarily on experience and judgment within specific geographical areas. This is primarily due to the wide range of variables affecting the performance of the spur dikes and the varying importance of these variables with specific applications. Parameters affecting spur dike design include width, depth, velocity, sinuosity of the channel, size and transportation rate of the bed material, cohesiveness of the bank, length, width, crest profile, orientation angle and spacing of the spur dikes.

Dimensional analysis

The variables required to define the scour and deposition

(river bed variation) in straight and curved open channels are velocity of flow (v), depth of flow above channel bed (y), mean sediment particle size (d_{50}), mass density of water (ρ), mass density of solid (ρ_s), viscosity of water (μ), acceleration due to gravity (g), and angular displacement (θ). Using Buckingham Pie's method following dimensionless number have been found.

$$d_s = f \{v, \rho, y, \theta, d_{50}, \mu, g, b, t, \alpha, \rho_s, w\} \quad (1)$$

Now, from Equ.(1)

$$d_s/w = \prod_1$$

So we can write all Pie terms

$$\prod_1 = f(\prod_2, \prod_3, \prod_4, \prod_5, \prod_6, \prod_7, \prod_8, \prod_9, \prod_{10})$$

$$\text{Therefore } d_s/w = f(\rho_s/\rho, y/w, b/w, t/w, \alpha, \theta, d_{50}/w, \rho v w/\mu, v/\sqrt{g w}) \quad (2)$$

Since only one dyke of constant size, shape is used so b/w & t/w both are constant hence both parameter are dropped. Also discharge was constant so y/w , $\rho v w/\mu$ (Reynolds No.) and $v/\sqrt{g w}$ (Froude no.) all were dropped. Thus finally two were left therefore it can be concluded that d_s/w is a function of angular displacement and spur dyke angle.

$$d_s/w = f(\theta, \alpha) \quad (3)$$

Now, using above dimensionless parameters all data analysis were carried out and graphs were plotted to investigate the actual effect of spur dyke's orientation & location on bed variation in curved channel.

2. Experimental Setup and Procedure

Experiments were conducted in the Advanced Post Graduate Hydraulics Laboratory, Department of Civil Engineering, Zakir Hussain College of Engineering & Technology, Aligarh Muslim University, Aligarh.

2.1 Flume

The data are collected in an open horizontal rectangular sinuous (meandering/curved) channel (0.35m wide and 0.43m deep) made up of 0.5mm thick tin sheet, carefully installed in an open horizontal rectangular flume (0.76m wide and 0.60m deep and 10.5m long) prismatic glass walled channel with cement plastered bottom. In channel, bed is prepared by 0.22m height of sand throughout the channel. Schematic diagram and photographic view of the experimental setup are shown in Figures 1, 2 and 3. The model has a straight upstream reach of 2.88m and a straight downstream reach of 2.1m. In between the upstream and the downstream reach two sinuous bends having the same dimensions are present. The four 80° curved channel bends were provided in series. Each bend has rectangular cross section with 0.35 m width, 0.43 m height and with 0.705 m radius of curvature at center line.

The central angle of the each bend is 80° and the central radius of the channel (R_c) is 0.705 m. The width of the experimental model is 0.35 m here $R_c/W = 2.014$ (Ratio of the central radius to the width of the channel). Since the ratio R_c/W is less than 3, the bend is considered as a sharp bend. A straight transition of 0.05 m is provided between each bends.

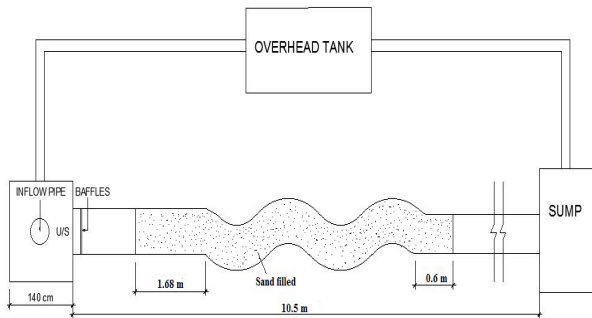


Figure 1. Schematic line diagram of bed flume

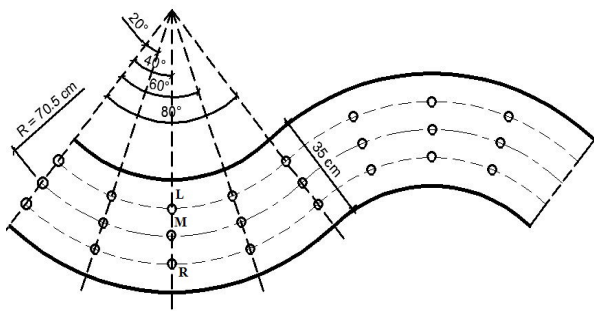


Figure 2. Schematic view of bend angle



Figure 3. Installation of spur dyke

2.1.1 Dyke Model

In present study spur dyke is made up of wooden sheet having width ($b = 7.5\text{ cm}$) and thickness ($t = 1.5\text{ cm}$). Spur dyke of non-submerged condition is installed one by one at three orientation ' α ' (measured from tangent of right

hand side of channel in clockwise direction) 60° , 90° and 120° and three different locations in Bend 1 and Bend 3 separately. Bend angle and orientation of spur dyke are shown in Figure 2.

2.1.2 Contraction Ratio

Contraction ratio is defined as the ratio of the width of spur dyke to the width of the flume. In present study contraction ratio is 0.214 which is less than 0.25. If contraction ratio is greater than 25% with higher values of Froude number, the stability of the opposite bank will be in danger, in addition to the stability of the spur itself, which will cost a lot to protect the spur foundation and the channel banks against the scouring process.

2.1.3 Source of Sediment and Its Properties

Sediment size d_{50} as 0.27mm was used for making the bed of channel.

2.1.4 Flow Condition

Discharge = 4.5 l/s, Flow depth = 4.5 cm, Average velocity = 0.286 m/s and Froude No. = 0.43 (Subcritical). Discharge is measured by a sharp crested calibrated rectangular weir provided at the end of downstream drain channel by recording the head on the weir with the help of point gauge (with 0.10 mm accuracy).

2.1.5 Calibration of Weir

A sharp crested rectangular weir provided at the end of downstream drain channel was first calibrated. Through the gate valve feeding the channel, a small discharge was allowed to pass and after obtaining the steady state flow condition, head on the weir was recorded with the help of a point gauge (with 0.10 mm accuracy) and rise in water level in the underground collecting well was recorded in three mutually perpendicular directions with the help of two theodolite simultaneously. The corresponding time for the rise mentioned above was recorded with the help of stopwatch (with 0.01 seconds least count). For each head over the weir, three sets of rises in water level and corresponding time were recorded. In this way six values of this discharge for one head were recorded for getting the best accuracy. Average value of these six observations was noted and calibration curve is plotted. Table 1 shows the data of deposition and scour for Bend 1 at $\theta = 0^\circ$ displacement when dyke installed at location 1.

2.2 Experimental Procedure

Test bed was first prepared by filling the well graded

sand having d_{50} as 0.27 mm with uniform compaction method. It was first ensured that test bed is properly compacted and smoothened. When test bed is ready than a flow of amount 4.5 l/s is allowed to pass over the bed for about 3-4 hours. After that test run is stopped there was slight variation in the test bed level in straight and curved reaches. All readings along and across were taken. In second phase the spur dyke of designed shape and size was installed at a particular location and similar run was passed and again all readings were recorded. Similarly at many locations and orientations for same discharge $Q = 4.5$ l/s run were taken and data for bed variation were collected for further analysis.

3. Analysis of Data and Results

3.1 Bed Variation along the Longitudinal Direction without Spur Dyke

Figure 4 shows the variation of scour and deposition

along the longitudinal direction in meandering channel without installing spur dyke for $Q = 4.5$ l/s. Maximum scouring and maximum deposition occurred at concave (outer) side and convex (inner) side respectively in the vicinity of bank. Scouring and deposition pattern at 5 cm and 30 cm are mirror image of each other. At 20 cm, scouring and deposition pattern lies in between the 5 cm and 30 cm.

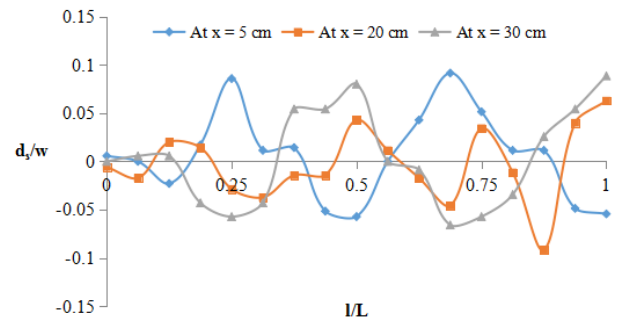


Figure 4. Bed variation along the longitudinal direction throughout the channel without spur dyke

Table 1. Data for bed variation at section $\theta = 0^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

BEND 1				BEND 3			
NO SPUR DYKE							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.3	0	0.008571	0	-3.5	0	-0.1
5	0.2	0.142857	0.005714	5	-2	0.142857	-0.05714
10	0.2	0.285714	0.005714	10	0	0.285714	0
15	0	0.428571	0	15	1.4	0.428571	0.04
20	-0.2	0.571429	-0.00571	20	1.5	0.571429	0.042857
25	-0.2	0.714286	-0.00571	25	1.1	0.714286	0.031429
30	0	0.857143	0	30	2.8	0.857143	0.08
35	0	1	0	35	1.6	1	0.045714
SPUR DYKE ORIENTED AT $\alpha = 90^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.6	0	0.017143	0	-0.2	0	-0.00571
5	-0.1	0.142857	-0.00286	5	-1.3	0.142857	-0.03714
10	-1	0.285714	-0.02857	10	-0.5	0.285714	-0.01429
15	-3.2	0.428571	-0.09143	15	1.4	0.428571	0.04
20	-2.1	0.571429	-0.06	20	-0.5	0.571429	-0.01429
25	-4.2	0.714286	-0.12	25	0.2	0.714286	0.005714
30	-2.2	0.857143	-0.06286	30	-0.6	0.857143	-0.01714
35	-0.9	1	-0.02571	35	0	1	0
SPUR DYKE ORIENTED AT $\alpha = 60^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0.7	0	0.02	0	-3.9	0	-0.11143
5	-1.5	0.142857	-0.04286	5	-2.7	0.142857	-0.07714
10	-1	0.285714	-0.02857	10	-1.2	0.285714	-0.03429
15	-0.7	0.428571	-0.02	15	0.8	0.428571	0.022857
20	-3.6	0.571429	-0.10286	20	1.1	0.571429	0.031429
25	-3.9	0.714286	-0.11143	25	1.5	0.714286	0.042857
30	-2.1	0.857143	-0.06	30	-1.7	0.857143	-0.04857
35	-1.5	1	-0.04286	35	-2	1	-0.05714
SPUR DYKE ORIENTED AT $\alpha = 120^\circ$							
x	ds	x/w	ds/w	x	ds	x/w	ds/w
0	0	0	0	0	-3.8	0	-0.10857
5	0.2	0.142857	0.005714	5	-3	0.142857	-0.08571
10	0.1	0.285714	0.002857	10	-0.5	0.285714	-0.01429
15	-0.3	0.428571	-0.00857	15	0.3	0.428571	0.008571
20	-1.9	0.571429	-0.05429	20	1.1	0.571429	0.031429
25	-3.5	0.714286	-0.1	25	2	0.714286	0.057143
30	-2	0.857143	-0.05714	30	-0.5	0.857143	-0.01429
35	-2	1	-0.05714	35	-1.5	1	-0.04286

3.2 Bed Variation along the Transverse Direction without Spur Dyke

Figures 5 and 6 show the bed variation along the transverse direction for Bend 1 and Bend 3 respectively at various values of angular displacement (θ) without spur dyke. At $\theta = 0^\circ$ negligible scour and deposition occurred at Bend 1 but this phenomenon is not same for Bend 3 because of transition zone in Bend 1. In Bend 3, at $\theta = 0^\circ$, initially scouring occurred till $1/4^{\text{th}}$ of width of channel and after which deposition start. This difference of bed pattern of Bend 1 & Bend 3 occurred till the $\theta = 40^\circ$ and after that similarity in bed pattern begins.

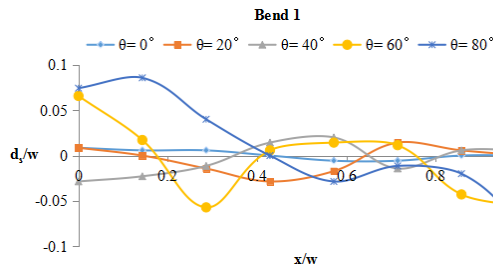


Figure 5. Bed variation of Bend 1 along the transverse direction without spur dyke

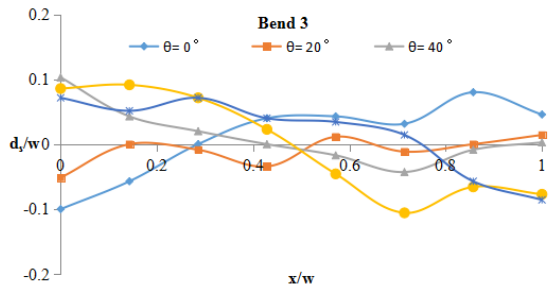


Figure 6. Bed variation of Bend 3 along the transverse direction without spur dyke

3.3 Bed Variation along the Transverse Direction of Bend-1

Figure 7 shows the bed variation along the transverse direction at angular displacement ($\theta = 0^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ & 120°) and without spur dyke which is installed at $\theta = 0^\circ$ (location 1) of Bend 1. Maximum scouring occurred near the spur dyke for all ' α ' but $\alpha = 120^\circ$ gives less scouring near spur dyke in comparison to other $\alpha = 60^\circ$ and 90° .

Figure 8 shows the bed variation along the transverse direction at angular displacement ($\theta = 40^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 0^\circ$ (location 1) of Bend 1. Maximum scouring occurs at center of the channel when $\alpha = 120^\circ$. At $\alpha = 90^\circ$ and without spur dyke

show almost same pattern.

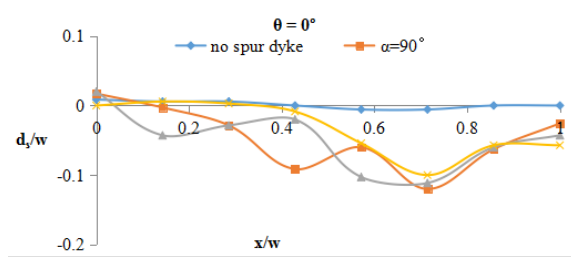


Figure 7. Bed variation of Bend 1 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

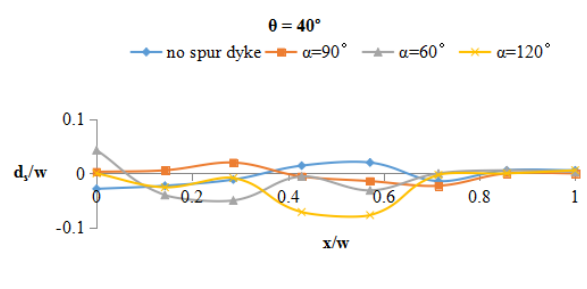


Figure 8. Bed variation of Bend 1 at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

Figure 9 shows the bed variation along the transverse direction at angular displacement ($\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 0^\circ$ (location 1) of Bend 1. Graphs at $\alpha = 60^\circ, 90^\circ, 120^\circ$ and without spur dyke show almost same bed variation.

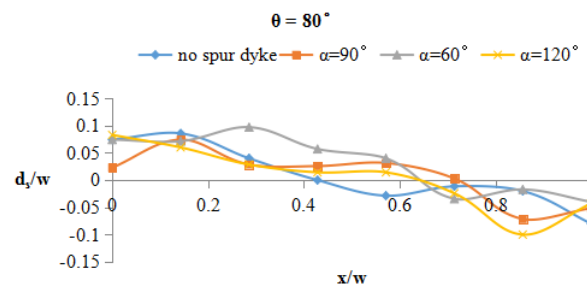


Figure 9. Bed variation of Bend 1 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

Figure 10 shows the bed variation along the transverse direction at angular displacement ($\theta = 0^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 1. In this figure all the graphs $\alpha = 60^\circ, 90^\circ, 120^\circ$ and without spur dyke show the same bed variation.

Figure 11 shows the bed variation along the transverse direction at angular displacement ($\theta = 40^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and

without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 1. This section is important for analysis because at this section spur dyke is also installed. Near the spur dyke scouring is less in comparison to when spur dyke installed at $\theta = 0^\circ$. So we can say at $\theta = 40^\circ$ is the stable location for the spur dyke.

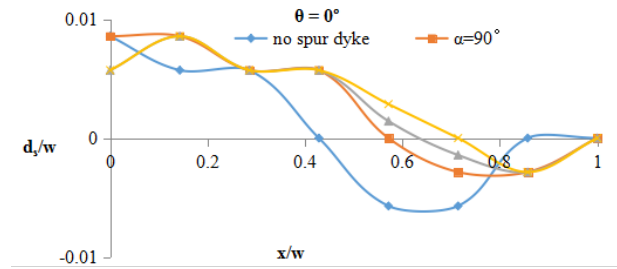


Figure 10. Bed variation of Bend 1 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

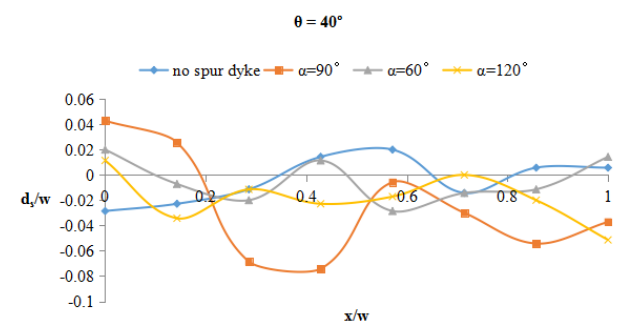


Figure 11. Bed variation of Bend 1, at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

Figure 12 shows the bed variation along the transverse direction at angular displacement ($\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 1. In this figure all the graphs at $\alpha = 60^\circ$, 90° , 120° and without spur dyke shows almost same bed variation.

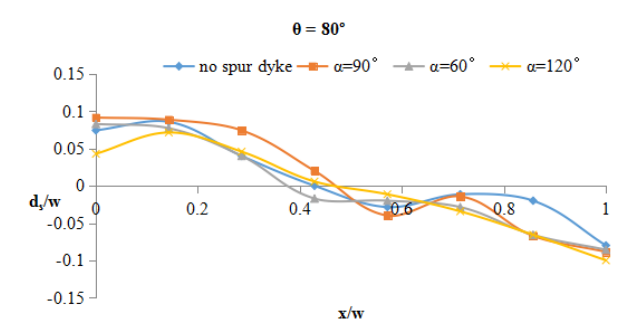


Figure 12. Bed variation of Bend 1 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

Figure 13 shows the bed variation along the transverse

direction at angular displacement ($\theta = 0^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 60^\circ$ (location 3) of Bend 1. In Figure 13, all the graphs at $\alpha = 60^\circ$, 90° , 120° and without spur dyke shows almost same bed variation.

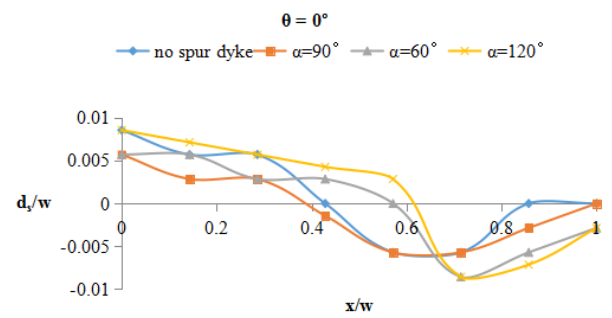


Figure 13. Bed variation of Bend 1 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

Figure 14 shows the bed variation along the transverse direction at angular displacement ($\theta = 40^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 60^\circ$ (location 3) of Bend 1. In this graph at $\alpha = 60^\circ$ shows the less deposition and less scouring in comparison to other graph.

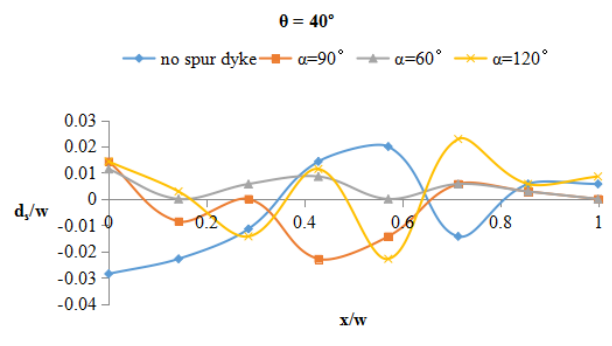


Figure 14. Bed variation of Bend 1 at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

Figure 15 shows the bed variation along the transverse direction at angular displacement ($\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 60^\circ$ (location 3) of Bend 1. In this figure, graph of without spur dyke shows maximum scouring near concave (outer) side of bank. This scouring is minimized by installing spur dyke at $\alpha = 60^\circ$ and 90° but $\alpha = 120^\circ$ dose not minimize scouring. Maximum scouring is minimized by $\alpha = 60^\circ$ in comparison to $\alpha = 90^\circ$.

