STUDY OF CLARIFICATION OF WATER BY METHOD OF SETTLING COLUMN ANALYSIS

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

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IN

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With specialization in

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Under the supervision of

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to

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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled **"STUDY OF CLARIFICATION OF WATER BY METHOD OF SETTLING COLUMN ANALYSIS"** for partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in "**ENVIRONMENTAL ENGINEERING"** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out By **Gaurav Thakur (Enrolment No. 152761**)during a period from July 2016 to may 2017 under the supervision of **Dr. Rajiv Ganguly (**Associate Professor, Department of Civil Engineering), Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

Surface water source like river contain suspended solids, these suspended solids impart turbidity and colour making the water aesthetically unpleasant. These suspended solids make water unacceptable for specific end use as drinking, industrial water supply, irrigation, including being safely returned to the environment. Therefore, to make water fit for drinking purpose solid separation of particle is required and is done by gravity settling. In this study to understand the phenomenon of gravity settling models for type-1 and type-2 settling were constructed and settling characteristics were analyzed. For the analysis raw water samples from different location were collected. Isoremoval lines for type-2 settling and plot between mass fractions remaining vs. settling velocity for type-1 were drawn, which helped us about knowing the settling characteristics of raw water samples collected from different location.

Keywords: suspended solids, settling, isoremoval.

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CHAPTER 1: INTRODUCTION

1.1GENERAL

Water is essential for all known forms of life. Water covers 71% of the Earth's surface. On Earth, 96.5% water is found in seas and oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapors, clouds, and precipitation. Only 2.5% of this water is freshwater, and 98.8% of that water is in ice caps and glaciers and groundwater [9]. Freshwater from surface sources like rivers contains suspended solid which makes water aesthetically unpleasant and impart turbidity and colour to water. Sedimentation is most commonly used process for the removal of inorganic settleable solids from raw water. The settling tank represents about one-fourth of the total capital cost for treatment plant. Sedimentation and clarification are used interchangeably for potable water, and both refer to the separation of solid material from water. Since most solids have a specific gravity greater than 1, gravity settling is used to remove suspended particles. When specific gravity is less than 1, floatation is normally used [6]. Settling generally depends on particle size, shape and density. Various types of sedimentation exist, based on characteristics and concentrations. Discrete or type-1 settling: particles whose size, shape, and specific gravity do not change over time. Flocculating or type-2 settling: particles that change size, shape and perhaps specific gravity over time. Type-3: hindered settling and type-4: compression settling, mostly in waste water [6]. Above types have both dilute and concentrated suspensions. In dilute suspension, number of particles is insufficient to cause displacement of water (most potable water sources). In concentrated suspension, number of particles is such that water is displaced (most waste waters). The rate at which discrete particles will settle in a fluid of constant temperature is given by the Stokes equation for laminar flow [8] equation1.1.

$$v_t = \frac{g(\rho_p - \rho_w)d^2}{18}\mu \quad \text{... (Equation 1.1)}$$

Where;

g = acceleration due to gravity

ρ_p = density of the particle

ρ_w = density of the water

d = diameter of particle

μ = coefficient of viscosity

However in type-1 settling, direct application of above equation is not often possible in water treatment because the size of particles must be known and the correction factor to account for departure from sphercity has to be determined. In type -2 settling Stokes equation cannot be used because flocculating particles are continually changing in size, shape because of agglomeration of flocculant particle. An indirect method for determining settling characteristics of a suspension was invented by T.R.Camp 1943. Settling column is constructed. Suspension is placed in column and completely mixed and then allowed to settle quiescently [6].

1.2 STUDY AREA

The thesis study proceeds only after samples are collected from certain sampling points. These sampling points were situated in different areas and locations. These different locations constitute our study area. This study area which lies in the Shimla (31.1231° N, 77.6536° E) [9], Solan (31.0498° N, 76.9182° E) [9] and Sirmour district (30.5628° N, 77.4702° E) [9] comprises primarily of two streams i.e. Ashwani and Giri. The sampling points were located at Renuka ji and Gumma shown in fig. 1.1 and fig. 1.2 respectively for Giri River, Sadhupul and Ashwani Khad for Ashwani River shown in fig. 1.3 and fig. 1.4 respectively. As mentioned above the study area is widely spread over the regions of Himachal Pradesh covering three major districts. Likewise the geographical variation in the three districts is also significant, which gives our study a wider scope of analysis for example, the amount of rainfall in the Shimla study area is significantly higher than in the Sirmour district which gives different turbid water conditions for our study.