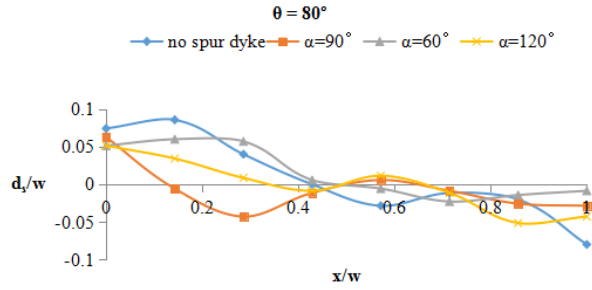


Figure 15. Bed variation of Bend 1 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

3.4 Bed Variation along the Transverse Direction of Bend-3

Figure 16 shows the bed variation along the transverse direction at angular displacement ($\theta = 0^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 0^\circ$ (location 1) of Bend 3. In this figure maximum scouring occurs near the spur dyke but $\alpha = 90^\circ$ shows less scouring near spur dyke in comparison to $\alpha = 60^\circ$ and 120° .

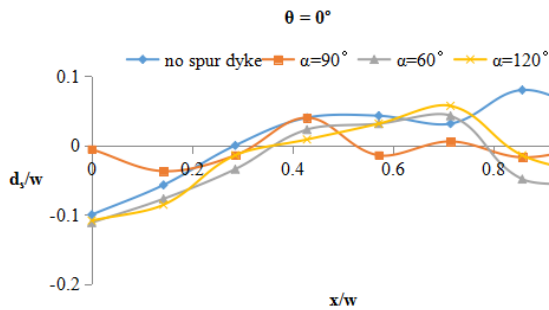


Figure 16. Bed variation of Bend 3 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

Figures 17 & 18 show the bed variation along the transverse direction at respective angular displacement ($\theta = 40^\circ$ and $\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 0^\circ$ (location 1) of Bend 3. In Figures 17 & 18, all the graphs at $\alpha = 60^\circ, 90^\circ, 120^\circ$ and without spur dyke shows almost same bed variation.

Figure 19 shows the bed variation along the transverse direction at angular displacement ($\theta = 0^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 3. In this figure, all the graphs show almost same bed variation.

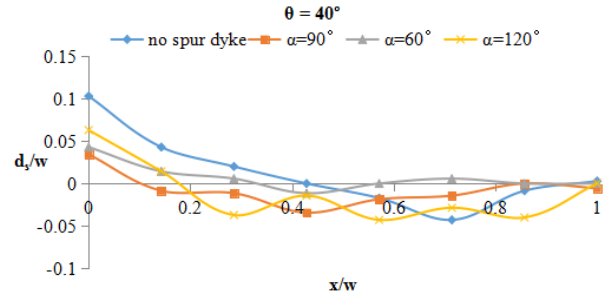


Figure 17. Bed variation of Bend 3 at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

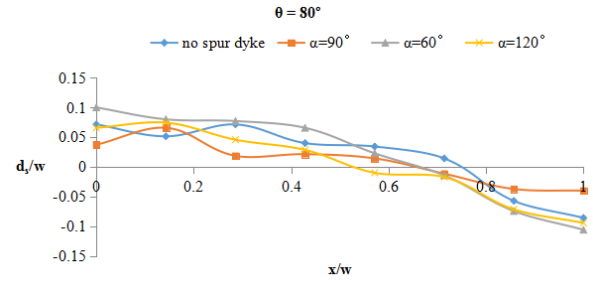


Figure 18. Bed variation of Bend 3 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 1, $\theta = 0^\circ$

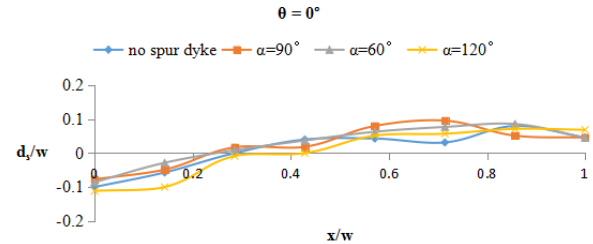


Figure 19. Bed variation of Bend 3 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

Figure 20 shows the bed variation along the transverse direction at angular displacement ($\theta = 40^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 3. In this figure near spur dyke maximum scouring occur but at $\alpha = 60^\circ$ shows the more scouring in comparison to $\alpha = 90^\circ$ and 120° .

Figure 21 shows the bed variation along the transverse direction at angular displacement ($\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ, 90^\circ$ and 120°) and without spur dyke which is installed at $\theta = 40^\circ$ (location 2) of Bend 3. In Figure 21, all the graphs at $\alpha = 60^\circ, 90^\circ, 120^\circ$ and without spur dyke shows almost same bed variation.

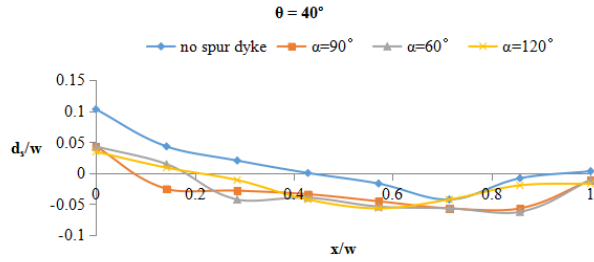


Figure 20. Bed variation of Bend 3, at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

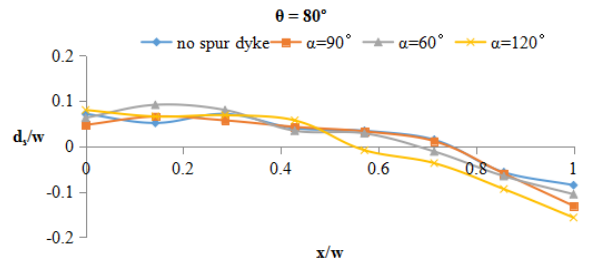


Figure 21. Bed variation of Bend 3 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 2, $\theta = 40^\circ$

Figures 22 and 23 show the bed variation along the transverse direction at respective angular displacement ($\theta = 0^\circ$ and $\theta = 40^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 60^\circ$ (location 3) of Bend 3. In these figures, all the graphs at $\alpha = 60^\circ$, 90° , 120° and without spur dyke shows almost same bed variation.

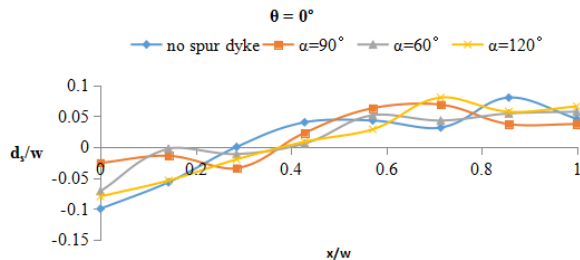


Figure 22. Bed variation of Bend 3 at angular displacement $\theta = 0^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

Figure 24 shows the bed variation along the transverse direction at angular displacement ($\theta = 80^\circ$) of various orientation of spur dyke ($\alpha = 60^\circ$, 90° and 120°) and without spur dyke which is installed at $\theta = 60^\circ$ (location 3) of Bend 3. In this figure, graph of without spur dyke shows maximum scouring near concave (outer) side of bank. This scouring is minimized by installing spur dyke at $\alpha = 60^\circ$ and 90° but $\alpha = 120^\circ$ dose not minimize much scouring. Maximum scouring is minimized by $\alpha = 60^\circ$ in

comparison to $\alpha = 90^\circ$.

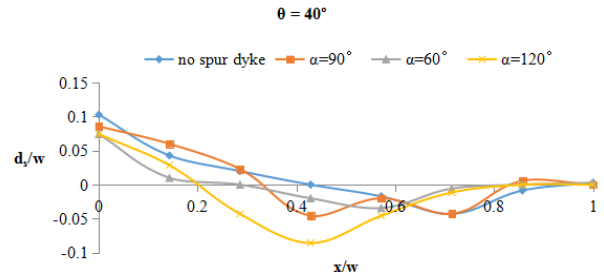


Figure 23. Bed variation of Bend 3 at angular displacement $\theta = 40^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

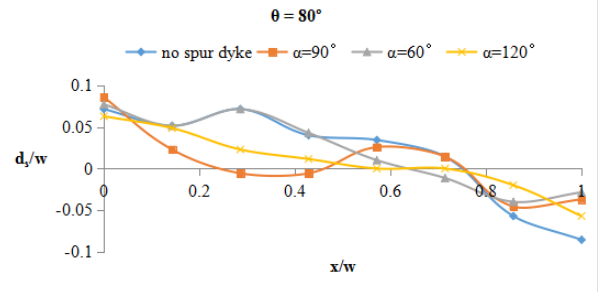


Figure 24. Bed variation of Bend 3 at angular displacement $\theta = 80^\circ$ along the transverse direction when dyke installed at location 3, $\theta = 60^\circ$

4. Conclusions

Following conclusions have been drawn from the present study:

It was observed that in meandering portion there was scouring on the bed but on the same flow condition there was no scouring in straight channel.

The maximum scouring occurs in between $\theta = 60^\circ$ to 80° of the outer side of bend and it is having a peak at $\theta = 80^\circ$. This was found without installing spur dyke.

When spur dyke is installed at location 1 ($\theta = 0^\circ$), this affects the bed till $\theta = 40^\circ$. After that spur dyke's effect reduces on bed. So it does not reduce the scouring at $\theta = 60^\circ$ to 80° .

When spur dyke is installed at location 2 ($\theta = 40^\circ$), scouring near angular displacement ($\theta = 60^\circ$) reduces.

When spur dyke is installed at location 3 ($\theta = 60^\circ$) scouring near angular displacement ($\theta = 80^\circ$) reduces. So it does not minimize the scouring at 60° to 80° .

Spur dyke oriented at ($\alpha = 60^\circ$ or 90°) reduces the scouring and maximum scouring is minimized by $\alpha = 60^\circ$. But spur dyke oriented at $\alpha = 120^\circ$, it reduces the scouring very less.

Scouring around spur dyke is more for the spur dyke's angle $\alpha = 90^\circ$ but the extent of this scouring is more for α

= 120°.

The extent of scouring around spur dyke occurs in that direction where the spur dyke is oriented.

When spur dyke installed at location 2 ($\theta = 40^\circ$) than scouring around spur dyke is negligible in comparison to other location because near $\theta = 40^\circ$ zone prevails no flow condition.

As we know maximum scouring occurs at concave (outer) side of bend but the location of this maximum scouring depends on bend geometry. If bend is sharp ($R_c/w < 3$), scouring will be more near the end of bend at outer side.

If bend is sharp, spacing of spur dyke should be less for protection of bank.

Bed pattern (scouring & deposition) of bend 1 & bend 3 are different because bend 1 continues with straight portion while bend 3 continues with other bend hence we can say transition zone affects bed pattern (scouring & deposition).

References

- [1] M. Pandey, Z. Ahmad, P. K. Sharma, Scour around impermeable spur dikes: A review, *ISH J. Hyd. Eng.* (2017), 24:25-44.
- [2] H. Zhang, H. Nakagawa, H. Mizutani, Bed morphology and grain size characteristics around a spur dyke, *Int. J. Sediment Res.*, (2012), 27:141-157.
- [3] M. F. M. Yossef, H. J. D. Vriend, Flow details near river groynes: Experimental investigation, *J. of Hyd. Engg.* (2011), 137:193-210.
- [4] S. Karki, Y. Hasegawa, M. Hashimoto, H. Nakagawa, K. Kawaike, Short-term evolution of flow & morphology in an erodible meandering channel with & without groynes, *Annu. J. Hyd. Eng., JSCE*, (2018), 74:1147-1152.
- [5] H. Zhang, H. Nakagawa, Characteristics of local flow and bed deformation at impermeable and permeable spur dykes, *Annu. J. Hyd. Eng., JSCE*, (2009), 53:145-150.
- [6] Przedwojski, Bed topography and local scour in rivers with banks protected by groynes, *J. Hyd. Res.*, (2015), 33:257-273.
- [7] R.J. Garde, K.S. Subramanya, K.D. Nambudripad, Study of scour around spur dikes, *J. Hyd. Eng.*, (1961), 87:23-27.
- [8] M.A. Gill, Erosion of sand beds around spur-dikes, *J. Hyd. Div. ASCE*, (1972), 98:1587-1602.
- [9] N.A. Zaghoul, Local scour around spur-dikes, *J. Hydrol.*, (1983), 60:123-140.
- [10] R. Kuhnle, C. Alonso, F.D. Shields, Geometry of scour holes associated with 90° spur dikes, *J. Hyd. Eng. ASCE*, (1999), 125:972-978.
- [11] IS 8408: 1994, Planning and design of groynes in alluvial river-Guidelines, Bureau of Indian Standards Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002.
- [12] H. Zhang, Study on flow and bed evolution in channels with spur dykes, PhD thesis, Kyoto University, 2005.
- [13] E. Elawady, M. Michiue, O. Hinokidani, Movable bed scour around submerged spur- dikes, *Proc. of Hyd. Eng.*, (2001), 45:373-378.
- [14] A. Parashar, N.K. Tiwari, M.Tech dissertation, Experimental study of spur dykes, Deptt of Civil Eng., NIT Kurukshetra, 2014.
- [15] A. Masjedi, M. Bejestan, A. Moradi, Experimental study on scour depth in around a T-shape spur dike in a 180 degree bend, *J. Am. Sci.*, (2010), 6:886-892.
- [16] M. Vaghefi, M. Ghodsian, Salehi Neyshaboori, S.A.A., Experimental study on the effect of a T-shaped spur dike length on scour in a 90° channel bend." *Arab. J. Sci. Eng.*, (2009), 34:337.

ARTICLE

Degree of Integrated Water Resources Management Implementation in Context of Climate Change in a Watershed: Case of Oueme Basin, Benin (West Africa)

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ARTICLE INFO

Article history

Received: 14 October 2021

Accepted: 3 November 2021

Published Online: 10 November 2021

Keywords:

Decision tool

IWRM level

Medium

Low

Oueme bassin

ABSTRACT

This study is based on the hypothesis that the implementation of Integrated Water Resources Management (IWRM) tools in the Oueme watershed has not led to a systematic improvement in the degree of IWRM implementation in the Oueme Valley in Benin. Methodologically, data were collected through a semi-structured survey of stakeholder families in the study area using snowball sampling. The tool used was the form developed by the United Nations to collect data to assess the level of IWRM implementation. The four (4) assessment criteria, each covering a key component of IWRM, are the enabling environment, institutions and participation, management tools and financing. The results obtained per criteria according to the stepwise methodology adopted reveal on average a degree of implementation of 40 on a scale of 0 to 100 in the Oueme basin. This value varies according to the geographical area and the factors considered. This study, which is a decision-making tool, provides a guide for governments to monitor the progress of integrated water resources management in their territory.

1. Introduction

Today, increasing population pressure, economic development, and climate change are among the major

changes that greatly threaten the availability and quality of the water resource^[1,2]. To preserve the water resource, collegial management should be organized at the watershed scale. The rational management of water

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DOI: <https://doi.org/10.30564/hsme.v3i2.3837>

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resources contributes effectively to the mitigation of climate change, because it reduces the pressure on these resources ^[3]. ^[4] work supported this statement to some degree by showing that climate change is altering water resources.

Reportedly, it has been estimated an average of 13.106 billion m³/year of surface water and 1.870 billion m³/year of groundwater recharge in Benin ^[5]. Groundwater is a prime resource for supplying drinking water to the population because it is of relatively good quality and low cost, unlike surface water, the cost of which is staggering and often beyond the reach of countries with modest economies such as Benin ^[6]. The decrease in the amount of water available per person due to population pressure, pollution, climate change, and the respect of the principles of the international conference of Dublin in 1992 on water and the environment, led Benin to adopt the principle of IWRM since 1998. However, the implementation of this management at the national level and in particular in the Oueme basin is quickly facing some obstacles. It is in this context that the present study aims to assess the level of IWRM implementation in the Oueme basin, the second richest valley in the world after the Nile with a lot of potentials ^[7].

2. Methods

Presentation of the study environment

The Oueme basin is located between 1°23'47" and 3°27'54" east longitude and 6°20'54" and 10°12'59" north latitude. It extends over three countries: Benin, Nigeria and Togo. With a surface area of 52 511 km², including 4 974 in Nigeria and 319 in Togo, the Beninese portion of this basin is estimated at 47 218 km², for 41.14 % of the national territory ^[8]. It straddles eight departments and covers all or part of 48 communes out of the 77 in the country. It has an estimated population of 6 million inhabitants, the equivalent of 44 % of the total population ^[9]. The average farm size is 1.60 hectares ^[10]. According to ^[11], the main economic activities are fishing, agriculture, animal husbandry, trade, crafts and hunting. It has been subdivided into 4 sub-basins, namely: Upper Oueme basin, Okpara, Zou and Lower and middle Oueme valley sub-basins. Figure 1 shows the delimitation of the basin.

After describing the basin in its physical and climatic aspects, ^[12] defines the interannual and seasonal variations of the river flow in the upper basin as well as in the delta. The basin enjoys two types of climate. Downstream, an equatorial climate with high humidity, alternating dry seasons and rainy seasons. Upstream, a tropical climate with a dry season from November to April and a rainy

season from June to September. Temperatures are stable all year round downstream (28 to 32°) and oscillate between 30 and 38° upstream. Rainfall is abundant during the rainy seasons, with an annual average of 1300 mm downstream and 950 mm upstream. The hydrological regime of the Oueme is characterized by a minimum flow in March and a maximum flow during the high-water period in September. In Sagon, during the low-water period (February-April) its flow is 10 m³/s, whereas it reaches 900 m³/s during the high-water period (August-November) ^[13].

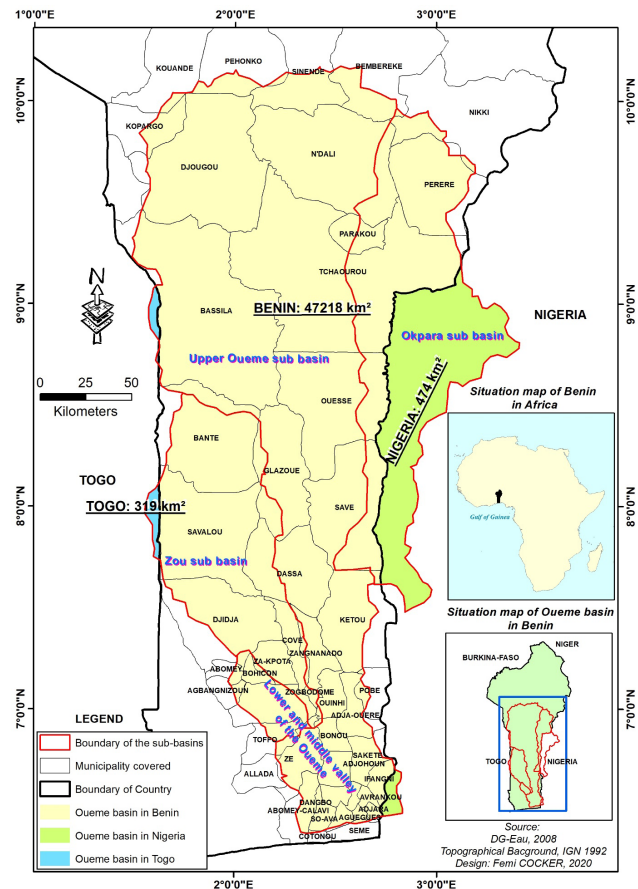


Figure 1. Presentation of the study area

Data Collection

The assessment of IWRM implementation in the Oueme basin in Benin is based on indicator 6.5.1, which represents the degree of implementation of integrated water resources management of Goal 6 of the SDGs. This indicator is based on the IWRM implementation level assessment form used by ^[14] in a similar study in the lower Oueme valley, which is downstream of the basin. This step-by-step methodology developed by the United Nations is composed of several relevant questions that are grouped into four sections, each covering a key IWRM

component:

- **Enabling Environment:** This is an enabling environment, which is about creating the conditions to support the implementation of IWRM. This section includes the basic policy, legal and planning tools for IWRM.

- **Institutions and participation:** The section deals with the different institutional stakeholders and their political, social, economic and administrative roles involved in the implementation of IWRM. It includes some of the leading institutions for IWRM at various levels of society and the gender approach.