Fig. 1.1 Location map of Renuka Ji

Source - https://www.google.co.in/maps/@30.6028882,77.4373912,14z

Fig. 1.2 Location map of Gumma

Source- https://www.google.co.in/maps/@31.1189042,77.4798774,15z

Fig. 1.3 Location map of Sadhupul

Source- https://www.google.co.in/maps/@30.9957721,77.1576207,16z

Fig. 1.4 Location of Ashwani Khad

Source- https://www.google.co.in/maps/@31.0731904,77.1544971,17z

1.3OBJECTIVE

1 The initial objective of this study was to design and make a working model for type-1 and type-2 settling.

2 Collection of water samples and determination of the settling characteristics of rivers or river tributary near Jaypee University of information technology, Waknaghat (Distt. Solan, Himachal Pradesh) which are being used for water supply for villages in Shimla, Solan and Sirmaur district.

3 Calculation of removal efficiency of particles present in raw water suspension using the determined settling characteristics for type-1 and type -2 settling.

1.4NEED OF STUDY

Surface water contains impurities like suspended solids, dissolved solids and chemical and biological impurities. Water treatment is required to make water more acceptable for a specific end-use. The end-use may be drinking, industrial water supply, irrigation, river, water recreation or many other uses, including being safely returned to the environment. A clarification step is the first part of conventional treatment for waste and surface water treatment. Clarification includes sedimentation, coagulation-flocculation, and allows the large flocs containing much of the suspended matter to sink to the bottom of clarifier, while the clear water over flows and is then further treated. Clarification of water is removal of turbidity caused by suspended solids to make water aesthetically pleasant, healthy and potable. Sedimentation is most commonly used process for the removal of inorganic settleable solids from raw water. Sedimentation is the physical water treatment process of allowing particles in suspension in water to settle out of the suspension under the effect of gravity. Most solids have a specific gravity greater than 1 and gravity settling is used to remove these suspended particles. When specific gravity is less than 1, sedimentation is done by coagulation and flocculation. Settling generally depends on particle size, shape and density. Two types of sedimentation exist in raw water, based on characteristics and concentrations. Discrete or type 1 settling and flocculating or type 2 settling. The rate at which discrete particles will settle in a fluid of constant temperature is given by the Stokes equation [6] for laminar flow which is not applicable for flocculant particle. Because flocculating particle size increases with depth and time. To determine the settling behavior of flocculating particle settling column were constructed. Raw water suspension allowed to settle quiescently for determination of settling characteristics.

1.5 SCOPE OF PROJECT

This study is limited to determination of settling characteristics by settling column analysis, also the study include the use of only alum as a coagulant. Further, the scope of research in this field includes.

- Determination of settling characteristics by using various other techniques.
- Replacement of coagulant alum by various other natural or chemical coagulants.
- The designed settling column for laboratory study can be of different dimensions which can be used for the same as well as different studies.

CHAPTER 2: LITERATURE REVIEW

2.1GENERAL

The under mentioned literature provides the objective and summary of previous work done in this field.

Chakraborti R.K., Kaur, J. (2014). [1] The objective of research paper is Noninvasive Measurement of Particle-Settling Velocity and Comparison with Stoke's Law. An image-analysis technique was applied for noninvasive measurements of settling rate of polystyrene latex spheres of 6, 10, 20, 50, 100, and 160 µm diameters in a quiescent environment. This technique not only measures the settling rate at any depth in the water column, but it also gives geometric information of the particles. A CCD (charged couple device) camera and strobe light were used to capture insitu images of the particles, which were analyzed using image-analysis software. Particle-settling behavior was not disrupted for any kind of sample handling, and measurements were made without hindering particle settling and allowing particle movement under gravity alone. Measurements were compared with settling rates calculated with Stokes' law, and the validity of Stokes' law under low particle Reynolds number ($R < 0.1$) was investigated for solid and spherical particles. Smaller particles settled at a rate closely predicted by Stokes' law, the larger particles settled slightly more slowly than was predicted.

Swamee, P. K., and Tyagi, A. (1996). [2] The objective of this research paper is Design of Class-1 sedimentation tanks. The present practice for the design of primary settling tanks is based on the overflow rate corresponding to the percentage removal using iso-removal plots. The design procedures would be more rational if based on the removal efficiency and the scour criterion of the deposited particles. This technical note presents closed-form equations for the removal efficiency and scour velocity of particles. The removal efficiency equation considers the size distribution of particles, and the scour velocity equation is based on the Rouse equation. The removal efficiency equation yields the minimum particle size completely removed by the sedimentation tank.

- Design particle size do to provide the required removal efficiency is given by d_o, equation 2.1.

$$d_o = d \times [(0.5m + 1)(1 - \eta_d)]^{\frac{1}{m}}$$ … (Equation 2.1)

Where;

η_d = Design efficiency

d_0 = Design particle size

d_*= Particle-size-distribution parameter

m = Particle-size-distribution parameter

- Scour velocity (V_{sc}), equation 2.2.

$$Vsc = \frac{k(s-1)gd_{sc}^2}{3v}(\frac{Q}{vB})^{0.125}$$ … (Equation 2.2)

Where;

V_{sc} = scour velocity

k = should lie between 0.5 and 0.8.

s = specific gravity of particles

g = gravitational acceleration

v = kinematic viscosity of water

Q = discharge

B = width of settling tank

d_{sc} = scour diameter

Using above equations the design equations is obtained for the length and width of the settling tank. Equation 2.3 is for width and equation 2.4 is for length of tank.

$$B = \frac{3.51Q}{d_0\sqrt{k(s-1)gD}}(\frac{v}{d_0\sqrt{k(s-1)gD}})^{\frac{9}{7}}$$ ... (Equation 2.3)

$$L = 5.31 kD\left(\frac{d_0\sqrt{k(s-1)gD}}{v}\right)^{\frac{2}{7}} \quad \text{… (Equation 2.4)}$$

Besides other parameters, the design equations involve the completely removed minimum particle size, the specific gravity of the sediment particles, and the kinematic viscosity of water. According to this research paper these equations will be useful for the design of grit chambers and settling basins undergoing class-I settling.

Ozer, A. (1994). [3] The purpose of study in this paper is to study of Simple Equations to Express Settling Column Data. Settling-column-test data are analyzed by a traditional-graphical method, which is time consuming. In this study two simple equations are separately fitted to the concentration percentages remaining in suspension. Published data is used to test the applicability of the equations. The equation parameters are statistically significant at the 95% confidence level. The overall removal efficiency is expressed as a function of the equation parameters, depth, and time. The critical-time definition given in this paper can be useful in the experimental planning and the design of settling tanks.

Srivastava, R. M., (1992). [4] The objective of study is Type- II Sedimentation: Removal Efficiency from Column Settling Tests. Removal efficiency from column-settling tests for type II (or flocculent) sedimentation for a given time is commonly evaluated using one of two types of equations available seemingly different forms of the same basic relationship. Proof of these equations establishes their equivalence.

San, H. A., (1939). [5] The objective of study is Analytical Approach for Evaluation of Settling Column Data. In this study, An empirical equation, containing three parameters (a,b and k), for iso-percentage curves is developed for quiescent settling of suspensions. The equation reflects the behavior of iso-percentage curves. Its validity is verified by using the experimental data reported in reliable references. A flocculation coefficient α is also defined by means of these parameters to characterize suspensions. α is equal to zero for discrete particles. For flocculent suspensions α. is within the range of $0 < \alpha < 1$. Values of α are characteristic of a suspension; the larger then α, the more flocculent the suspension. An expression in a convergent series form is obtained in order to determine overall-solids removal efficiency. The proposed technique based on the method of least squares provides a unified procedure to derive iso-percentage curves and to determine the overall solid removal efficiencies. It is not restricted to regions of the settling data and it also minimizes the possible errors.

CHAPTER 3: MATERIAL AND METHODOLOGY

For laboratory studies, jar test, suspended solid test, turbidity, type-1 and type-2 settling for discrete and flocculating particle is done to determine the settling characteristic of raw water suspensions. The suspension to be tested is placed in the column and is mixed completely to ensure uniform distribution of particles. The suspension is than allowed to settle quiescently, laboratory studies for collected water samples is done for 30 minutes and at timed interval of 5 minutes samples are collected form each port provided in settling columns. Then collected samples are tested for settling characteristics.

3.1 COLUMN DESIGN

Two settling columns were constructed for discrete and flocculating settling. Designed settling columns were cylindrical tubes of length 2m and diameter 4 inch each, type-1 settling column is designed with single sampling port 0.2m above from the bottom of column and type-2 settling column is designed with six sampling ports. One port is at distance 0.2 m above the bottom and remaining five ports at distance 30 cm c/c from each other. Layout of settling columns for type-1 and type-2 is shown in Fig 3.1(a) and Fig 3.2(b) and working model constructed on the basis of design is shown in fig 3.2.

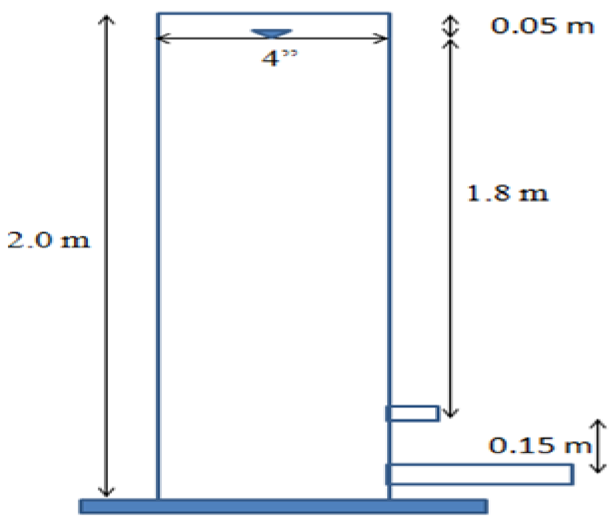

Fig 3.1: (a) Layout for type-1settling column.