- **Management Instruments:** These are the tools and activities to help decision-makers and users make rational and informed choices when it comes to identifying and adopting the right actions to take.

- **Financing:** This section deals with the adequacy of the funding made available and used for water resources development and management and the management of these resources by the various recipient entities.

The families of actors who filled out the form are local authorities, users, decentralized state structures and civil society. The approach used was a semi-structured interview. It was supported by documentary research at the General Directorate of Water, the National Water Institute and in non-governmental organizations that work on the theme of environmental protection related to water.

Sampling

In the study sector, the organ in charge of water resource management is the Oueme Basin Committee set up by Decree N°2018-130 of April 18, 2018. This organ gathers various public and private stakeholders of the basin, acting in the water sector or whose activities impact water resources. It is made up of 51 members, representing local authorities, Decentralized State Structures, civil society associations and users. On this basis, an exhaustive survey was carried out among the 51 structures constituting this committee. Table 1 presents a breakdown of the respondents by family of actors.

According to the decree setting up the Oueme River Basin Committee, the representatives of local authorities and users constitute 2/3 of the total seats. This provision allows the grassroots stakeholders to be better represented since they are the most concerned by the impacts of actions in the basin.

Semi-structured interviews

The snowball survey technique was used to fill out the form with stakeholder families. The possible scores that can be assigned to each question, depending on the level of application of the IWRM aspect addressed, are between

0 and 100 with an increment of 10. Each score assigned is justified by its author with evidence in the corresponding column.

Data analysis

The degree of IWRM implementation in the Oueme River Basin is equal to the average of the scores for each section of the evaluation form. The score for SDG indicator 6.5.1 indicates the "degree of implementation of integrated water resources management", on a scale of 0 to 100, where 0 indicates no implementation and 100 represents full implementation. This method is tested and adopted by the UN Environment to assess the level of implementation of IWRM. An interpretation according to [15] is provided as follows:

- - 0 - <=10 : Very low: Development of IWRM elements has generally not started or has stalled.
- - 10 - <=30 : Low : Implementation of IWRM elements has generally begun, but with limited acceptance and relatively low engagement of stakeholder groups.
- - >30 - <=50 : Medium-low: IWRM elements are generally institutionalised and implementation is underway.
- - >50 - <=70 : Medium-high: Capacity to implement IWRM elements is generally appropriate and elements are generally implemented through long-term programmes.
- - >70 - <=90 : High: The objectives of IWRM plans and programmes are generally achieved and the geographical coverage and commitment of different stakeholders is generally good.
- - >90 - <=100 : Very high: The vast majority of IWRM elements are fully implemented, with objectives achieved as defined and plans and programmes are periodically evaluated and reviewed.

3. Results

The results of this evaluation are presented by criteria. These are the sections Enabling Environment, Institutions and participation, Management Instruments and Financing.

Enabling Environment

The enabling environment includes the basic policy, legal and planning tools to support IWRM implementation. In a chronological sequence, several documents are developed, implemented and evaluated. This is the case of the National Strategy for Rural Water Supply (SNAEPMR) which has been implemented in several phases since 1992. At the beginning, it was based on the demand approach. In 2003, it was influenced by the advent of decentralization. As a result, the communes

Table 1. Breakdown of the respondents by family of actors

Families of stakeholders	Structure/Organization	Headcount	Percentage
Local authorities	Abomey-Calavi Town Hall; Parakou Town Hall Tchaourou Town Hall; Dassa Town Hall; Save Town Hall; Bassila Town Hall; Copargo Town Hall; Cotonou Town Hall; Aguegues Town Hall; Avrankou Town Hall; Seme-Podji Town Hall; Pobè Town Hall; Bohicon Town Hall	13	25%
Users	Pineapple Producers' Union Allada; of oil palm Ouidah; cotton N'Dali; rice Glazoue; Market Gardeners Union Djougou; Association of Women Farmers Adjohoun; Professional Organizations of Ruminant Breeders Gogounou; Save; Kétou; Abomey; Fishermen's Union Save; Cotonou; Fish Farmers Union Djougou; Zakpota; Consumers' Association Parakou.; Drinking Water Consumers' Association Dassa Zoume; Water Farmers Association Cove ; Sand and Gravel Operators Parakou; Sugar Corporation Save; Hotel Industries Committee Djougou; Oil company Pobe	21	41%
Deconcentrated structures of the State	Zou Prefecture; Departmental Directorate of Agriculture, Livestock and Fisheries Atlantique; Borgou; Oueme; Departmental Directorate of the Living Environment and Sustainable Development Atlantic; Forest Inspection Borgou; Zou; Departmental Directorate of Water and Mines Atlantique; Donga; Water Service Collines; Oueme; Departmental Directorate of Health Zou.	12	24%
Civil society	Tropical Nature Green Coalition CONOGEDA (Environment and Sanitation) Union of the Crowned Heads of the Hills High Council of the Kings of Oueme/Plateau	5	10%
TOTAL		51	100%

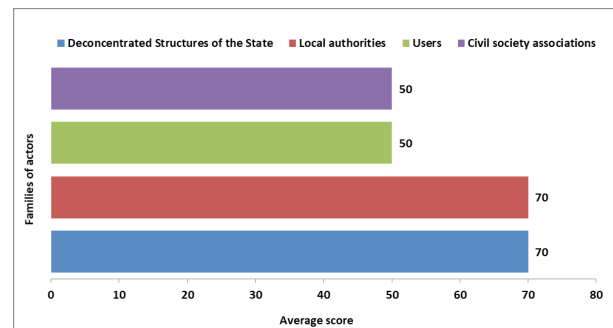
Source: Field survey, 2021

became the new project owners, who plan, implement and manage water facilities based on local needs. The evaluation showed that the management of water resources still needs to be improved.

At the policy level, the water sector has had a National Water Policy since 2008. Its strategic orientation is to ensure equitable and sustainable access to drinking water and sanitation for the population. To reinforce these provisions, the National Action Plan for Integrated Water Resources Management (PANGIRE) was adopted in 2011. This plan has a broad vision and embraces specific areas of action. These include the water governance framework, human capacity building, economic and financial aspects, knowledge, mobilization, development, conservation, protection and monitoring of water resources and the environment. This plan also aims to put in place measures for prevention, mitigation and adaptation to climate change and other water-related risks. However, these policies, although they exist, are characterized by a medium-low degree of implementation in the rating scale. Thus, according to stakeholders in IWRM implementation in the Oueme basin, these policies are based on IWRM, approved by the government, and are tentatively beginning to be used by the authorities to guide the work.

With regard to the legal and regulatory framework for water management, Benin has a large and diversified

legal arsenal that has made provisions for the protection and safeguarding of natural resources in general and water resources in particular. However, even though the country's legal arsenal is quite extensive, there are problems of implementation followed by concrete results. In fact, almost all the actors report a lack of application of the legal texts and their poor dissemination. According to the respondents, these laws exist, but are not fully implemented due to a lack of political will. The degree of implementation of national laws on water resources in the study area is also unsatisfactory. Figure 2 presents the result of the degree of the "Enabling Environment" section by the different families of stakeholders.

**Figure 2.** Degree of enabling environment

Source: Cocker, 2021

The level of implementation of basic policy, legal and planning tools to support IWRM implementation in the Ouame River Basin varies among the stakeholders interviewed. Civil society associations and users gave a score of 50 and thus consider the policy and legal environment to be halfway favorable to IWRM implementation. Better still, local authorities and decentralized state structures gave a higher score of 70, believing that, even if there is still work to be done, implementation efforts are noticeable for this criterion.

In sum, the average score for this section after the calculations according to the technique used in the methodology is 60.

Institutions and participation

The institutional framework for water resources management includes public sector actors, in particular the ministries concerned with water management, local authorities, user groups and private sector actors through their various actions in the field. Consultation bodies have also been set up. At the basin level, we can mention the Oueme River Basin Committee (CBO) set up by decree n° 2011-621 of September 29, 2011. It is composed of local authorities, users' representatives, decentralized State structures and socio-professional organizations. Its mission is to define and plan, in a concerted manner, the axes of management and protection of water resources on the scale of the Oueme river basin. At the national level, there is the National Water Council, created by Decree No. 2011-574 of 31 August 2011. It is composed of public administration, local authorities, civil society, scientists and researchers, the National Water Fund and also the Water Agency. Its mission is to contribute to decision-making in water resources management in accordance with Benin's development policies and strategies.

All this information is proof that the institutional framework is already in place and well oriented towards IWRM. But at the operational level, the effect of all this organization is not apparent. Figure 3 confirms this observation, especially with the scores attributed by local authorities and civil society.

The analysis of Figure 3 shows that the scores given by civil society and local authorities are 35 and 30 respectively. These actors consider that the action of political, social, economic and administrative institutions involved in the implementation of IWRM is not very perceptible. On the other hand, the users and the decentralized structures of the State consider that the action of the political, social, economic and administrative institutions that participate in the implementation of IWRM is appreciable.

Finally, the institutional framework scores 45 on the 0-100 scale and is thus close to average.

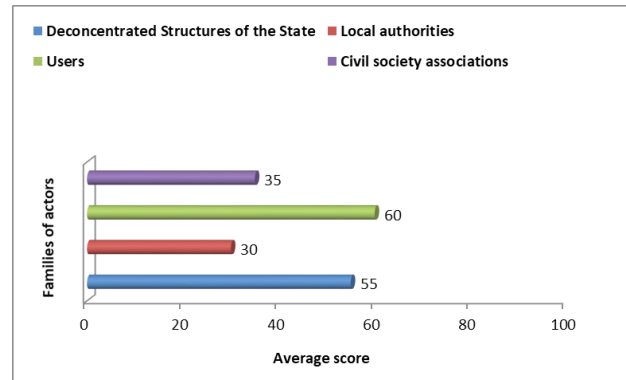


Figure 3. Degree of institutions and participation section

Source: Cocker, 2021.

Management Instruments

At the scale of the study area, it appears from the exchanges with the stakeholders that the Oueme River Basin Committee has already been designated and has 51 members elected by their peers from the different families of stakeholders in the basin. However, the sub-committees have not yet been set up, which has not facilitated the proper functioning of this important management instrument. The Oueme Water Development and Management Plan has been drawn up, validated and is available. It is structured in sequential intervention plans (PIS). One of these PIS, called the Oueme delta plan, is currently being developed by the National Water Institute of the University of Abomey-Calavi. Figure 4 presents the situation of the "Management Instruments" section by families of stakeholders.

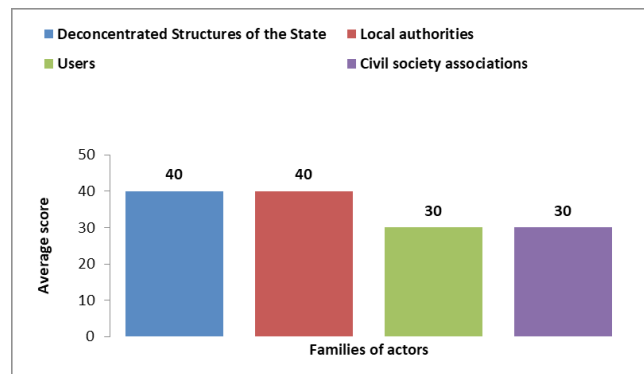


Figure 4. Degree of management instruments section

Source: Cocker, 2021.

The "management instruments" section was poorly

rated by all actors. Indeed, civil society associations and users gave it 30 points, while decentralized State structures and local authorities gave it 40 points. On average, these scores lead to a mark of 35 for this criterion.

Financing

Funding is more oriented towards the supply of drinking water than towards the development of IWRM, which has remained theoretical with very few concrete achievements accompanied by significant funding. The lack of funding is a limiting factor for all aspects of water resources development and management. The stakeholders we met criticized the small share often reserved for IWRM. This is reflected in Figure 5 in the scores given by the stakeholder families to the "financing" section.

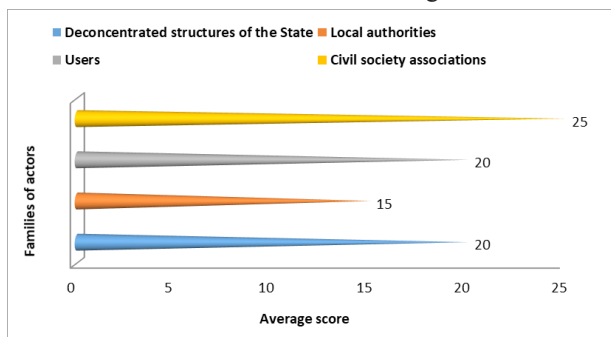


Figure 5. Degree of financing section

Source: Cocker, 2021.

The various stakeholders gave scores ranging from 15 to 25 to the funding section. The highest score was only a quarter. This is low for this section, which is very sensitive because finances play a major role in the success of a mission. At the end of the discussions with the stakeholders, the summary of the scores is 20 on a scale of 0 to 100.

Synthesis of the evaluation

The assessment of sustainable water resource management shows that actions are already underway, but highlights several weaknesses, including the level of funding, the inadequacy of management instruments, the level of implementation of policies and legal texts. There is also a lack of information and communication on activities that could give IWRM visibility and the place it should have in the water sector. Figure 6 shows the level of implementation of IWRM in the study area.

The integrated management of water resources at the scale of a hydrological basin should be regulated by a specific law with the implementation of an organized

system of continuous monitoring. In Europe, it is the Water Framework Directive, 2000, of which the Law on Water and Aquatic Environments, 2006 is the transposition into French law. In the case of African countries south of the Sahara, such as Benin, regulatory efforts are to be noted. This has therefore been analyzed here in the case of the Oueme River basin. Numerous tools to support decision-making and resource management, based on integrative approaches, are currently being tested. However, their adequate implementation in the sense of providing a solution to the need for concerted management with a view to protecting nature in a vision of resilience to climate change is not yet mastered by the stakeholders. The assessment of the degree of implementation of IWRM then provided an idea of the state of water resources already facing management difficulties and the ravages of climate change. Although the public and private sectors, as well as civil society and users, are involved in this management process, the results are not satisfactory as they reveal that sustainable water resource management is not well implemented in the Oueme basin. These results are corroborated by the National Water Politics document ^[16], which recognizes that Benin's water resources are still poorly valorized and, consequently, only contribute to the country's socio-economic development to a very small extent in relation to existing potential. The overall score reflecting the degree of IWRM implementation for this study is 40, which is close to the national score of 35 obtained in 2015 by the Ministry of State for Planning and Development. These values are confirmed by the study conducted by ^[14] in the lower Oueme valley, which also revealed a low score of 31. As the results obtained in the present study fall within this same range, they are therefore similar to those of ^[17] and allow us to conclude that IWRM elements are generally institutionalized and their implementation is underway in the Oueme basin.

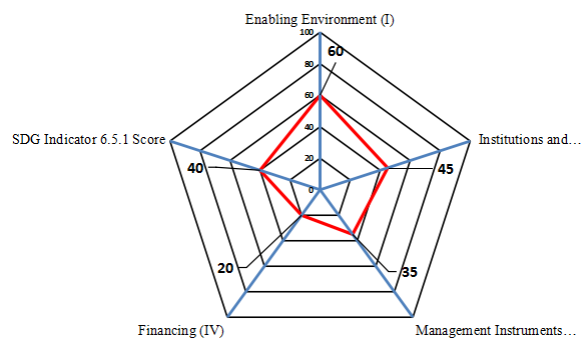


Figure 6. Degree of IWRM Implementation

Source: Cocker, 2021

In addition, according to the UN IWRM Data Portal, the main scores for Benin in 2017 and 2020 for indicator 6.5.1 of the Sustainable Development Goals are more optimistic with values of 63 and 68 respectively. An overview in a larger dimension, meaning outside Benin, shows that the issue of IWRM implementation is still relevant in Sub-Saharan Africa. According to the recent UNESCO and UN-Water (2020) report ^[18], IWRM scores are still medium-low in 2018 for Cameroon with a score of 34, Ghana progresses a little more to 49 and Kenya a little more than them with a score of 53. In summary, all these scores have the same appreciation and are all qualified as medium-low in reference to the stepwise methodology for monitoring UN Indicator 6.5.1. A comparative reading of the results for these same countries shows a slight advance for the 2020 scores published in 2021 by the UN's IWRM Data Portal. Cameroon and Kenya moved up 6 points to 40 and 59 respectively, followed by Ghana, which moved up 8 points to a score of 57.

With reference to the results of the present study, (score of 40), there is still a long way to go to reach the national level, which is already very advanced compared to the reality of the sector under study. It can therefore be deduced that the overall score can be high for a country, but the same exercise, duplicated on a lower scale, can reveal a notable disparity, which can be understood by the particularities of each environment.

4. Conclusions

The assessment of integrated water resources management is a complex activity that requires a lot of information to be cross-referenced and consistency in the methodology adopted to avoid biasing the data that could reduce the credibility of the results. The interest here is that a reference model exists and approved results are available. The present study therefore drew on the existing model and the results are analyzed and discussed in relation to the known values. Thus, the differences and similarities were explained and commented according to the objectives of the study. It emerges that apart from the objective criteria noted, the degree of implementation of IWRM can increase or decrease depending on the factors involved and the territory considered and the resilience to the impacts of climate change. This study is therefore positioned as a decision-making guide, since it presents a photograph of the level of IWRM implementation in a basin at a given time and highlights the points of weakness.

Funding

No funding was received to assist with the preparation

of this manuscript.

Conflicts of Interest

There are no conflicts of interest or competing interests associated with this manuscript.

Ethics Approval

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Availability of Data and Material

All data, models, and code generated or used during the study appear in the submitted article.

Code availability

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Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Femi H. Cocker, Eric A. Alamou, Bernadin M. Elegbede and Ismaïla I. Toko. The first draft of the manuscript was written by Femi H. Cocker and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

- [1] R. Q. Grafton and K. Hussey, *Water Resources Planning and Management*. Cambridge: Cambridge university press, 2011.
- [2] C. J. Vörösmarty, P. Green, J. Salisbury, and R. B. Lammers, « Global Water Resources: Vulnerability from Climate Change and Population Growth », *Science*, vol. 289, n° 5477, p. 284-288, juill. 2000. DOI: <https://doi.org/10.1126/science.289.5477.284>.
- [3] OCDE, « OECD Water Studies, Reforming water policies: how to meet the challenge ». 2012. *accessed on*: <https://www.actu-environnement.com/media/pdf/news-34457-reformer.pdf>.
- [4] B. Zolghadr-Asli, O. Bozorg-Haddad, and C. Xuefeng, « Effects of the uncertainties of climate change on the performance of hydropower systems », *Journal of Water and Climate Change*, vol. 10, n° 3, p. 591-609, 2019.
- [5] DH (Directorate of Hydraulics), « Benin Water Vision 2025 », Cotonou, 2000.

- [6] F. Cocker, J. B. Vodounou, and J. Yabi, « Mapping of the groundwater potential of the lower Oueme Valley, south Benin (West Africa) », *LHB*, n° 2, p. 74-85, avr. 2020.
DOI: <https://doi.org/10.1051/lhb/2020018>.
- [7] F. Cocker, « Mapping and Integrated water resources management in the context of climate change in the lower Oueme valley in Benin (West Africa) », Doctoral School of Agricultural and Water sciences, Parakou, 2020. *accessed on*: <http://rgdoi.net/10.13140/RG.2.2.12999.01447>.
- [8] General Directorate for Water, « General report on the implementation of the Master Plan for Water Development and Management in the Oueme Basin », DGEau, Benin, Study report 3, 2013.
- [9] National Institute of Statistics and Economic Analysis (INSAE), « National Institute of Statistics and Economic Analysis (INSAE) », Directorate of Demographic Studies/INSAE/Primature, Benin, Demographic report, 2016.
- [10] C. Codjia, « Perceptions, local knowledge and climate change adaptation strategies of producers in the communes of Adjohoun and Dangbo in South East Benin », Agricultural engineer, University of Abomey-Calavi, Benin, 2009.
- [11] F. Legba, « Relevance of the development of the lower Oueme valley in Benin », DESS thesis, option: Hydro-Agricultural Development, 2ie, International Institute of Water and Environmental Engineering, Ouagadougou, Burkina-Faso, 2006.
- [12] F. Moniod, « Hydrological regime of the Oueme (Dahomey) », *Cah. O.R.S.T.O.M., ser: Hydrol.*, vol. x, n° 2, p. 171-183, 1973.
- [13] E. A. Alamou, M. G. L. D. Quenum, E. A. Lawin, F. Badou, and A. Afouda, « Spatial and temporal variability of rainfall in the Oueme basin, Benin », *Afrique Science*, vol. 12, n° 3, p. 315-328, 2016.
- [14] F. Cocker, J.-B. K. Vodounou, and J. A. Yabi, « Evaluation of the implementation of IWRM in the lower Oueme valley, south Benin », *H2Open Journal*, vol. 3, n° 1, p. 554-565, janv. 2020.
DOI: <https://doi.org/10.2166/h2oj.2020.056>.
- [15] UN Environment, « IWRM Data Portal - SDG IWRM Monitoring », <http://www.unepdhi.org/>, 2021.
- [16] Ministry of Energy and Water, *National Water Politics*. Cotonou, Benin, 2008.
- [17] Ministry of Planning and Development, « National Development Plan 2018-2025 », Cotonou, Benin, 2018.
- [18] UN Water, Éd., *Water and climate change*. Paris: UNESCO, 2020.