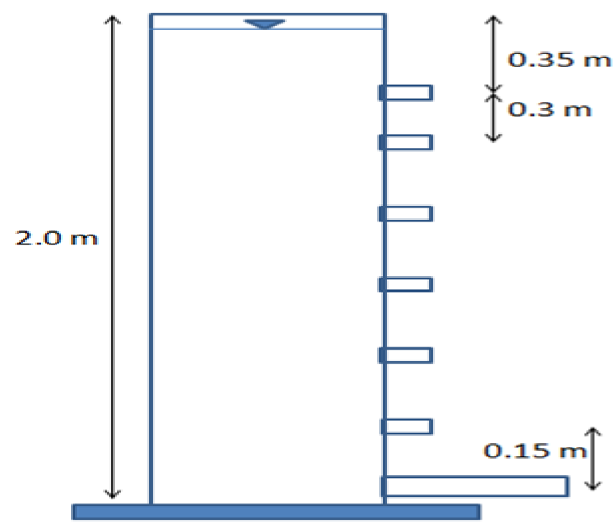

Fig 3.1(b): Layout for type-2 settling column.

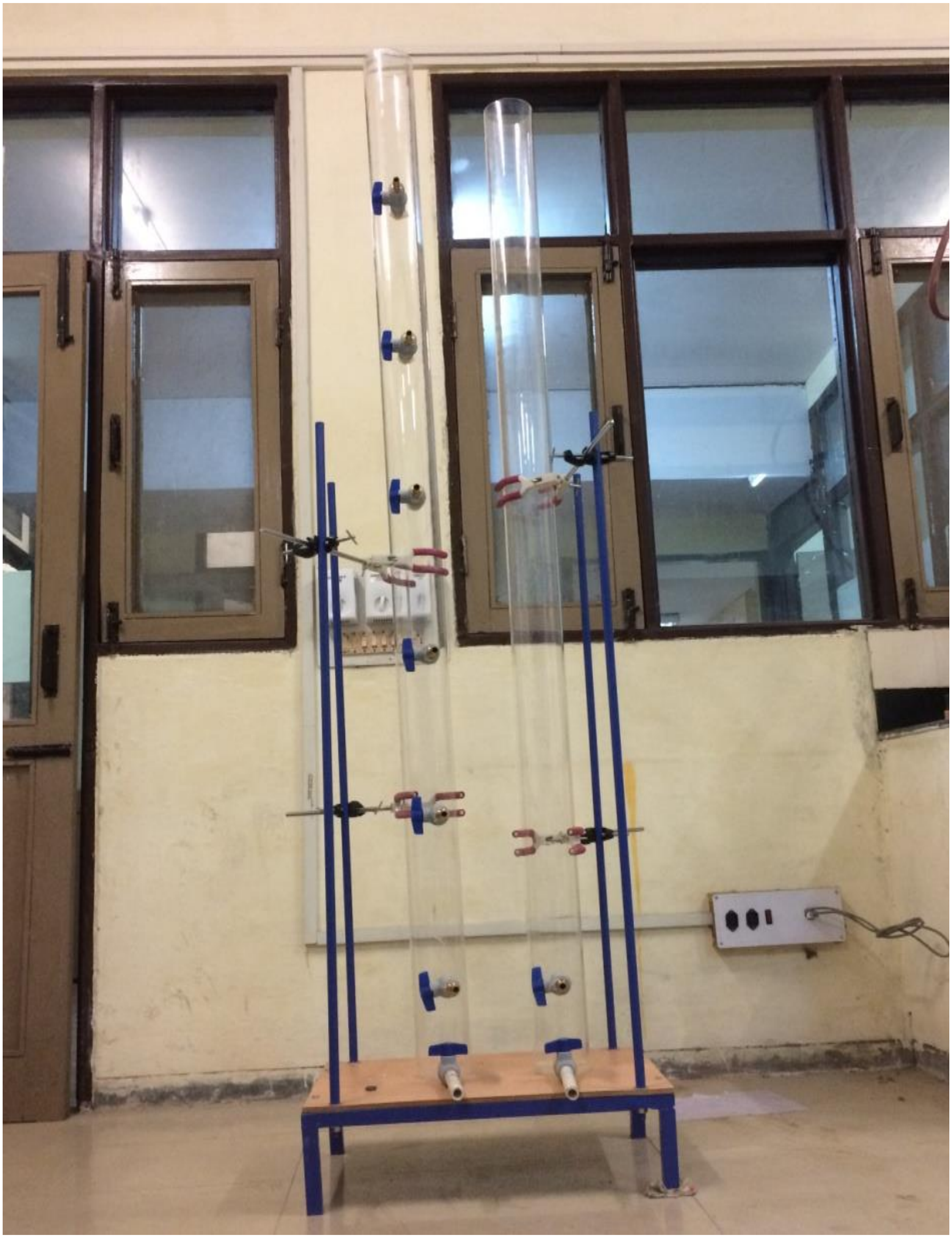

Fig 3.2: Working model of settling columns for laboratory work.

3.2 RAW WATER SAMPLE COLLECTION

Sample of 45 liters from each location for laboratory studies were collected from Hill Rivers “Ashwani” and “Giri” at two different locations. Raw water sample of “Ashwani” river were collected from location “Sadhupul” which is a small village situated in Himachal Pradesh between Solan and Chail and “Ashwani Khad” near Salogra in district Solan Himachal Pradesh. Raw water sample of “Giri” river were collected from location “Gumma” village in Jubbal Kotkhai Tehsil in Shimla District and “Renuka Ji” in Sirmour District of Himachal Pradesh

3.3 LABORATORY STUDY

To determine the settling characteristics of raw water jar test, type-1 settling and type-2 settling, suspended solid test, jar test, turbidity and filtration are performed to determine settling characteristics of raw water suspension. Volume of sample collected from each location is 45L, for laboratory study collected sample is uniformly mixed to get random distribution of particles in suspension and then allowed to settle quiescently in designed working models of 4 inch diameter and 2 meter length.

3.3.1 JAR TEST

Jar testing is a small scale preliminary study test of the treatment chemicals used to simulates the coagulation/flocculation process in a water treatment plant and helps operators determine if they are using the right amount of treatment chemicals, and thus, improves the plant’s performance. For jar test treatment chemical used is alum ($Al_2 (SO_4)_3.16H2O$). Fig 3.3 shows the jar test performed in laboratoy.

PROCEDURE

Jar test is performed by filling the beakers with raw water sample (1000 ml). Usually jar test is performed by using 6 beakers .Add different doses of the selected coagulant alum i.e., 1 ml, 2 ml, 3 ml, 4 ml, 5 ml to different Beaker simultaneously. For this 1% alum solution is prepared by adding 10mg alum to 1000 ml water. Rapid mix each jars at 100 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container. Reduce the stirring speed to 40 rpm and continue mixing for 10 minutes. Turn off the mixers and allow 20 minutes for settling. Then supernatant from each jar is tested for turbidity using apparatus turbidity meter.