Websites consulted

- (1) <https://www.un.org>, accessed on October 06 2021, 11 :34 a.m.
- (2) www.paia-vo.org accessed on October 22 2019, 11 :34 a.m.
- (3) www.iwrmdataportal.unepdhi.org, accessed on January 03 2020, 12 :54 a.m.
- (4) <https://capaustral.com/climat-meteo-benin.php>, accessed on August 15 2021, 11 p.m.
- (5) <https://unesdoc.unesco.org/ark:/48223/pf0000372985.locale=en>, accessed on September 18 2021, 05 :58 p.m.

EDITORIAL

Recent Development in Ice Engineering

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ARTICLE INFO

Article history

Received: 8 November 2021

Accepted: 10 November 2021

Published Online: 17 November 2021

Ice Engineering is associated with how to solve challenges from different kinds of ice, such as, sea ice, river ice, lake ice, icing, and snow in cold regions. The aim is to design special structures which could resist structural and global impact from drifting ice and freezing ice.

The foundation of ice engineering is to study ice properties and its action on various structures, icing process within ice mechanics by using theoretical analysis, numerical simulation, model scale tests and field measurements. Ice is a kind of non-uniform material and its properties depends on many factors such as loading rate, temperature, freezing disturbance. The scope of Ice Engineering covers the science and engineering projects in cold regions, especially for offshore oil and gas, Arctic shipping, and offshore renewable energy.

Arctic area is very popular for oil and gas industry. In this area, it accounts 28% of total oil and gas production so far. Moreover, there are 23.9% of world's

undiscovered oil and gas resources in the Arctic^[1]. There is an increasing interest in oil and gas activities for the petroleum industry in Arctic waters, including a number of locations in Arctic and Subarctic regions where ice loads and ice operations pose major challenges for year around operations^[2]. Depending on ice conditions, operation season and location of operation, different types of offshore structures are developed and applied to the oil and gas activities, such as fixed structures, floating platforms and dynamically-positioned vessels.

As for renewable energy, the focus of offshore engineering is changed from fossil fuel exploration and extraction to renewable energy in ice-covered waters. The energy harvesting is mainly from offshore wind and solar in lakes. In winter, icing on wind blades may cause problems to efficiency of electrical production as well as safety and life of wind turbines^[3]. The drifting ice may act on marine structures which are used to support solar systems and accumulate around the structures to pile up.

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DOI: <https://doi.org/10.30564/hsme.v3i2.4081>

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This will endanger overall safety of offshore solar power plant.

A number of scientists and engineers are working at the frontier of Ice Engineering and Hydro Science & Marine Engineering provides an excellent platform for the publication of most updated research outcomes. The Journal focuses on innovative research methods at all stages and is committed to providing theoretical and practical experience for all those who are involved in Ice Engineering.

References

- [1] Gautier D L. First ever release of USGS offshore arctic resource assessment [J]. *Offshore*, 2009, 69(8): 46-50.
- [2] Henderson J, Loe J . The Prospects and Challenges for Arctic Oil Development. 2016.
- [3] Ming Song, Wei Shi, Zhengru Ren, Li Zhou. Numerical study of the interaction between level ice and wind turbine for estimation of ice crushing loads on structure. *Journal of Marine Science and Engineering*. 2019, 7, 439.

ARTICLE

Effect of Meander on Bridge Pier Scour

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ARTICLE INFO

Article history

Received: 10 November 2021

Accepted: 29 November 2021

Published Online: 7 December 2021

Keywords:

Meandering channel

Angular displacement

Scour and deposition

Bridge piers

Inner bank and outer bank

ABSTRACT

Lots of work regarding the scour around bridge piers in straight channel have been done in the past by many researchers. Many factors which affect scour around piers such as shape of piers, size, positioning and orientation etc. have been studied in detail by them. However, similar studies in meandering channels are scanty. Very few researchers have studied the effect of angular displacement which has considerable effects of scour around bridge piers.

In this paper an attempt has been made to carry out a detailed study of angular displacement on scour. A constant diameter bridge pier of circular shape has been tested in a meandering channel bend with bend angle as 80° . The test bed was prepared by using uniform sand having d_{50} as 0.27 mm and run was taken for a discharge of 2.5 l/s.

1. Introduction

Local scour is defined as the removal of bed materials from the vicinity of hydraulic structures such as abutments, below spillways, at upstream and downstream of causeways etc. The hydraulic failure of any structure depends upon the local scour that occurs around the structures. Specially, the main cause of bridge failure is the failure of its piers and abutments during heavy flood when water passes the piers and abutments. The basic

mechanism of occurrence of local scour around the piers highly depends upon the vortex flow which develops near the obstruction site. Generally, pier scour occurs due to a complex vortex system. This system consists of a horseshoe vortex initiated from the down flow at the upstream face of the pier, wake vortices which shed from sides of the pier due to flow separation as well as boe vortex which is also called surface roller. This complex system digs the scour hole and deepens it. Flow pattern and mechanism of scour around a bridge pier have been

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DOI: <https://doi.org/10.30564/hsme.v3i2.4079>

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studied experimentally in past by many investigators in cohesion less as well as cohesive soils.

Some of the most reliable studies were carried out in straight channel by [8,13,14,2,3,9], and many others. There is little information available about the scour at bridge pier in curved channel reaches. The studies related to this context at hand are, those conducted by [5,10-12,6,1]. The main feature of a bend flow is the presence of spiral flow, and lateral sediment transport across the channel bend is observable. Particles at the surface of the flow in the bend tend to move toward the outer wall while at the bed elevation they tend to move forward the outer wall they tend to move toward the inner wall of the channel. Keeping in mind the gap, the present work has been taken up to study the effect of angular spacing i.e. presence of bend on scour and deposition pattern around the bridge pier.

2. Dimensional Analysis

The variables required to define the flow characteristics in straight and curved open channels are, velocity of flow (v), the radial spacing x , depth of flow above channel bed (y), mean sediment particle size (d_{50}), mass density of water (ρ), viscosity of water (μ), acceleration due to gravity (g), and angular displacement (θ).

$$\text{Since, } d_s = f(v, x, \theta, d_{50}, \mu, W) \quad (1)$$

Carrying dimensional analysis following dimensionless numbers obtained. $\pi_1 = f\{\pi_2, \pi_3, \pi_4, \pi_5, \pi_6\}$ or $d_s/y = \{d_{50}/y, x/W, \theta, \rho v y/\mu, v/\sqrt{gy}\}$ (2)

Since ranges of d_{50}/y , $\rho v y/\mu$ and $v/\sqrt{gy}$ are very small and only one size of sediment is used hence all three terms are dropped. And finally we have $d_s/y = (x/W, \theta)$. (3)

2.1 Experimental Model Description

Experiments were carried out in Advanced Post Graduate Hydraulics Laboratory, Department of Civil Engineering, Zakir Hussain College of Engineering & Technology, Aligarh Muslim University, Aligarh. The data are collected in an open horizontal rectangular sinuous (meandering/curved) channel (0.35 m wide and 0.43 m deep) made up of 0.5 mm thick tin sheet, carefully installed in an open horizontal rectangular flume (0.76 m wide and 0.60 m deep and 10.5 m long) prismatic glass walled channel with cement plastered bottom. The schematic diagram and photographic view of the experimental setup are shown in Figures 1 and 2.

The experimental channel consisted of 2.88 m long upstream and 2.11 m long downstream straight reaches. The model has a straight upstream reach of 2.88 m and a straight downstream reach of 2.1 m. In between the upstream and the downstream reach four sinuous bends having same dimensions are present. The four 80° curved channel bends were provided in series. Each bend has rectangular cross section with 0.35 m width, 0.43 m height and with 0.705 m radius of curvature at center line. The central angle of the bend is 80° and the central radius of the channel (R_c) is 0.705 m. The width of the experimental model is 0.35 m here $R_c/W = 2.014$ (Ratio of the central radius to the width of the channel). Since the ratio R_c/W is less than 3, the bend is considered as a sharp bend. A straight transition of 0.05 m is provided between each bends. The test bed was made using Ganga sand with d_{50} as 0.27 mm and $sg = 1.35$. The bed was properly compacted using tamping rod with equal efforts

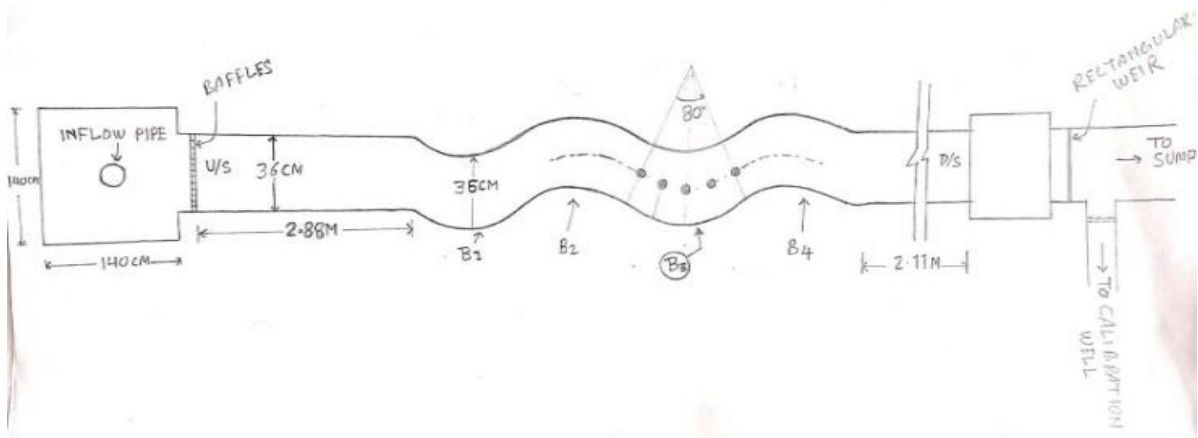


Figure 1. Schematic view of experimental channel

to make even surface with equal compacted density prior to start of run. The circular piers with diameter of 5.75 cm made of G.I pipe were used for observation of scour and deposition. Predetermined locations were first decided to take the readings as shown in Figures 3 and 4.



Figure 2. Schematic view of scour around pier used in present study

2.2 Experimental Procedure

Water is allowed to pass in the experimental channel at a constant rate from a re-circulated water supply system. After steady state condition of flow is reached, the observations for measuring the scour around bridge pier

have been started. The experimental data were mainly concentrated for the 3rd Bend of meander channel as shown in Figure 2. Experimental data collected in the vicinity of pier were taken at each 20° interval of angular displacement in meander bend i.e 0°, 20°, 40°, 60° and 80° as shown in Figure 3. To collect the experimental data at each predetermined locations of 3rd Bend of meander channel, five transverse sections as shown in Figure 4 were taken to cover the whole surrounding of pier and scour extent. Moreover, the data were also collected for local scour around pier in straight u/s reach of experimental channel and also experimental data were collected for 3rd Bend of meander channel without pier, reading were taken across the width of bend at each 20° interval of angular displacement, beginning from 0° angular displacement to 80°. The whole above mentioned procedure were conducted for flow rate $Q = 2.5$ l/s.

3. Data Analysis, Discussion and Results

Figure 6 shows that the variation of scour and deposition across the bend from inner side of the bend to outer side ($x/W = 0$ to 1.0) i.e. along transverse direction for discharge $Q = 2.5$ l/s for various angular displacement

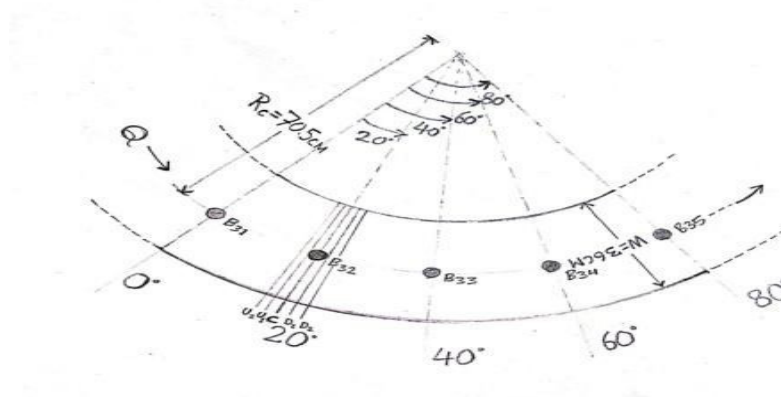


Figure 3. Schematic View of Bend - 3 (B-3) and Pier position at different angular displacement (θ).

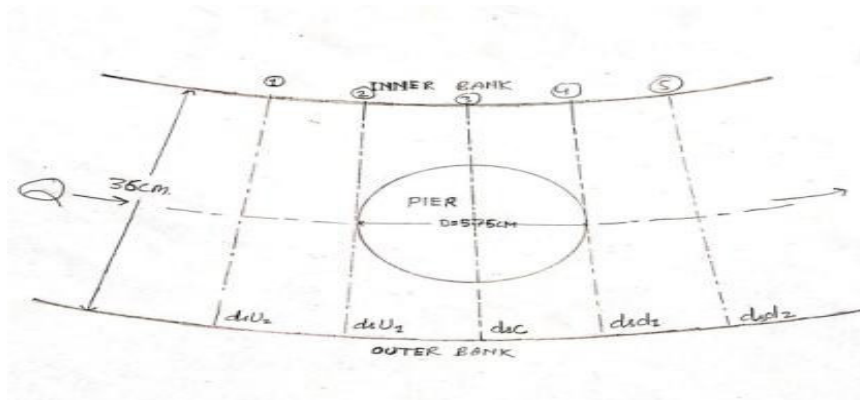


Figure 4. Showing the Centrally positioned Pier in Bend -3 of experimental

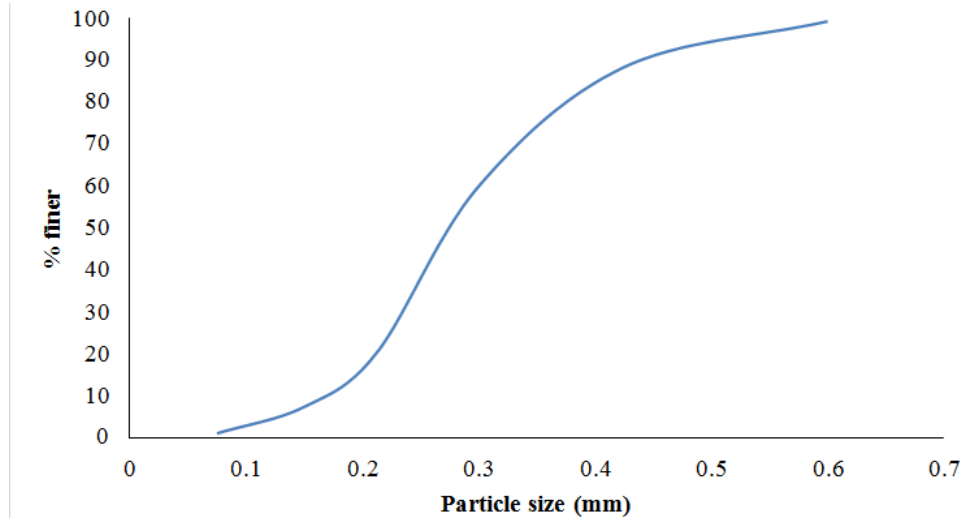


Figure 5. Particle size distribution curve

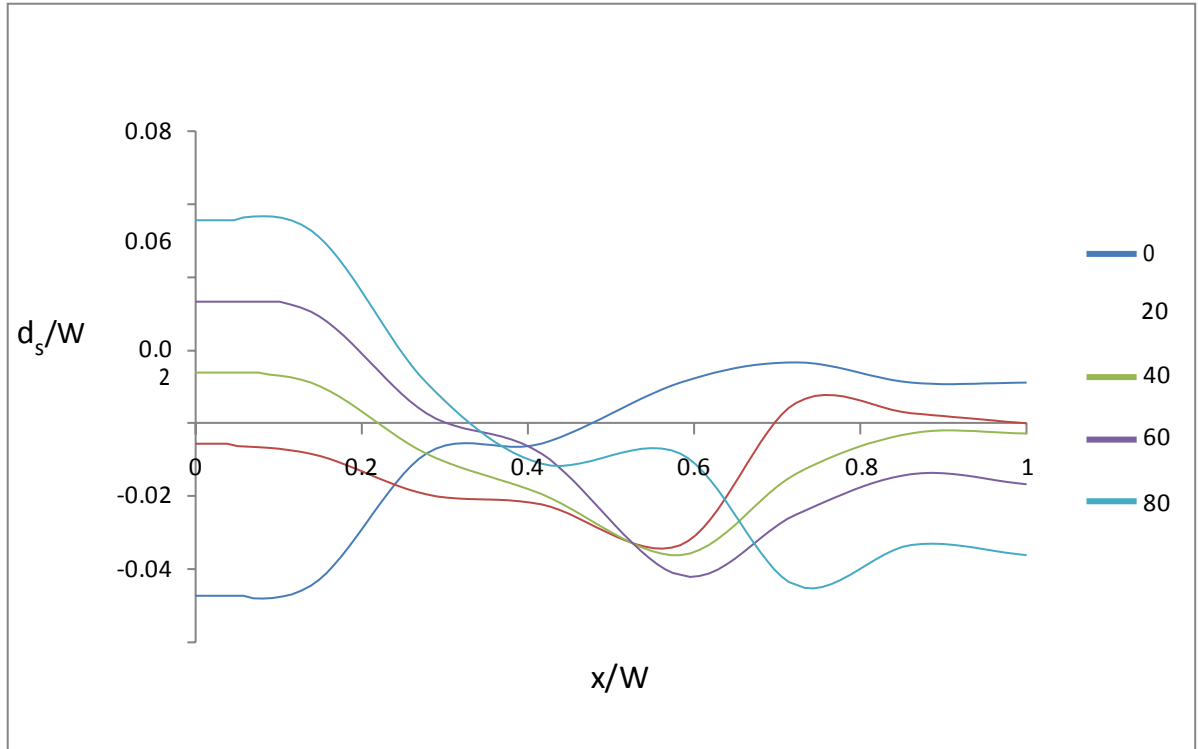


Figure 6. Variation of general scour and deposition in meander channel at different angular displacement θ for $Q = 2.5$ l/s

(θ). Here x is the normal distance measured from inner bank towards outer bank. W be the total width of the channel. It is clear from this graph that the scour and deposition both depend upon angular displacement (θ). As θ increases the scour decrease and deposition of bed material increases attaining a maximum value for $\theta = 80^\circ$ on inner bank of bend ($x/W = 0.0$). It is also found that at outer bank of bend ($x/W = 1.0$), this phenomenon is just reverse. And in between two banks where $x/W = 0.2$ to 0.8 , the scour is considerable in comparison to deposition.

Figure 7 shows the variation of scour and deposition across the width of the meandering channel at different θ , for discharge $Q = 2.5$ l/s. along inner wall. It can be seen from the Fig.6 that at $\theta = 0^\circ$, there is scour and it reduced at $\theta = 20^\circ$, as θ ($40^\circ, 60^\circ, 80^\circ$) values increases the scour reduces and deposition increase at inner wall. It can also be seen from the Fig.7 that at $\theta = 0^\circ$ there is deposition and as θ increases from $\theta = 20^\circ$ to $\theta = 80^\circ$, the deposition reduces as a result of the

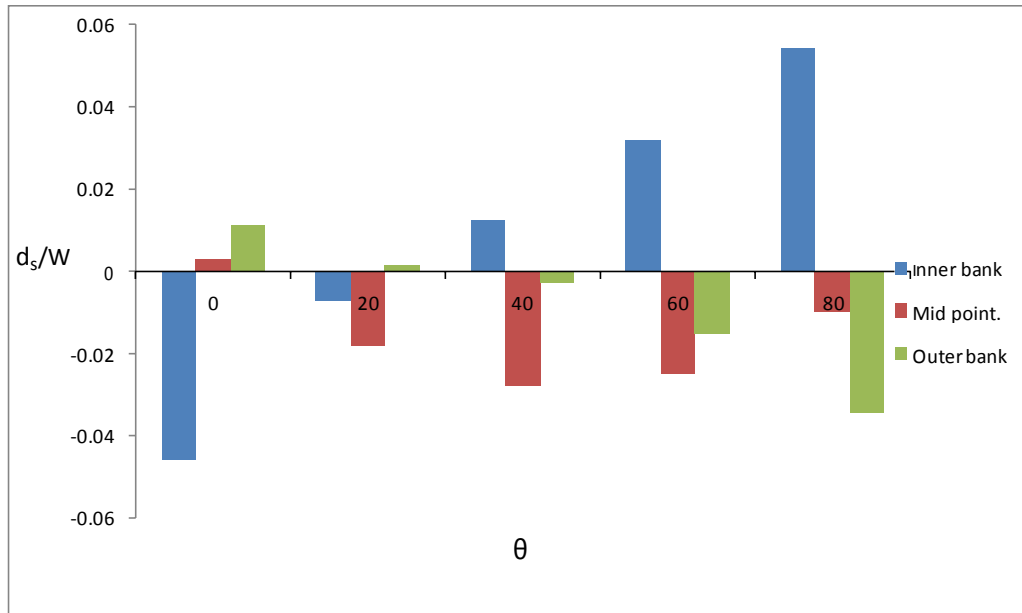


Figure 7. Variation of general scour and deposition in meander channel at different angular displacement θ for $Q = 2.5$ l/s.