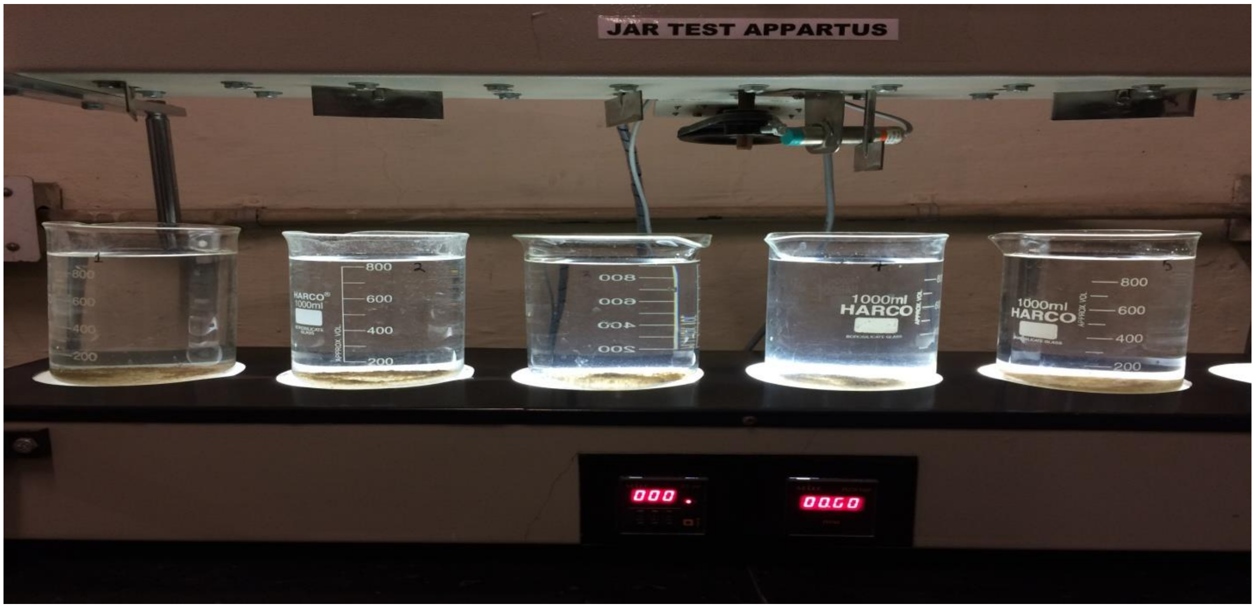

Fig 3.3: Jar Test apparatus.

After calculating turbidity of supernatant from each jar graph between turbidity on y-axis and alum dosage on x-axis plotted which gives the optimum dosage of the coagulant showing least turbidity for excellent flock formation.

3.3.2 SETTLING

Raw water constitutes of discrete and flocculating particle .Settling of discrete particle is known as type-1 settling, which is also called primary sedimentation. Settling of flocculating particle is known as type-2 settling and also known as secondary sedimentation. In type-1 settling discrete particles settles independently and there is no change in size of particle. Thus, settling velocity for discrete particle remains constant. In flocculant settling, flocculant particle forms flocs and get bigger in size. Thus, the settling velocity of flocculant particle increases with depth. Concentration calculations were done by passing the samples through whatman filter paper and weighing the suspended solids after oven drying the filter paper at 100 to 103 degree Celsius

3.3.2.1 DISCRETE SETTLING, TYPE-1

In discrete settling, particle present in suspension settle separately without interaction with other nearby particle. In this type of settling specific gravity of particles do not change with time thus settling velocity of particle remains constant. Fig 3.4 shows the type -1 settling performed in laboratory by using designed working model.