Variation of Scour along different sections and Angular Displacement (θ) for $Q = 2.5$ l/s

Figures 8 and 9 show the variation of scour depth along transverse direction at $\theta = 0^\circ$ for a discharge of $Q = 2.5$ l/s. The various colored lines shows the scour variation

along five transverse sections; such as centre line (dsC), u/s section-1(dsU1), u/s section-2 (dsU2), d/s section-1 (dsD1) and d/s section-2 (dsD2). It is clear from these plots that for x/W from 0 to 0.2 there is scour at $\theta = 0^\circ$; this value is increasing at all section from $x/W = 0.2$ to 0.8. After that i.e. near to outer bank there is deposition.

Table 1. Showing the values of scour at different locations

G.R Position (cm)	Initial B.L. (cm)	Final bed level (G.R) at diff. sections (cm)					ds (cm)				
		dsC	dsU1	dsU2	dsD1	dsD2	dsC	dsU1	dsU2	dsD1	dsD2
0	68	68.9	68.8	68.7	70	70.2	0.9	0.8	0.7	2	2.2
5	68	68.6	68.6	68.6	68.7	70	0.6	0.6	0.6	0.7	2
10	68	66	66.6	67.9	66.4	67	-2	-1.4	-0.1	-1.6	-1
15	68	63.9	64	66	64.5	65.5	-4.1	-4	-2	-3.5	-2.5
21	68	64.6	64.7	65.6	65.8	67.6	-3.4	-3.3	-2.4	-2.2	-0.4
25	68	66.9	66.5	66.1	67.4	68.1	-1.1	-1.5	-1.9	-0.6	0.1
30	68	67.3	67	66.9	67.9	67.6	-0.7	-1	-1.1	-0.1	-0.4
35	68	67.3	67.6	67.6	67.8	67.7	-0.7	-0.4	-0.4	-0.2	-0.3

Pier position at angular displacement, $\theta=60^\circ$

Initial bed level gauge reading (G.R), $Y_b = 68.0$ cm

Discharge, $Q = 2.5$ l/s

Depth of water flowing, $y = 3.375$ cm

Width of channel, $W = 35$ cm

B.L= Bed Level

G.R = Gauge reading

ds(cm), scour depth

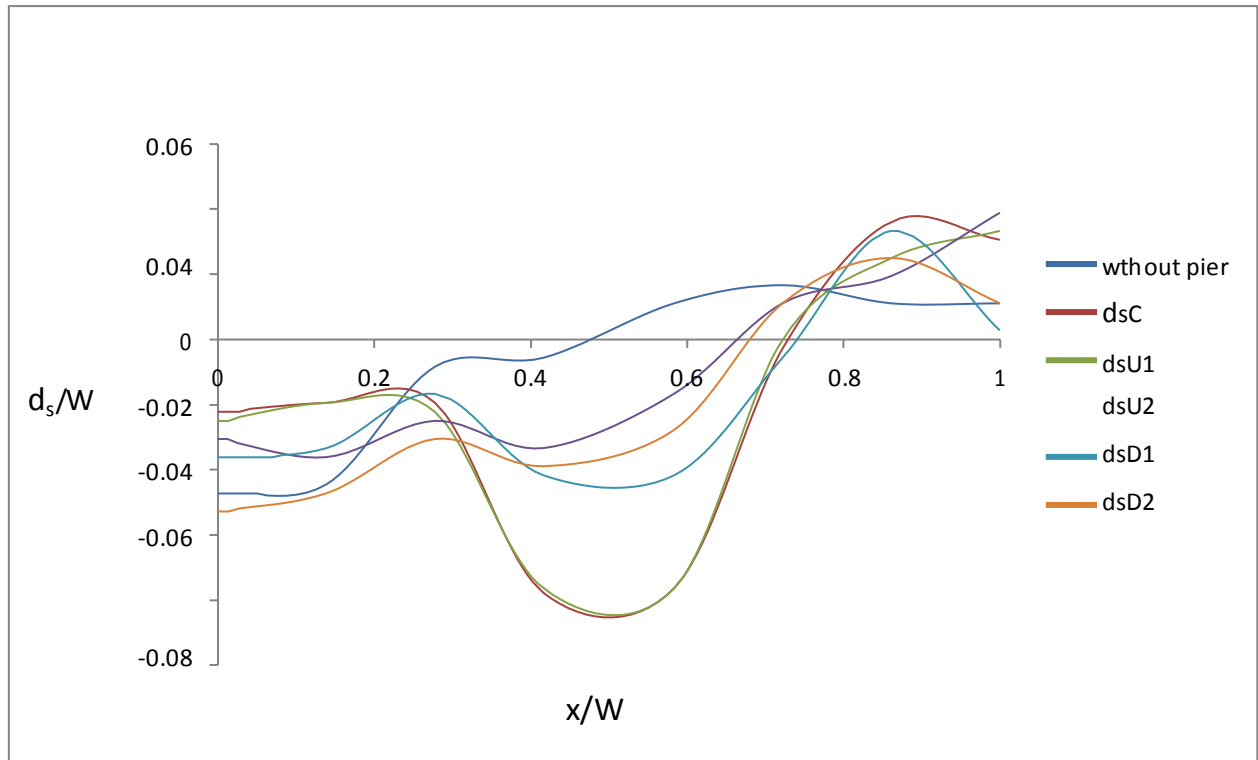


Figure 8. Variation of scour along different sections at $\theta = 0^\circ$ for $Q = 2.5$ l/s

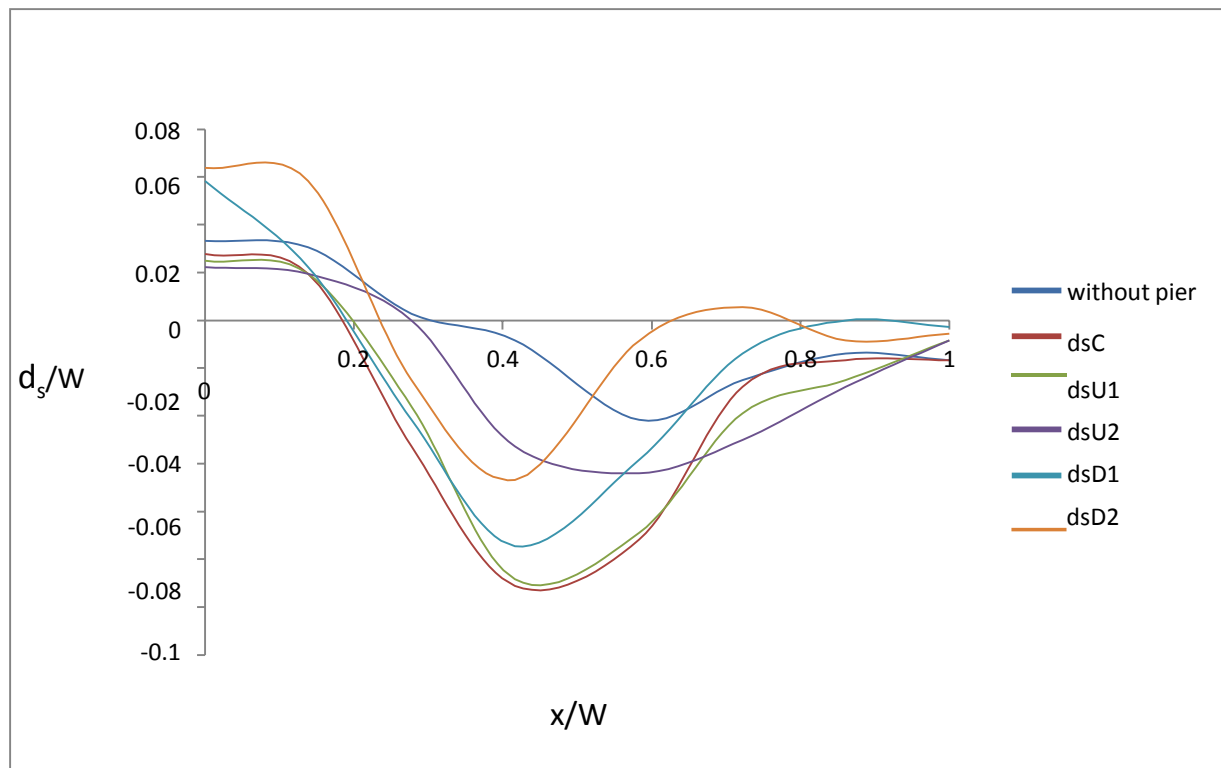


Figure 9. Variation of scour along different sections at $\theta = 60^\circ$ for $Q = 2.5$ l/s

Variation of Scour and Deposition along Various Sections at Different Angular Displacement (θ) and Discharges

Figure 10 shows the variation of scour along transverse direction for discharge $Q = 2.5$ l/s at various angular displacement θ . It is clear from this two graph that at inner bank scour decreases gradually with θ values, then start increasing gradually and attained peak values in the vicinity of pier ($x/W = 0.42$ to 0.58). Further as x/W increases towards outer bank, scour start decreasing gradually and deposition start toward outer bank. It is also clear from the graph, the maximum scour occur for 60° displacement. However the scour values are almost equal for $\theta = 40^\circ$ and 60° .

Variation of Scour and Deposition along Various Sections at Different Angular Displacement (θ) and Discharges

Figure 12 shows the variation of scour/deposition at the centre line section for two discharges i.e $Q = 2.5$ l/s and $Q = 4.5$ l/s at various angular displacement. It is found that it depends on discharge (flow rate). As discharge is increasing, the scour increases. Also it is clear that as displacement increases gradually for 0° to 80° , the scour increases slowly up to 60° after that start decreasing gradually. This pattern was obtained for both Q values. Similar trend of variation have been found for the remaining sections (dsU1, dsU2, dsD1, dsD2) not shown here.

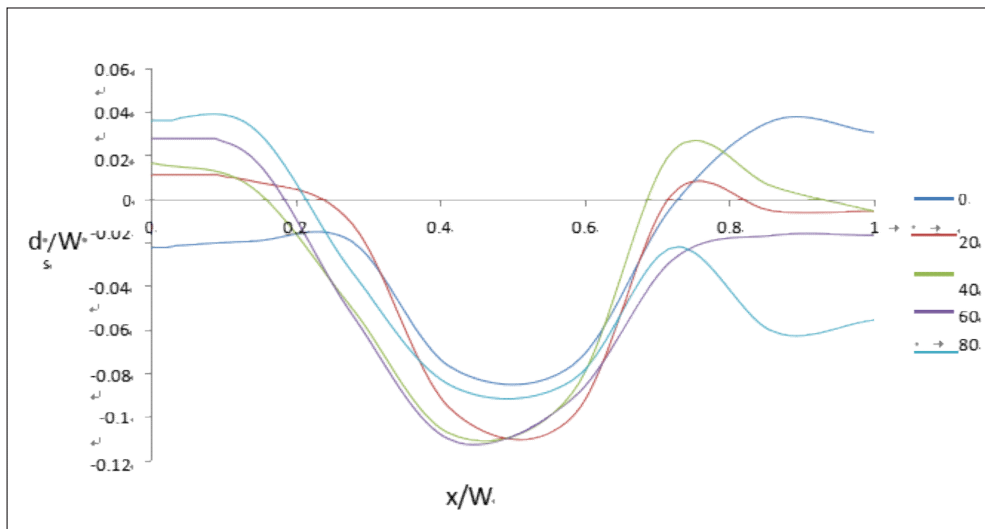


Figure 10. Variation of scour along centre line section (dsc) at different angular displacement, θ for $Q = 2.5$ l/s

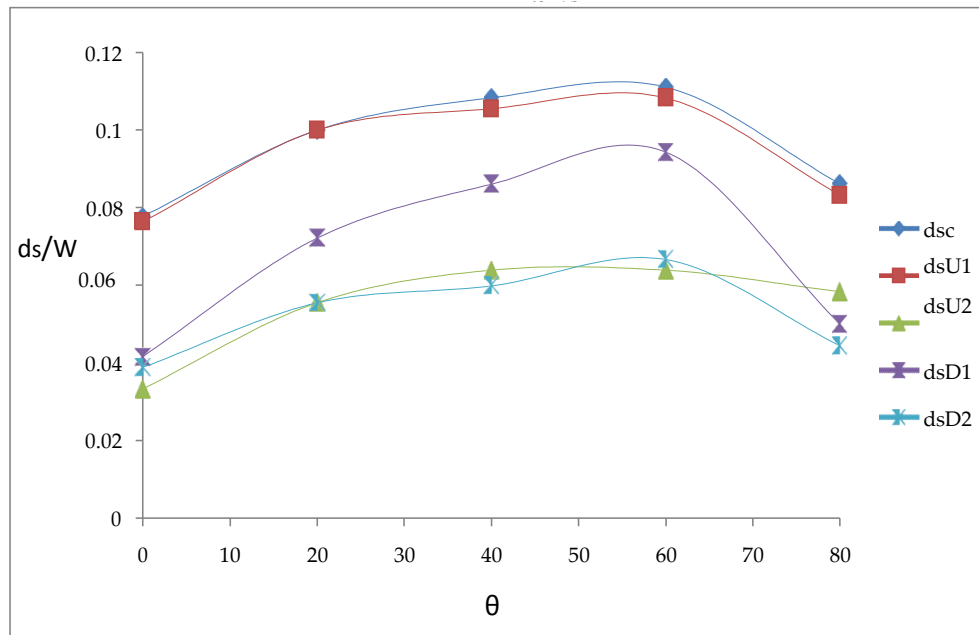


Figure 11. Variation of bridge pier scour in meander channel at different angular displacement (θ) and transverse sections for $Q = 2.5$ l/s.

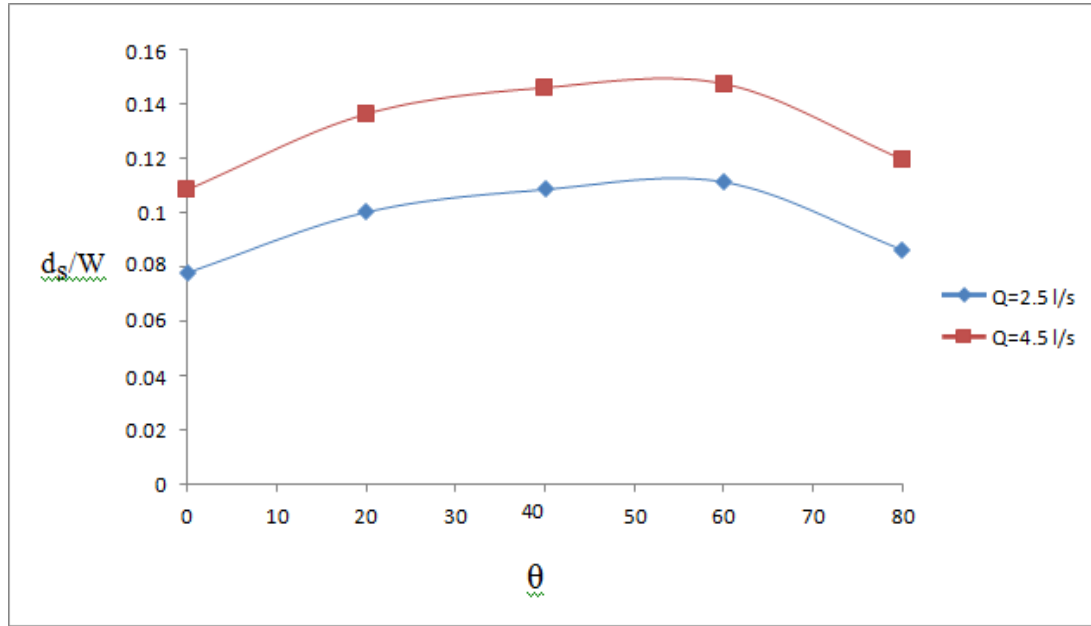


Figure 12. Variation of bridge pier scour in meander channel at different angular displacement (θ) and discharge for centre line section (dsC).

Variation of Scour and Deposition in Straight Channel and at Angular Displacement (θ) in Meander Channel for Different Discharges

Figure 13 shows the variation of scour in straight and meander portion of channel with and without pier. The graph is plotted for $Q = 2.5$ l/s along transverse direction for various angular displacement. It is found that without

pier in meandering channel there is scouring along inner side while deposition on outer side at 0° displacement. When pier was installed at mid of channel scour is occurred which obtained maximum value near pier and further scour decreases towards outer bank. It is also found that at 0° location of pier the value of scour in meander channel is slightly less then the scour obtained in straight channel.

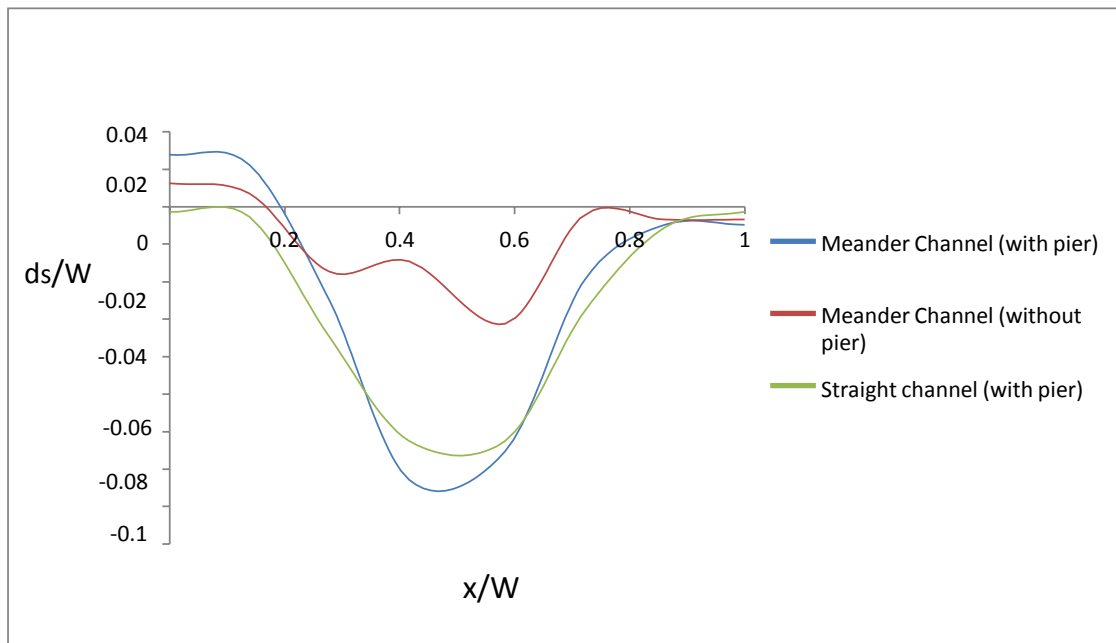


Figure 13. Variation of scour in meander channel at $\theta = 400$ and in straight channel for $Q = 2.5$ l/s

Comparison of Bridge Pier Scour in Meander Channel at Different Angular Displacement (θ) to Straight Channel for $Q = 2.5$ l/s

Figure 14 shows the comparison of scour for two discharges at various θ values between straight and meandering channel. It is very clear from these two plots at $\theta = 0^\circ$ and $\theta = 80^\circ$, the scour is less in meandering channel in comparison to straight channel. For remaining θ values from $\theta = 20^\circ$ to $\theta = 60^\circ$, the scour is more in meandering channel in comparison to straight channel. Also it is clear that at 60° angular displacements the scour attains the maximum.

Transverse Variation of Scour and Deposition with Pier in Meander Channel at Different Angular Displacement (θ) for $Q = 2.5$ l/s

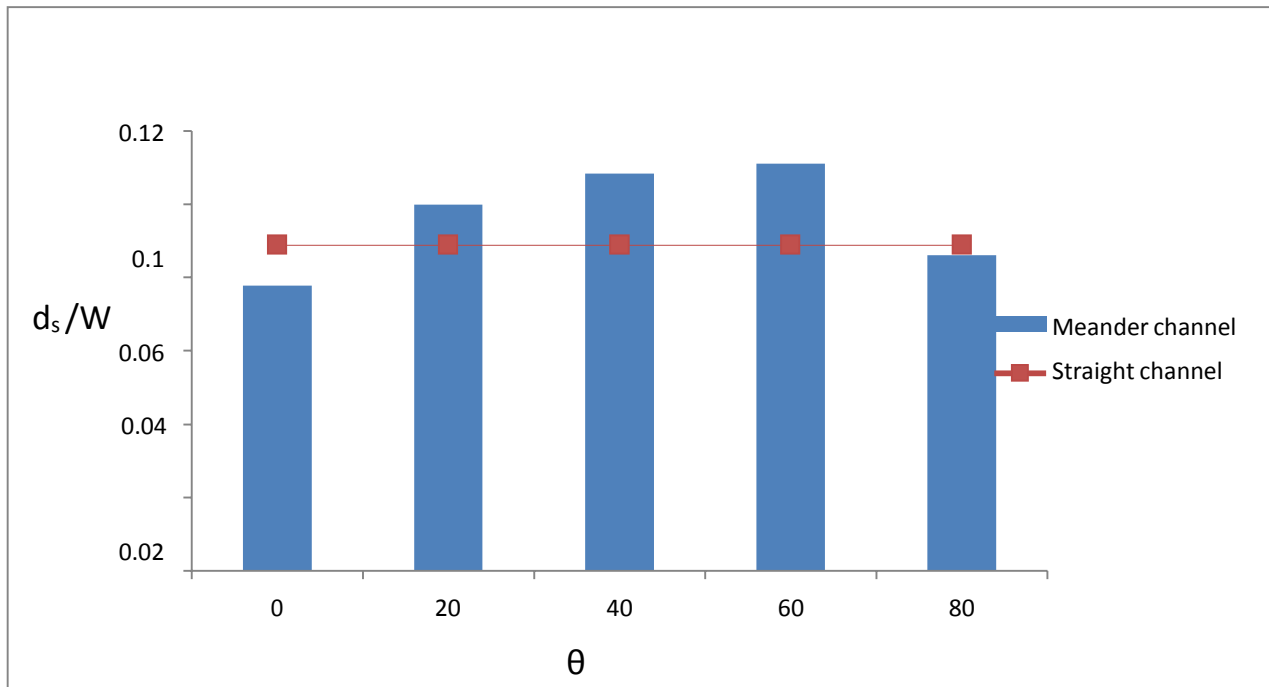
Figure 15 shows the variation scour and deposition with pier across the width of the meander channel at different θ , for discharge $Q = 2.5$ l/s. It can be seen from this graph that, at $\theta = 0^\circ$, there is scouring and this reduces at $\theta = 20^\circ$, and as θ ($40^\circ, 60^\circ, 80^\circ$) values increases the scour reduces and deposition increase at inner wall. It also can be seen from this graph that at $\theta = 0^\circ$, there is deposition at outer wall and as θ increases from $\theta = 20^\circ$ to $\theta = 80^\circ$ the deposition reduces as a result of the scouring increases at the outer wall. Also local

scour around circular pier placed at centre of the meander channel at different angular displacement can be noticed. It can be noticed that the maximum scouring around pier is at $\theta = 60^\circ$ angular displacement.

Comparison of Bend Scour with and without Pier in Meander Channel at Different Angular Displacement (θ) for $Q = 2.5$ l/s.

Figure 16 shows the variation of scour and deposition at inner wall with and without pier at different angular displacement θ . It is evident from the above figure, on inner wall of bend at $\theta = 0^\circ$, effect of scour has reduced after installing the pier at same location ($\theta = 0^\circ$). As θ no effect when pier increases from 0° , the nature of scour on inner wall after installing pier is still reducing and have installed at angular displacement $\theta = 50^\circ$ i.e scour on inner wall is almost equal before and after installing the pier at $\theta = 50^\circ$ angular displacement of the bend. After $\theta = 50^\circ$ angular displacement of the bend, the effect of pier on deposition on inner wall at the same location is to reduce the deposition till the end of bend ($\theta = 80^\circ$).

Figure 17 shows the variation of scour and deposition at outer wall with and without pier at different angular displacement θ . It is evident from the above figures, on outer wall of bend at $\theta = 0^\circ$, effect of deposition has increased after installing the pier at same location ($\theta = 0^\circ$). As θ increases from 0° , the nature of deposition on outer



3

Figure 14. Comparison of bridge pier scour in meander channel at different θ to straight channel for $Q = 2.5$ l/s

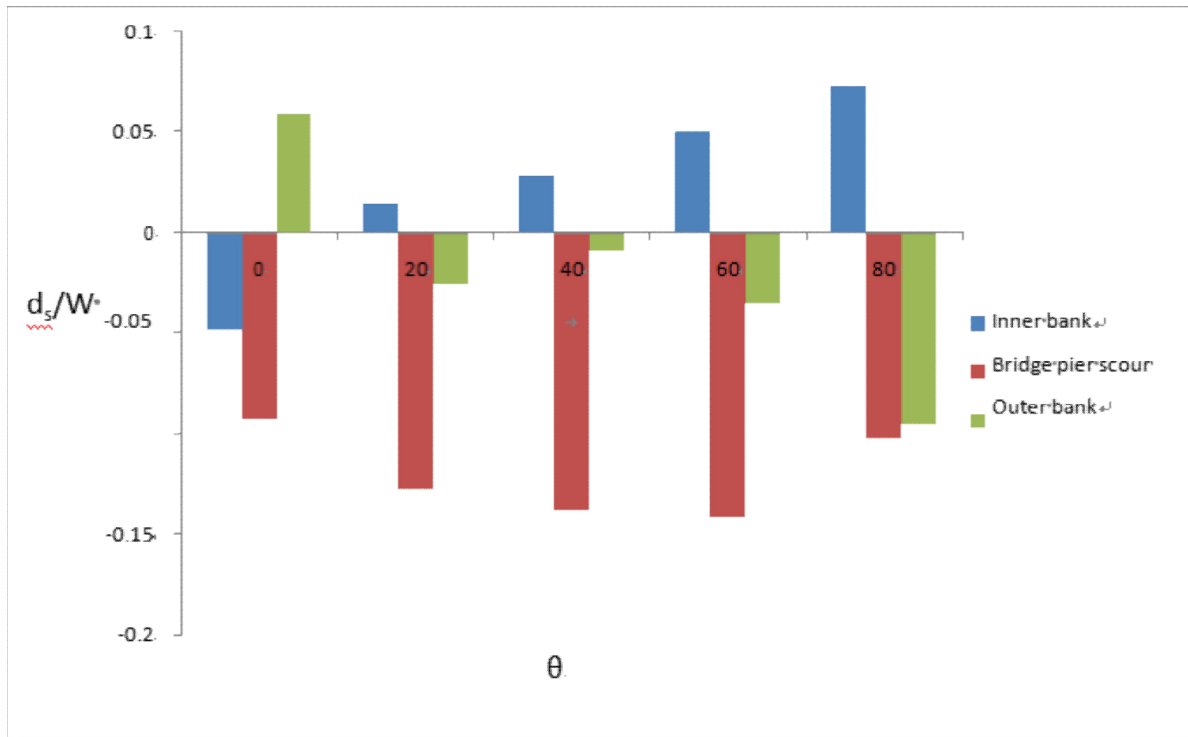


Figure 15. Transverse variation of scour with pier in meander channel at different θ for $Q = 2.5$ l/s

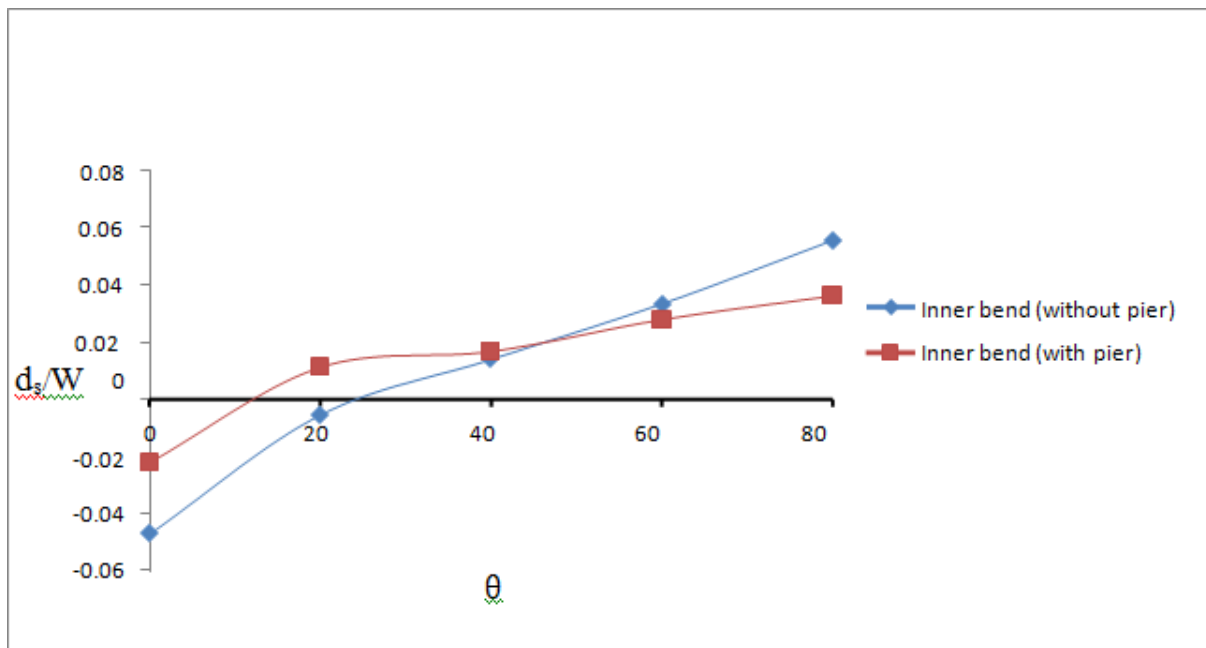


Figure 16. Comparison of bend scour with and without pier in meander channel at different θ for $Q = 2.5$ l/s

wall after installing pier is reducing up to 20° and have no effect when pier installed between angular displacement $\theta = 40^\circ$ and $\theta = 50^\circ$ i.e scour on outer wall is almost equal before and after installing the pier between angular displacement $\theta = 40^\circ$ and $\theta = 50^\circ$ of the bend. After $\theta = 50^\circ$ angular displacement of the bend, the effect of pier on scouring on outer wall at the same location is to increase

the scouring till the end of bend ($\theta = 80^\circ$).

Variation of Scour with Angular Displacement (θ) for Various Investigations

Figure 18 shows the variation of scour with angular displacement (θ) for studied by various investigators. It is clear from this graph that as θ increases, the scour

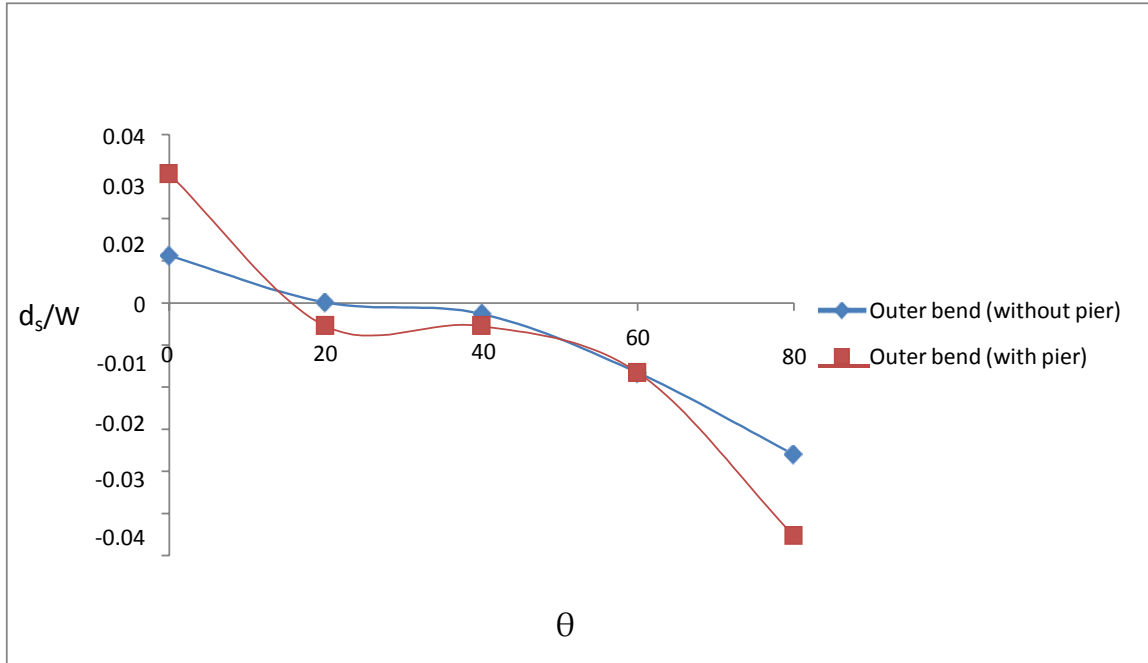


Figure 17. Comparison of bend scour with and without pier in meander channel at different θ for $Q = 2.5$ l/s

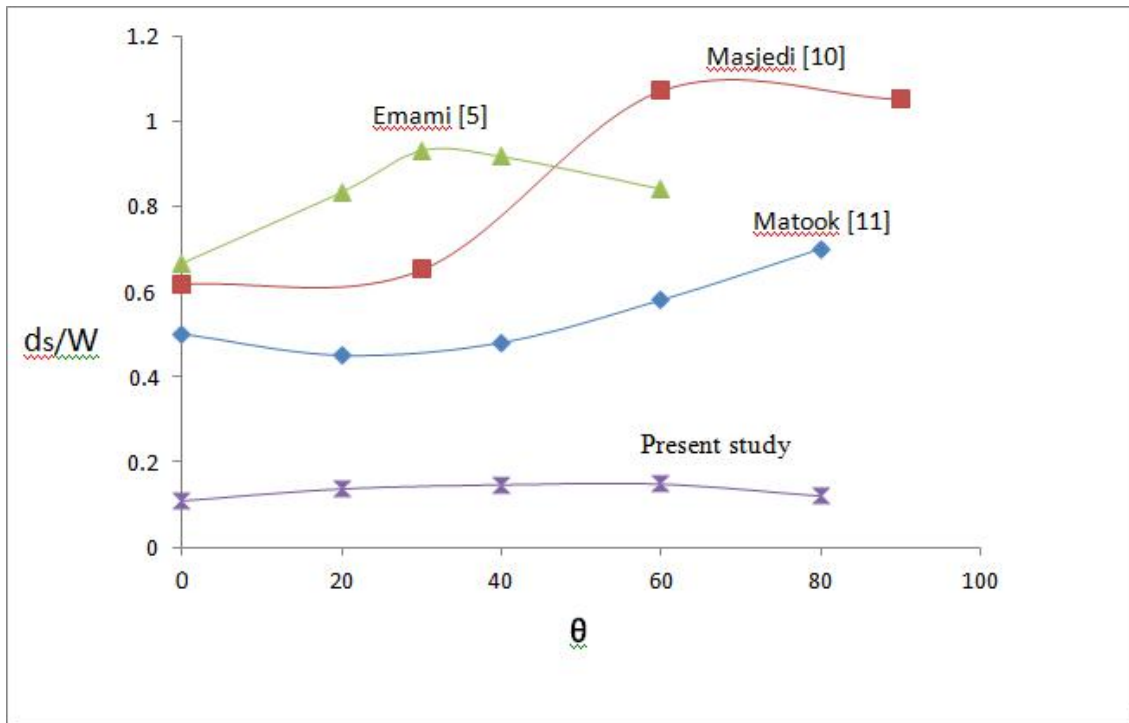


Figure 18. Show the variation of local scour studied by various investigators

depth also increases in all the studies and reaches up to maximum for θ varying from 40° to 60° . This value is maximum at $\theta = 30-35^\circ$ in the study of Emami. At $\theta = 60^\circ$ the scour is maximum. Almost in all studies except Matook. One can emphasize that at $\theta = 60^\circ$, the scour will always be maximum as obtained by most of the investigators. The discrepancy in the various graphs

(lines) may be attributed to sediment sizes and other hydraulic parameters such as discharge, pier locations, orientation etc.

4. Conclusions

Following conclusions have been drawn from the

present study:

1) It is found that the scour depends on flow rate i.e. higher scour hole depth at higher discharge.

2) It is also found that the maximum scour is at 60° angular displacement.

3) Similar trend of scour are obtained at all five sections (dsC , dsU_1 , dsU_2 , dsD_1 , dsD_2).

4) At $\theta = 0^\circ$ and $\theta = 80^\circ$, the value of scour around pier is less in meandering channel in comparison to straight channel.

5) However, for all other θ values i.e. from $\theta = 20^\circ$ to $\theta = 60^\circ$ the bridge pier scour in meander channel is more than in straight channel.

6) The effect of pier on bend scour at inner bank of the bend in comparison to bend scour on inner bank of bend when there is no pier in channel is to reduce the scouring between $\theta = 0^\circ$ to $\theta = 20^\circ$ angular displacement and there is no effect closer to $\theta = 50^\circ$, then as value of θ increases up to $\theta = 80^\circ$, the effect of pier is to reduce the deposition on inner bank.

7) The effect of pier on bend scour at outer bank of the bend in comparison to bend scour on outer bank of bend when there is no pier in channel has increased the deposition at $\theta = 0^\circ$ then deposition start reducing. There is no effect on scour at $\theta = 40^\circ$, then as value of θ increases from $\theta = 40^\circ$ up to $\theta = 80^\circ$, the effect of pier has increase the bend scouring at outer bank and maximum bend scour was found at $\theta = 80^\circ$.

8) It is found that the as θ increases, the scour depth also increases in all studies and reaches up to maximum for θ varying from 40° to 60° . At $\theta = 60^\circ$, the scour is maximum. All graphs are not matching because their hydraulic and sediment sizes were different.

References

- [1] Ajeel S., Gholami A., Bonakdari H., Bagheri N., Akhtari A. A., 2016. Comparison of flow pattern in a 60° sharp bend by using Fluent software and artificial neural network, support Vector Machine Methods, Mesopotamia Environmental Journal, Vol. 2, No. 2, pp. 27-39.
- [2] Bruce Melville, 2008. The Physics of Local scour at Bridge Piers, Fourth International Conference on Scour and Erosion, pp. 28-40.
- [3] Debnath K. and Chaudhuri S., 2010. Bridge Pier Scour in Clay-Sand Mixed Sediments at Near-Threshold Velocity for Sand, Journal of Hydraulic Engineering, Vol. 136, No. 9, pp. 597-906.
- [4] Ettema, R., 1980. Scour at Bridge Piers, Report No.216, School of Engg., The University of Auckland, Auckland, Newzealand, p. 572.
- [5] Emami Y., Salamatian S. A and Ghodsian M., 2008. Scour at Cylindrical Bridge Pier in a 180 Degree Channel Bend, Fourth International Conference on Scour and Erosion, pp.256-262.
- [6] Gholami A., Akhtari A. A., Minatour Y., Bonakdari H., and Javadi A. A., 2014. Experimental and Numerical Study on Velocity Fields and Water Surface Profile in a Strongly-Curved 90° Open Channel Bend, Journal of Engineering Applications of Computational Fluid Mechanics, Vol. 8, No. 3, pp. 447-461.
- [7] Garde R. J and Raju K. G. R., 2014. Mechanics of Sediment Transportation and Alluvial Stream Problems, New Age International (P) Ltd., Publishers.
- [8] Garde, R. J., 1961. Local Scour variation at Bridge Piers in Alluvial channels, University of Roorkee, Journal, Vol. No. 1, pp. 101-116.
- [9] Ibrahim H. Elsebaie, 2013. An Experimental Study of Local Scour Around Circular Bridge Pier in Sand Soil, International Journal of Civil & Environmental Engineering IJCEE- IJENS, Vol.13, No, 01, pp. 23-28.
- [10] Masjedi A, Bejestan M.S. and Kazemi H., 2010. Effects of Bridge Pier Position in a 180 Degree Flume Bend on Scour Hole Depth, Journal of Applied sciences, vol.10, No.8, pp. 670-675.
- [11] Matooq, J. S. and Mahmood, E.S., 2018. Local Scour around single Central Circular Bridge Pier located within 180° Bend, ARPN Journal of Engineering and Applied Sciences, Vol.13, No.5, pp.1639 -1648.
- [12] Rossell R.P and Ting F.C.K, 2013. Hydraulic and Contraction Scour Analysis of a Meandering Channel: James River Bridges near Mitchell, South Dakota, Journal of Hydraulic Engineering, Vol. 139, No. 12, pp.1286-1296.
- [13] Shen, H. W., Schneider, V.R. and Karakiss, 1969. Local Scour around Bridge Piers, ASCE, Vol. 95, HYS, pp. 1919-1940.
- [14] Ting F.C.K. and Briaud J. L., 2001. Flume Tests for Scour in Clay at Circular Piers, Journal of Hydraulic Engineering, Vol. 127, No. 11, pp. 969-978.