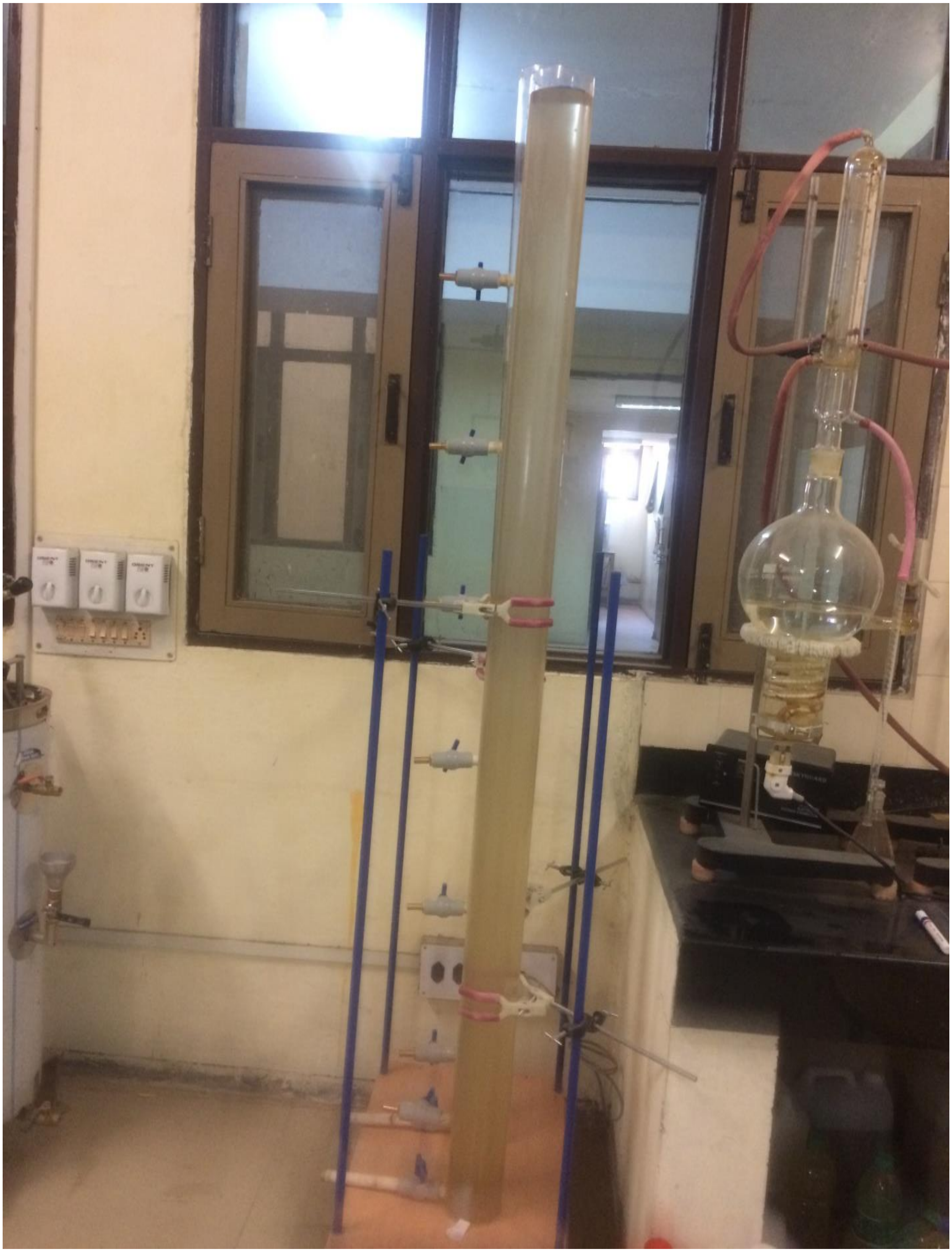

Fig 3.4: Type-1 settling.

THEORY

Suspension to be tested is mixed completely to ensure uniform distribution and is placed in the column for quiescent settling. Shown in fig.3.5.

Particle placed at the surface has an average settling velocity of:

$$V_0 = \frac{\text{distance travelled}}{\text{time of travel}} = \frac{Z0}{t0} \qquad \text{… (Equation 3.1)}$$

Another particle placed at distance Zp, terminal settling velocity less than the surface particle V_0, but arrives at the same time, has a settling velocity of

$$V_p = \frac{Zp}{tp} \qquad \text{… (Equation 3.2)}$$

Thus, the travel time for both particles is equal, where $t_0 = Z_o/v_o = Z_p/v_p$ and $v_p/v_o = Z_p/Z_o = h/H$ Thus some generalized statements can be made on the basis of above equation.

1. All particles having a diameter equal to or greater than d_o, i.e. have settling velocity greater than v_0, will arrive at or pass the sampling port in time t_o.
2. Particle with diameter $d_p < d_0$ will have a settling velocity $v_p < v_o$, will arrive at or pass the sampling port in time t_0, provided its position is at or below Z_p.