ARTICLE

Surface Water Quality Assessment of Panchagnaga River and Development of DO-BOD Relationship Using Empirical Approach

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ARTICLE INFO

Article history

Received: 21 November 2021

Accepted: 13 December 2021

Published Online: 20 December 2021

Keywords:

DO-BOD

Streeter phelp's model

DO sag curve

Chemical mass balance

Self purification capacity

ABSTRACT

Surface water samples were collected from selected locations along river Panchaganga, from Kolhapur to Narsobawadi during April 2019. Physicochemical parameters were determined in the laboratory and chemical mass balance approach was adopted to estimate the individual ionic loads in the river water. Streeter-Phelps equation was applied to derive a relationship between DO and BOD₅. Model parameters such as De-oxygenation Rate (K_d) and Re-aeration Rates (K_r) were optimized using different empirical methods. The result of chemical mass balance showed an increase in the loading of various ions from upstream to downstream which could be attributed to agricultural and industrial wastes that enter the main stream. De-oxygenation rate and re-aeration constants were calculated using various empirical methods. DO sag curve was developed using Streeter Phelps's model and compared with the observed parameters which showed a significant correlation. DO-BOD concentration observed along the course of the river indicated that the self-purification capacity of the river is high due to which the river regains the lost DO level at a distance less than 50 meters.

1. Introduction

Water quality of rivers is deteriorating due to rapid growth of population, industrial activity and unscientific agriculture development including, conversion of forest

and barren land to habitation and agriculture. Such an unwarranted growth, introduces a large quantity of organic matter into the water bodies in the form of domestic, industrial and agricultural wastes which contain many of the sensitive toxic elements. Therefore, change

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DOI: <https://doi.org/10.30564/hsme.v3i2.4121>

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in land use-land covers is an important aspect of water quality management which need immediate attention. The existing free electricity as an incentive to farmers resulted in uncontrolled over use of water. In many of the river basins in India, highly water intensive crops are being grown using conventional approaches rather than with a scientific understanding. Fertilizers and pesticides were used intermittently to obtain high crop yields which ultimately resulted in the accretion of inorganic chemicals thereby forming a threat to the adjacent riparian community and may lead to adverse impacts on ecology, crop growth, food security and health aspects. Though the situation is in highly alarming status all over the country, it is necessary to understand the riverine processes and water quality variations in river basins which flows through urban settlements and industrial zones. Globally, more than 80% of residual waters are released into the environment without any adequate treatment^[1]. It has been reported that, worldwide, around two million people die annually due to water-related diseases^[2]. In recent days, CPCB reported pollution of river Krishna due to various man made disturbances. One of the major tributaries of river Krishna is river Panchaganga. Panchganga river (flows through south western part of Maharashtra) receive large quantity of industrial wastes from City of Kolhapur and also from Ichalkaranji, a textile town of Sangli district. Waterborne diseases, and associated health hazards among the population in Panchganga basin have been reported for some time. The high concentrations of ions such as sodium, chloride, fluoride and ammonium may harm the surrounding environment including plants, animals and mankind. Further, the assimilation of certain ions by plants may lead to absorption of ammonia and ammonium ions. It is also important to note that the high concentrations of ammonium in water bodies can cause harm to humans when converted to nitrate^[3].

Both point and non-point sources of pollution are equally sensitive and need proper assessment with respect to the load which passes through the stream at any given point of time. Application of mass balance equation for a river stretch can be very useful means to understand the contributions (point and non-point source) of various ions during dry and wet seasons. This approach is based on flow and chemical concentrations of both anions and cations along the identified river reaches^[4]. The differential loads of chemical ions during the wet and dry periods can be considered as good indicators to understand the contribution of point and non-point sources. Jain (1996)^[5] carried out chemical mass balance studies for river Kali, Western Uttar Pradesh (India), and concluded that the river is subjected to a varying degree of

metal contamination due to numerous outfalls of untreated municipal and industrial wastes of the region. According to the study, the percentage increase in point sources from 61.5 % to 66.9 % (Fe), 57.1% to 77.8% (Zn) and 65.2% to 78.3 (Cu) during the period of study from (October 1993 to December, 1993). Jayashree (2000)^[6], found a good correlation between ionic concentrations of upstream and downstream of Bellary nala which receive large quantities of waste from Belagavi city. However, in post-monsoon samples, large variations in ionic concentration were attributed to the addition of non-point sources. Madhurima (2000)^[7] carried out a mass balance study for Ghataprabha river, a tributary of river Krishna (India) and observed the variation in ionic concentration to a tune of 1.5 times, between upstream and downstream indicating the impact of agricultural activities in the catchment. Similar study has been carried out by Hiremath (2001)^[8] for Ghataprabha during pre-monsoon and post-monsoon period. Malaprabha and Ghataprabha are the two major tributaries of river Krishna (India). A chemical mass balance study of Malaprabha river (a tributary of river Krishna) conducted by Purandara et al., (2004)^[9], showed the contribution of groundwater quality on river water characteristics, particularly in parts of M K Hubli, Hoelhosur and Bailahongal taluk.

Therefore, in the present study, surface water quality assessment of Panchaganga river at selected stretches has been carried out during the pre-monsoon season of 2019. Major anions and cations were determined and chemical mass balance approach was adopted to understand the contribution of various ions to river water quality variations. Further, highly sensitive water quality parameters such as DO (Dissolved Oxygen) and BOD (Biochemical Oxygen Demand) were also analysed which is highly essential for the survival of aquatic life. The variation of DO is directly dependent on BOD and is a measure of polluting effect of domestic waste which is responsible for the reduction of DO level in the river. Major anions and cations were also determined along with physical parameters. Such observations will help to assesses and predict contamination status, degradation of the waste discharge and self purifying capacity of the river^[10].

In order to understand the water quality variation with respect to river dynamics, Streeter Phelps model which is considered as a classical model has been adopted. The model will predict the longitudinal oxygen profile in flowing waters which works on basic principle of BOD-DO interaction in stream by mass balance phenomenon i.e. de-oxygenation and re-aeration processes.

2. Study Area

The Panchaganga river basin lies between 16°44'4" to 16°31'22" North latitudes and 74°10'33" to 74°36'3" to east longitude (Figure 1). Five small rivers viz. Bhogavati (83 km), Tulsi (30 km), Kasari (69 km), Kumbi (48 km) and Dhamani (41 km) confluence at Prayag Chikhali and it is renamed as Panchaganga. The river flows and meets Krishna River at Narsobawadi in Shirol taluka of Kolhapur district. There are 174 villages, two municipal towns (Ichalkaranji and Kurundwad), and a city (Kolhapur) are situated on the bank of the river ^[11].

3. Methodology

In the present study, the Panchaganga River between Shirol and Narsobawadi was divided into seven reaches by considering parameters such as population density, agriculture activity and industrial development. Station-5 and Station-6 are located near the industries that include steel, oil, sugar and textiles with an urban-agricultural interface. Samples were collected from the river Panchaganga at particular locations which are shown in Figure 1. The latitude-longitude of sampling locations is shown in Table 1. One litre of water using grab sampling method was collected from seven locations (from the middle of the stream) during pre-monsoon season (April) and transferred to clean air-tight plastic containers. During sampling, temperature, pH, DO, EC

and TDS were measured on site using Hach water quality samplers. Further, river cross sections and velocity were also determined using standard procedures. In the laboratory turbidity, acidity, alkalinity, chlorides, total hardness, calcium, sodium and potassium were analyzed as per procedure prescribed by American Public Health Association (APHA 2005) ^[12].

Table 1. Sampling locations along the Panchaganga river (between Shirol and Narsobawadi)

Sl.No	Sites with code	Distance (km)	Location		Elevation from mean sea level (m)
			Latitude	Longitude	
1	P1- Nagadev wadi	0.0	16.6917568	74.1654932	543.0
2	P2- Panchaganga Ghat	07.72	16.7615540	74.2621537	538.0
3	P3-Kasaba Bawadi	21.88	16.7121682	74.2805517	536.9
4	P4-NH-4highway Bridge	29.77	16.6660892	74.4757330	535.8
5	P5-Ichalkaranji	03.37	16.6810911	74.5082206	534.0
6	P6-Kurandwadi	17.70	16.6818394	74.5759011	531.9
7	P7-Narasoba Wadi	14.80	16.6918400	74.5965658	531.0

4. Streeter-Phelps Methods

One of the primary factors which indicate the pollution status of any flowing stream is the dissolved oxygen content. Though the replenishment of oxygen depends on hydraulic characteristics of the stream and oxidizable pollution load. All biochemical reactions, dependent

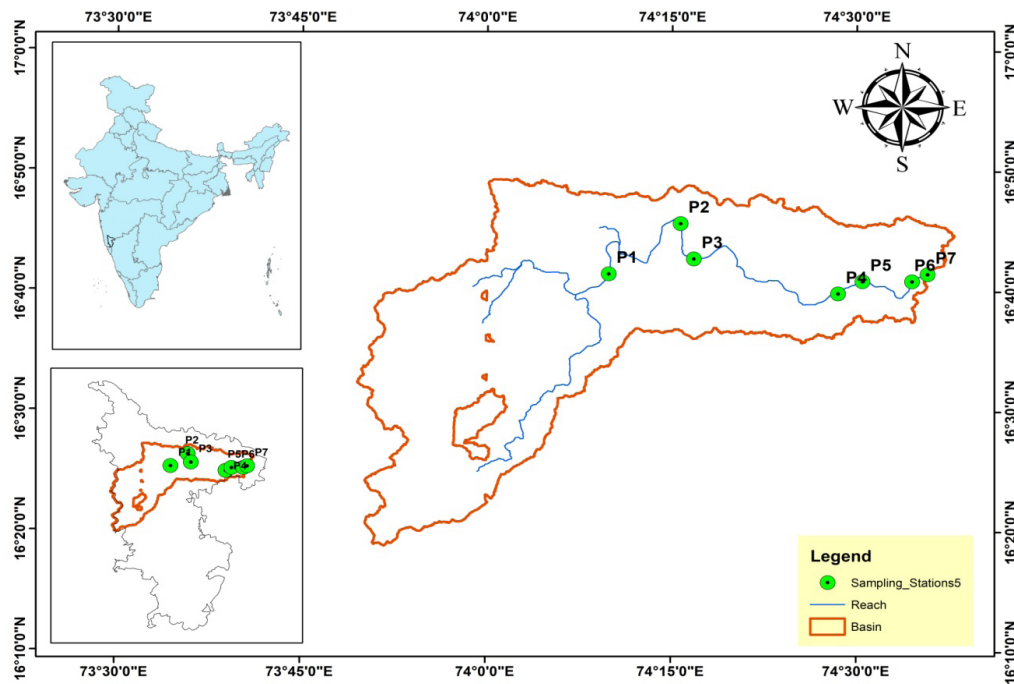


Figure 1. Water sampling points of Panchaganga River

basically on the density of micro-organisms which act as the sinks that depletes oxygen. Phytoplanktons and other pigmented aquatic organisms undergo the process of photosynthesis and provide support to the physical forces of re-aeration. Sludge deposits which form as a result of fine particles carried through streams influence heavily on the forces of oxygen depletion. Other physical parameters which impact the oxygen depletion are temperature, dissolved oxygen saturation percentage and stream morphological characters including sediment particles. One of the most significant parameters which affect the dissolved oxygen content is the waste load received by the stream at various locations. Therefore, in order to assess the waste assimilative capacity, it is important to develop the oxygen sag curves. Accordingly, in the present investigation,

Streeter-Phelps^[13] oxygen-sag equation (established for use on the Ohio River) was applied in the study of water contamination as a water quality modelling device. The model explains how dissolved oxygen decreases in a river or stream along a certain distance by degradation of biochemical oxygen demand (BOD). This model foresees deviations in the dissolved oxygen deficit as a function of BOD exertion and stream re-aeration. The major sources of pollution and water inflows to the River Panchaganga occur at number of locations along the selected river stretch between Nagdev wadi and Shirol MIDC (Kolhapur district) and also between Kasabawadi and Ichalkaranji (Sangli district) (Figure 2). The entire length of the river (under study) is further subdivided into seven reaches based on the location of wastewater outfalls, surface drains, and freshwater tributaries.

5. Model Parameters

5.1 Determination of De-oxygenation Rate

The De-oxygenation rate was determined by conducting laboratory measurements of DO uptake checking daily. Water samples were taken to the laboratory with appropriate procedures and incubated at 20 deg C using BOD bottles in the procedure carried out for 5 days. The data obtained from this method was calculated using Thomas method (Thomas, H. A., 1950)^[14]. It is also known as slope method which was used to determine De-oxygenation rate. The Thomas slope equation is expressed as

$$\left(\frac{t}{BOD_t}\right)^{1/3} = (KBOD_u)^{-1/3} + \frac{K^{2/3}}{6BOD_u^{1/3}} t \quad (1)$$

Where t = time at sample stations (day)

BOD_t = BOD that has been exerted in time t (mgL⁻¹)

K = BOD deoxygenation rate in base 10 (day)

BOD_u = Ultimate BOD (mgL⁻¹)

$\left(\frac{t}{BOD_t}\right)^{1/3}$ = It is plotted as a function of t, with the slope $\frac{K^{2/3}}{6BOD_u^{1/3}}$

$(KBOD_u)^{-1/3}$ = Gives K and BOD_u

5.2 Empirical Method of De-oxygenation Rate Determination

The de-oxygenation rate was obtained by using an empirical method^[15] which is based on physical condition of the river and depth of water. The empirical equation is

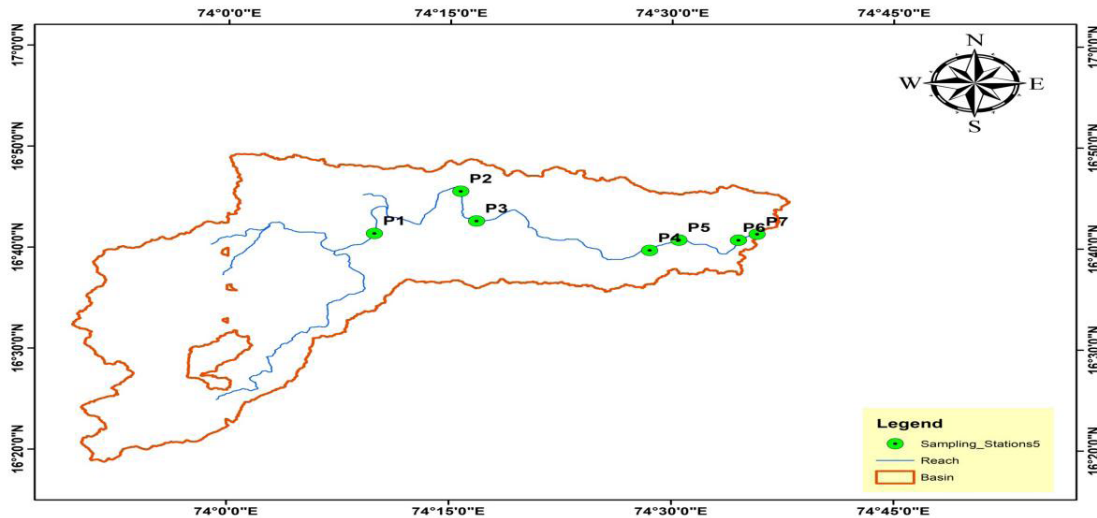


Figure 2. DO-BOD analysed stations:

shown below (Equation 2).

$$kd = 0.3 \left(\frac{H}{8} \right)^{-0.434} \quad (2)$$

Where, K_d = de-oxygenation rate (day)⁻¹

H = water depth (ft). $0 < H < 8$

5.3 Re-aeration Rates

Atmospheric re-aeration constant K_a was estimated using the following equation

$$(K_a)_r = (K_a)_{20} (\theta)^{r-20} \quad (3)$$

$(K_d)_{20}$ and $(K_a)_r$ are the reaeration rate constants at 20°C and at any temperature “T” respectively. For the constant “ θ ”, a value of 1.024 is used [16]. Many works have been carried out on mechanism of re-aeration as influenced by temperature, river geometry and hydrodynamics factors such as Connor et al [17], Churchill et al [18], Owens et al [19], Landgein and Durum [20] and Jha et al [21].

1) O Connor-Dobbins Equation:

$$(K_a) = \frac{3.9V^{\frac{1}{2}}}{H^{\frac{3}{2}}} \quad (4)$$

2) Churchill et al Equation:

$$(K_a) = \frac{5.06V^{0.919}}{H^{1.673}} - 1.024^{(T-20)} \quad (5)$$

Where T = Temperature.

3) Owens et al Equation:

$$(K_a) = \frac{5.32V^{0.67}}{H^{1.85}} \quad (6)$$

4) Langbein WB and Durum WH Equation:

$$(K_a) = \frac{5.14V}{H^{1.33}} \quad (7)$$

5) Jha et al Equation:

$$(K_a) = \frac{5.791V^{0.5}}{H^{0.25}} \quad (8)$$

Where K_a = re-aeration coefficient at 20° (day)⁻¹, V = Average stream velocity (m/s), H = average stream depth (m).

6. Streeter Phelps's Model

The Streeter-Phelps equation was widely applied for the evaluating the waste assimilative capacity of the river. The model elucidates how dissolved oxygen declines in a river or stream along a certain distance by decomposition of biological oxygen demand (BOD).

The model explains the decrease in the oxygen content of river water by the decomposition of the organic load (BOD) along the definite distance present in the river (Figure 3) and it calculate variations in the dissolved oxygen shortfall as a function of BOD exertion and stream re-aeration.

The classic Streeter -Phelps equation

$$D(t) = \frac{k_d L_0}{K_r - k_d} (\exp(-k_d t) - \exp(-K_r t)) + D_0 \exp(-K_r t) \quad (9)$$

Where;

K_r is re-aeration constant (day)⁻¹,

K_d is de-oxygenation constant (day)⁻¹,

t is the time of travel of wastewater discharge downstream(days)

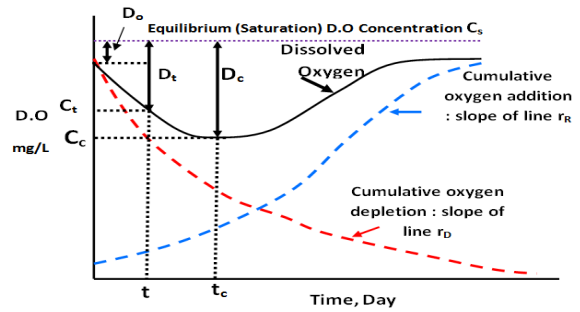


Figure 3. Streeter Phelps Oxygen Sag

7. Chemical Mass Balance

The law of conservation of mass states that “when chemical reactions take place, matter is neither created nor destroyed”. This is also applicable to pollutants moving between two sections. A substance that enters the region has three possible outcomes. Part of it may leave the region without any change; part of it may collect within the periphery and part of it may be recovered from other substances. The equation for mass balance can be written for each substance,

$$\text{Input rate} = \text{Output rate} + \text{Accumulation Rate} + \text{Decay rate} \quad (10)$$

The basic principle in defining the release of materials into a stream is to express a mass balance equation for different lengths of the river. The principal equation for mass balance supposing thorough mixing is,

$$\text{Load of material upstream} + \text{Load added by outfalls} = \text{Load of material immediately downstream from outfall}$$

Recalling that the load is the product of concentration and flow, the mass balance is given by

$$QuCu + \sum_{i=1}^n L_i = Q_D C_D \quad (11)$$

Where the flows of upstream and downstream are Qu

and Q_D , concentration in the receiving water at upstream and downstream are C_u and C_D , and is the sum of all individual loading to the receiving water. Mass balance for certain water constituents is determined to find the association between the water quality estimated and contamination due to natural process due to human activity, i.e. the weight of the substance transported through a cross-section of the river bed per second. When two or more rivers come together at one point, the sum of the loads carried by the streams above the confluence must be equal to the load of the river downstream of this point.

8. Results and Discussion

8.1 Physico-chemical Characteristics of Panchaganga River

The physico-chemical parameters were determined in the laboratory for the samples collected during pre-monsoon season of 2019. The results are presented in Table 2.