3. If the suspension is uniformly mixed, i.e. particles are randomly distributed. Then the fraction of particles with size d_p having settling velocity v_p which will arrive at or pass the sampling port in time t_o will be $Z_p/Z_o = v_p/v_o$. Thus, the removal efficiency of any size particle from suspension is the ratio of the settling velocity of that particle to the settling velocity v_o defined as Z_o/t_o.

PROCEDURE

For type-1 settling analysis in laboratory initial concentration C_o of completely mixed suspension at time zero is determined by suspended solid test. Time interval for taking out sample from type-1settling column is selected as 5 minutes. Measure C_1 at time t_1 equal to 5 minutes. All particles comprising C_1 have a settling velocity less than Z_o/t_1, where $v_1 = Z_o/t_1$. Thus, the mass fraction of particles removed with $v_1 < Z_o/t_1$ is given by $x = C_1/C_o$. Process is repeated seven times as duration of test is selected as 30 minutes, with x_i always being the mass fraction of particles being $v_i < Z_o/t_i$.

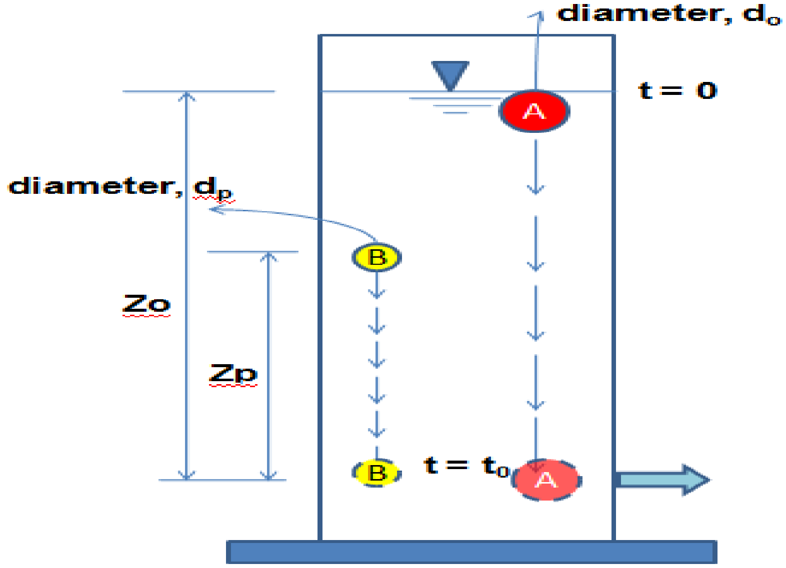

Fig.3.5: Settling column for analyzing type 1 suspension.