From Table 2, it is noticed that, pH vary from 7.14 to 7.78 and lies within the permissible limit and found to be steady from upstream Nagdevwadi to Narasobawadi in the downstream. Turbidity ranges between 1.4 and 6.3 (NTU) indicating that all values are within permissible limit except the one at station Kasaba Bawadi (P-3, the confluence of Jayanti nallah). During the field investigation, it is observed that, large quantity of sediments is transported into the stream and remain in suspension for certain distance. EC of Panchaganga River varies from 202.9 to 952.8 $\mu\text{S}/\text{cm}$. The relatively higher EC and TDS towards the downstream could be attributed to the large quantity of discharge of wastewater from local habitations and also from industries such as textiles which is widely spread over the downstream part of the river. The TDS content ranges from 100 to 500mg/L. Parameters like acidity, alkalinity, chlorides and Total hardness were found to be within the permissible limits. However, a significant change in the concentration of chloride (193 mg/L) was noticed at station P-5 which receives large quantity of liquid waste from textile industries located in the area. Further, cations such as calcium, magnesium, sodium and potassium were also remained within the permissible limits.

8.2 Chemical Mass Balance

The concentrations of major anions and cations were converted to chemical load by multiplying with river cross sectional area and velocity at each station in Table 3. Flow

varies between 89.81 m^3/s and 192.014 m^3/s during non-monsoon. The increase in stream flow between stations P1 and P7 (upstream and downstream) was caused by the outfalls of municipal and industrial wastes incoming from various towns located on the catchments. The estimated load of both anions and cations showed a general trend of increase towards the downstream.

Alkalinity is one of the key parameters which is distributed widely all along the course of the river stretch. Maximum load was recorded at Downstream (P7). The increased concentration of alkalinity could be due to the combined effect of agricultural waste and industrial effluents received from the riparian belt covering Ichalkaranji and adjoining areas. Chloride load in upstream estimated was 1673.717 kg/day and an increase was noticed in the immediate downstream location (13177.44 kg/day) which could be due to the inflow of huge quantity of domestic waste enter the river in the downstream Figure 4, particularly from the township of Ichalkaranji which include industrial, domestic and agriculture wastes.

In the case of sodium the increase was gradual with a highest load of (10348.84 kg/day) in the downstream of Ichalkaranji (P7). Similar observation was found in the distribution of potassium where the maximum load increased from 14.45 kg/day upstream to 39.7 kg/day in the downstream. However, potassium load was minimum at Ichalkaranji which could be due to the source area variation and also due to the hydrodynamic conditions and hydrochemical characteristics of the chemical load discharged from the industries. Further, it is noticed that both calcium and magnesium load are very high due to the mixing of industrial wastes. Higher loads are observed towards the downstream of Ichalkaranji (Ca= 16258.209 kg/day; Mg = 9290.40 kg/day). Therefore, it is evident that the excess load is added through effluents discharged from the textile industries. Figure 4 represents the variation of chemical load along the course of the river. It is found that there is a gradual increase in the load from upstream part of the study area to the downstream. The increase in the load of each parameter further substantiated the role of agriculture and industrial wastes into the river all along the river basin. It is also noticed that, due to the sanctity of the Narsobawdi temple located on the Panchganga river, receive large number of devotees on daily basis and use the river water for temple activities and also for swimming, bathing and cleaning of clothes. Therefore, the man made disturbances also causes significant damage to water quality of Panchaganga river. This was evident from the observations on DO and BOD concentrations monitored during the study period.

Table 2. Physico- chemical parameters of Panchaganga river between Shirol and Narsobawadi (Pre- monsoon, 2019)

Location	pH	Turbidity (NTU)	EC $\mu\text{S/cm}$	TDS mg/L	Acidity mg/L	HCO ₃ mg/L	Cl mg/L	TH mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L
P1	7.18	2.8	202.9	100	6	86	20.85	70	50	20	18.58	0.18
P2	7.14	4.2	486	200	10	112	22.83	94	76	18	25.66	0.35
P3	7.42	6.3	238.5	100	8	94	24.82	84	66	18	13.42	0.23
P4	7.18	4.5	617	300	12	116	36.73	90	84	6	55.84	0.18
P5	7.27	1.4	952.8	500	10	202	193.61	182	136	46	87.48	0.09
P6	7.33	4.3	836.2	400	12	196	64.53	130	120	10	47.89	0.41
P7	7.78	5.1	807.5	400	14	232	79.43	154	98	56	62.38	0.24

Table 3. Estimated Chemical load in Panchaganga river during Pre-monsoon (2019)

Source	Loads Kg/day					
	Cl	HCO ₃	Na	K	Ca	Mg
1 Shirol Section						
U/S	1673.717	6903.58	1491.49	14.449	4013.712	1605.484
D/S	1925.993	7294.25	1041.37	117.847	5121.49	1396.77
2 Ichalakaranji Section						
U/S	2948.47	9311.811	4482.513	14.449	6743.036	481.645
D/S	13177.44	38488.82	10348.84	39.816	16258.209	9290.40

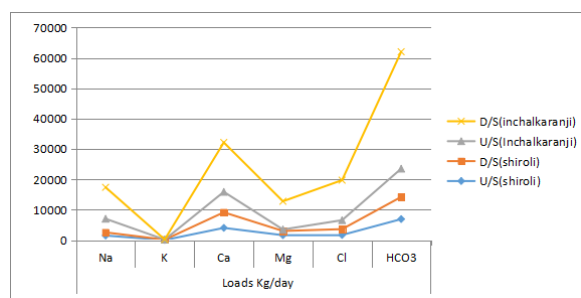
**Figure 4.** Variation of chemical load in Panchaganga river during Pre-monsoon (2019)

Figure 4 shows the concentrations of major anions and cations along the different stretches of Panchaganga river from Shirol (Kolhapur) to Narsobawadi. The differential loading between upstream (P1) and downstream (P7) sections varies considerably high (from less than 6 times in the case of bicarbonate and more than 8 times in the case of chloride and 2 times in case of potassium) during non-monsoon period. The higher concentration of anions and cations during pre-monsoon season could be attributed to base-flow components (supplied from adjoining aquifer) and also due to the drying of reservoir during non-monsoon period (dilution effect becomes

negligible). It is further noticed that, along the stretch of river Panchaganga intensive agriculture activities are ongoing all over the year which plays a significant role in contributing chemical loads both during pre-monsoon and post-monsoon seasons. The present observations as well as the discussions held with the locals also indicated the possible means of contamination from intensive agriculture activities and domestic wastes in addition to industrial loads. One of the important observations found during the study period is with regard to contribution of non-point source of pollution which is significant and need further investigations to quantify the load individually from point and non-point sources.

8.3 Determination of De-oxygenation Rate

The presence of dissolved oxygen in the flowing water depends on de-oxygenation and re-aeration coefficient. Both the coefficients indicate the hydraulic conditions, geomorphological characteristics and the organic matter content in water and sediments of the river. Various methods have been devised for the estimation coefficients. In the present study, de-oxygenation rate was determined using Thomas and Hydroscience methods and presented

in Table 4.

Variation of de-oxygenation coefficient showed only marginal variation indicating that the river health is considerably good all along the river stretch under study. It is found that the average de-oxygenation coefficient was higher in the case of Hydrosience method as compared to Thomas. The values were compared with other tributaries of Krishna (Tungabhadra, Ghataprabha and Malaprabha) and it is found to be closer to the one estimated by Hydrosience methods. Similar observations were made by the studies carried out for river tributaries of river Krishna by National Institute of Hydrology, Belagavi (unpublished), Highest de-oxygenation coefficient is noticed at Kasaba Bawadi and lowest in Narsobawadi. The highest value could be attributed to the higher concentration of organic matter carried from the effluent stream flowing through the Kolhapur city (Shiroli MIDC). However, there is a considerable reduction in the de-oxygenation rate towards the downstream. The wide variations observed in the downstream region could be due to the variation in the effluent supply and river hydraulics of the region. Further, as the agriculture activities are intensive in the region, large quantity of water is used for agriculture and such water re-enters the river as irrigation return flow. The reduced de-oxygenation coefficient observed at Kurandawadi and Narsobawadi could be due to the increased self-purification capacity and also due to the mixing of Krishna water with Panchganga at the confluence (Narsobawadi). This is evident from the observations taken during the study period.

Table 4. De-oxygenation coefficients calculated by Thomas and Hydrosience methods

Stations	De-oxygenation constants K_d (day) ⁻¹	
	Thomas method	Hydrosience Equation Method
P1	0.216	0.256
P2	0.152	0.226
P3	0.1	0.274
P4	0.126	0.215
P5	0.051	0.223
P6	0.058	0.184
P7	0.035	0.182

8.4 Estimation of Re-aeration Rate

Re-aeration coefficients estimated for different stations of Panchaganga river, using different methods viz., Connor et al (1956), Churchill et al (1962), Owens et al

(1964), Langbein and Durum and Jha et al (2003).

The estimated values of re-aeration coefficient by different empirical methods were compared with the one suggested by NIH (based on unpublished data) and it showed relatively closer resemblance with the method estimated by O'connor and William. Therefore, re-aeration coefficient values obtained from Connor and William method were considered for of Panchaganga River. The highest re-aeration coefficient is observed at Nagadevwadi (0.158/day) and lowest for Narsobawadi (0.058/day), which could be due to multiple factors such as the low flow conditions, geomorphological characteristics and depth of the stream. It is also found that the shallow water showed higher coefficient of re-aeration, due to ease of mixing across the depth profile and greater surface turbulence. Variation of re-aeration is significantly associated with the hydrodynamic conditions of the river. BOD₅, 20 °C showed marginal variations in all sections of the study area (in none of the cases, it exceeded the permissible limit). This could be attributed to the self purification capacity of the river. The summary of the estimated parameters and experimental observations Table 5 indicate that though the re-aeration coefficients are slightly lower than the de-oxygenation coefficient however, DO remained steady and also within the desirable limits.

The higher DO observed in majority of the locations reflect the higher primary productivity levels and eutrophication process taking place in the riverine environment. The presence of BOD (variation is between 0.9 mg/L and 1.88 mg/L) could be the result of accumulation of organic particles received from agriculture and industrial effluents. It is very important to observe that, as the river passes through rural habitations, due to lack of proper sewage systems, the untreated sewage enter the riverine environment from septic tanks and illegal piping connections. This kind of processes resulted in an increase of organic matter and increase in de-oxygenation coefficients (K_d)^[22]. Such changes in K_d could be due to variation in temperature which ultimately influence the metabolic activities of the microorganisms. Further,^[23] opined that the significance of K_d and BOD lies when two different samples have the same value as BOD₅, as it indicates the uptake of dissolved oxygen under similar conditions.

8.5 Streeter Phelp's Model

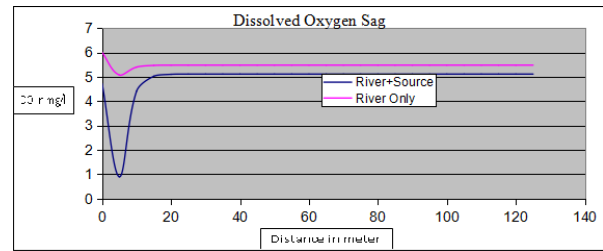
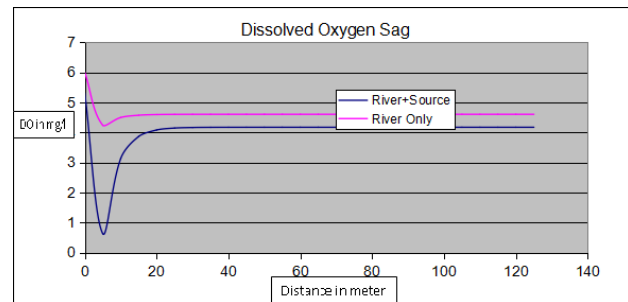
According to Streeter-Phelps model, the Oxygen sag

Table 5. Re-aeration coefficients calculated by different methods

Panchaganga basin		Re-aeration constant (day) ⁻¹ by different methods			
Stations	Connor & William Dobbins method	Churchill et al	Owens et al	Langbein& Durum	Jha et al
P1	0.158	0.047	0.088	0.067	1.120
P2	0.107	0.031	0.054	0.049	1.079
P3	0.200	0.061	0.117	0.083	1.164
P4	0.126	0.050	0.069	0.084	1.481
P5	0.138	0.054	0.078	0.089	1.463
P6	0.050	0.013	0.021	0.024	0.925
P7	0.058	0.018	0.0263	0.034	1.101

curve is one of the best tools to understand the oxygen deficit with respect to de-oxygenation (K_d) and re-aeration (K_r) at any time”^[23-25]. Self-purification capacity of a flowing stream decides the natural health of a river as it involves physical, chemical and biological processes and help to retain the original water quality characteristics of the stream. Therefore, the basic parameters of concern are de-oxygenation and re-aeration coefficients which were estimated by using simple empirical equations. Based on the above parameters, the DO sag curves were developed using Streeter Phelps’ equation for two sections of the river (Shiroli in the upstream and Narsobawadi in the downstream). Dissolved oxygen Sag curve for Shiroli (Figure 5) shows three distinctive zones of degradation, decomposition and the recovery along the river course. Initially observed DO at the confluence point of river and effluents (Shiroli MIDC) showed a sharp decline to less than 1 mg/L, whereas, in the flowing stream DO showed a normal value of 6 mg/L prior to the entry of waste water and the river mixed with effluents indicated a drop in the DO to 5 mg/L. It is very significant to note that the self purification capacity is so high that the DO attains almost a normal status within a distance of 15 m to 20 m. Therefore, the study implies that the impact of waste water mixing does not cause significant pollution at Shiroli. This kind of observation indicates that the industries may be discharging the water after primary and secondary treatments.

The above observation was done for a small stretch in the downstream of Ichalkaranji and Narsobawadi (Figure 6). The observations were similar, but need further evaluation. At Ichalkaranji, large quantity of waste enters the system, however, the flow pattern suggest that, the river maintain the DO to the normal due to the confluence of number of tributaries which supply comparatively large quantity of fresh water from the catchment.

**Figure 5.** DO sag curve developed using Streeter Phelps’s model (Shiroli MIDC)**Figure 6.** DO sag curve developed by Streeter Phelps’s model (Narsobawadi)

9. Conclusions

The primary objective of the present observation is to evaluate the water quality parameters to understand the impact of both agriculture and industrial wastes received by the river particularly between Shiroli and Narsobawadi.

(1) The water quality parameters during study period showed considerable variation from upstream to downstream. However, it is noticed that the variation in both physical and chemical ions are marginal. Turbidity was within permissible limit in all stations except in station P-3 where the Jayanti nallah confluent with Panchaganga.

(2) The estimated loads of major cations and anions during study period showed gradual increase in the load from upstream to downstream which is mainly due to agriculture and industrial wastes entering the

river. Therefore chemical mass Balance study showed contribution of non-point source of pollution is significant.

(3) The estimated De-oxygenation and re-aeration coefficient showed marginal variations and a considerable balance between the two parameters which clearly indicate the good health of the river stretch under investigation. The de-oxygenation coefficient value was slightly higher at Kasaba Bawadi due to discharge of domestic waste and industrial effluent near to it.

(4) Application of Streeter Phelp's model showed that the self purification capacity of the river is very high and the accumulation of organic load is significantly low due to geomorphologic and existed flow conditions. However, a critical assessment of the Panchaganga river is highly essential as the present study is limited to a particular period and time. It is also pertinent to understand the sediment water interaction process in the river as the organic pollutants can adsorb on to fine sediments and lead to intermittent issues of water quality hazard.

Acknowledgements

Authors are grateful to the Principal and Head, Department of Chemistry for their constant support and encouragement. I also thank all Faculty members and staff of Department of Chemistry, GIT for their help rendered during investigation and experiments. It is my pleasure to thank to Dr. B. Venkatesh, Scientist G & Head, NIH, Belagavi for permitting to carry out the laboratory analysis. I am also grateful to Scientists and staff of NIH Belgaum for their support.

References

- [1] UNESCO, 2017. Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2017. Aguas residuales: El recurso Desaprovechado; UNESCO: Paris, France. ISBN 978-92-3-300058-2.
- [2] WHO, 2018. Waterborne Disease Related to Unsafe Water and Sanitation. WHO: Geneva, Switzerland. pp. 9-10
- [3] Rachna Bhateria et al., 2016. Water Quality assessment of lake water: a review. *Sustain. Water Resour. Manag.* 2:161-173.
- [4] Fretes, V., Giugale, M., López, J., 2003. Ecuador: An Economic and Social Agenda in the New Millennium; the World Bank: Washington, DC, USA. ISBN 0821355457.
- [5] Jain, C.K., 1996. Application of chemical mass balance to upstream/downstream river monitoring data. *Journal of Hydrology*. Vol 182, Issue 1-4: 105-115.
- [6] Jayashree.k., 2000. Impact of sewage on water quality - a case study. M. Tech thesis, Vishweshwaraiah Technological University, Belgaum.
- [7] Madhurima. M. G, 2000. Evaluation of quality parameters and DO modelling using QUAL2E model. Vishweshwaraiah Technological University, Belgaum.
- [8] Hiremath.S.H., 2001. Impact of Land use on Water Quality- a case study. M.Tech thesis, Vishweshwaraiah Technological University, Belgaum.
- [9] Bekal.Kunkangar PPurandara et al., 2004. Application of chemical mass balance to water quality data of Malaprabha river. *Journal of Spatial Hydrology*. Vol-4, No.2.
- [10] Stephane Mbuyamba et al., 2018. Modeling of Dissolved oxygen (O₂) Dynamics on the Left Bank of the Congo River; Port Ex Onatra River City. *American Scientific Research Journal for Engineering Technology, and Science (ASRJETS)* Volume 45, No 1, pp1-19.
- [11] Gaikwad, S. S., 2014. Assessment of Heavy Metal Pollution of Panchganga River with Reference to Diversity of Molluscan Fauna. Dissertation, Shivaji University, Kolhapur. (Maharastra) India.
- [12] APHA, 2005. Standard Methods for the Estimation of Water and Waste Water, American Public Health Association, New York.
- [13] Streeter, H. W., Phelps, E. B., 1925. A study of the natural purification of the Ohio River. Washington: U. S. Public Health Service, 75p. (Public Health Bulletin, v. 146) APHA.(1998). Standard methods for the examination of water and wastewater (20th Ed). Washington: American Public Health Association. DC 20005-2605.
- [14] Thomas, H. A., 1950. Graphical Determination of BOD Curves Constants, Water and Sewerage Works, Vol 97.
- [15] Hydrosience Inc, Mar 1971. Simplified Mathematical Modeling of Water Quality Prepared for the Mitre Corporation and the USEPA, Water Programs, Washington DC. 127 pp, 4 Appendixes. 5 Monographs.
- [16] Edward R. Holley et al, 1984. Field Techniques for Reareation Measurements in Rivers. *Gas Transfer at Water Surfaces*, pp 381-401.
- [17] O'Connor, D. J., & Dobbins, W. E., 1956. Mechanism of reaeration in natural streams. *Transactions of the American Society of Civil Engineers*, 123, 641-684.
- [18] Churchill, M.A., Elmore, H.L., and Buckingham, R.A., 1962. Prediction of stream reaeration rates, *J. San. Engr. Div ASCE SA4:1*, Proc. Paper 3199.
- [19] Owens M., Edwards R.W. and Gibbs J.W., 1964. Some reaeration studies in streams, *Int. Jour. Air and*

- Water Poll., 2. 469.
- [20] Langbein WB, Durum WH, 1967. The American Capacity of Streams, USGS Circular No. 542. Washington (DC): United States Geological Survey.
- [21] Jha R, Ojha CSP, Bhatia KKS, 2003. A supplementary approach for estimating reaeration rate coefficients. *Hydrol Process.* 18:6.
- [22] Almeida, T. V. D., 2006. Índice de qualidade da água e coeficientes de autodepuração de trechos do Rio Pomba. 68f. Dissertação (Mestrado em Engenharia Agrícola) - Universidade Federal de Viçosa, Viçosa.
- [23] Von Sperling, M., 2014. Introdução à qualidade das águas e ao tratamento de esgoto. 4. ed. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental; Universidade Federal de Minas Gerais. v. 1. 472 p.
- [24] Bahadur, R., Amstutz, D. E., Samuels, W. B., 2013. Water contamination modeling: a review of the state of the science. *Journal of Water Resource and Protection*, v. 5, p. 142-155.
- [25] González, S. O., Almeida, C. A., Calderón, M., Mallea, M. A., González, P., 2014. Assessment of the water self-purification capacity on a river affected by organic pollution: application of chemometrics in spatial and temporal variations. *Environmental Processes*, v. 21, p. 10583-10593.



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