These values are then plotted on a graph to obtain Fig.3.6, where the fraction of particles remaining for any settling velocity can be determined.

1. For any detention time t_o, an overall percent removal (X) can be obtained, i.e. all particles having a settling velocity greater that $v_o = Z_o/t_o$, will be removed 100%, un-hatched area in Fig.3.6. Thus, $1 - x_o$ particles are completely removed in time t_o. The remaining particles have a $v_i < v_o$, hatched area in Fig.3.6 and will be removed according to ratio v_i/v_o.
2. If the equation relating v and x are known, then the area can be found through integration using Equation3.3 or Equation 3.4 , where X is the total mass fraction removed by sedimentation.

$$X = 1 - x_o + \int_0^{x0} \frac{v_i}{v_o} dx \qquad \text{… (Equation 3.3)}$$

$$X = 1 - x_o + \sum(\Delta x \cdot v_i)/v_o \qquad \text{… (Equation 3.4)}$$

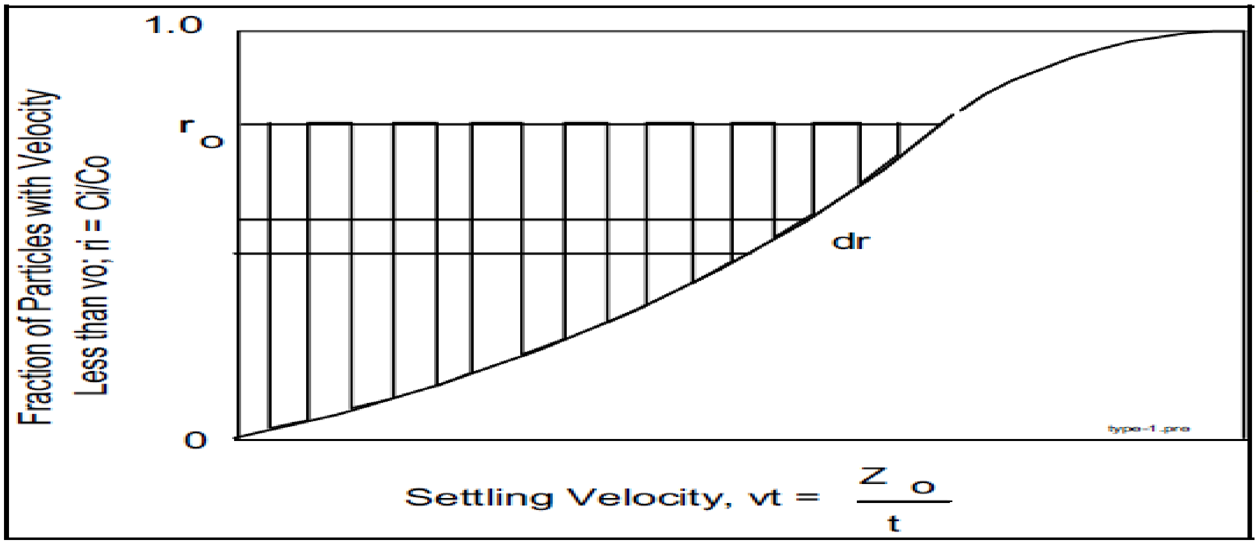

Fig.3.6: Removal efficiency as a function of settling time.

3.3.3 FLOCCULANT SETTLING, TYPE-2

In type -2 settling, settling of flocculant particles in suspensions takes place, particle settle and coalesces with other particles, the sizes of particles and their settling velocity increases. The analysis of settleability of a flocculating suspension is similar to analysis for discrete particle suspension. The only difference is that sampling ports are provided at several depths. Laboratory study of type-2 settling is shown in fig. 3.7.

PROCEDURE

Samples which are drawn at at several depths, analyzed for suspended solid concentration. These concentrations are then used to compute mass fractions removed at each depth and each time.

$$x_{ij} = \left(1 - \frac{\mathrm{Cij}}{Co}\right) X\ 100 \qquad \text{… (Equation 3.4)}$$

Where, x_{ij} is the mass fraction in present that is removed at the ith depth at the jth time interval. These values are graphed as shown in Fig.3.8 and isoremoval lines are drawn. The slope at any point on any isoremoval line is the instantaneous velocity of the fraction of particle represented by that line. Overall removal efficiency is calculated by equation 3.5.

$$R = ro + \sum \frac{\Delta \mathrm{r\ x\ Zi}}{1.8} \qquad \text{… (Equation 3.5)}$$

Fig 3.7: Type-2 settling.

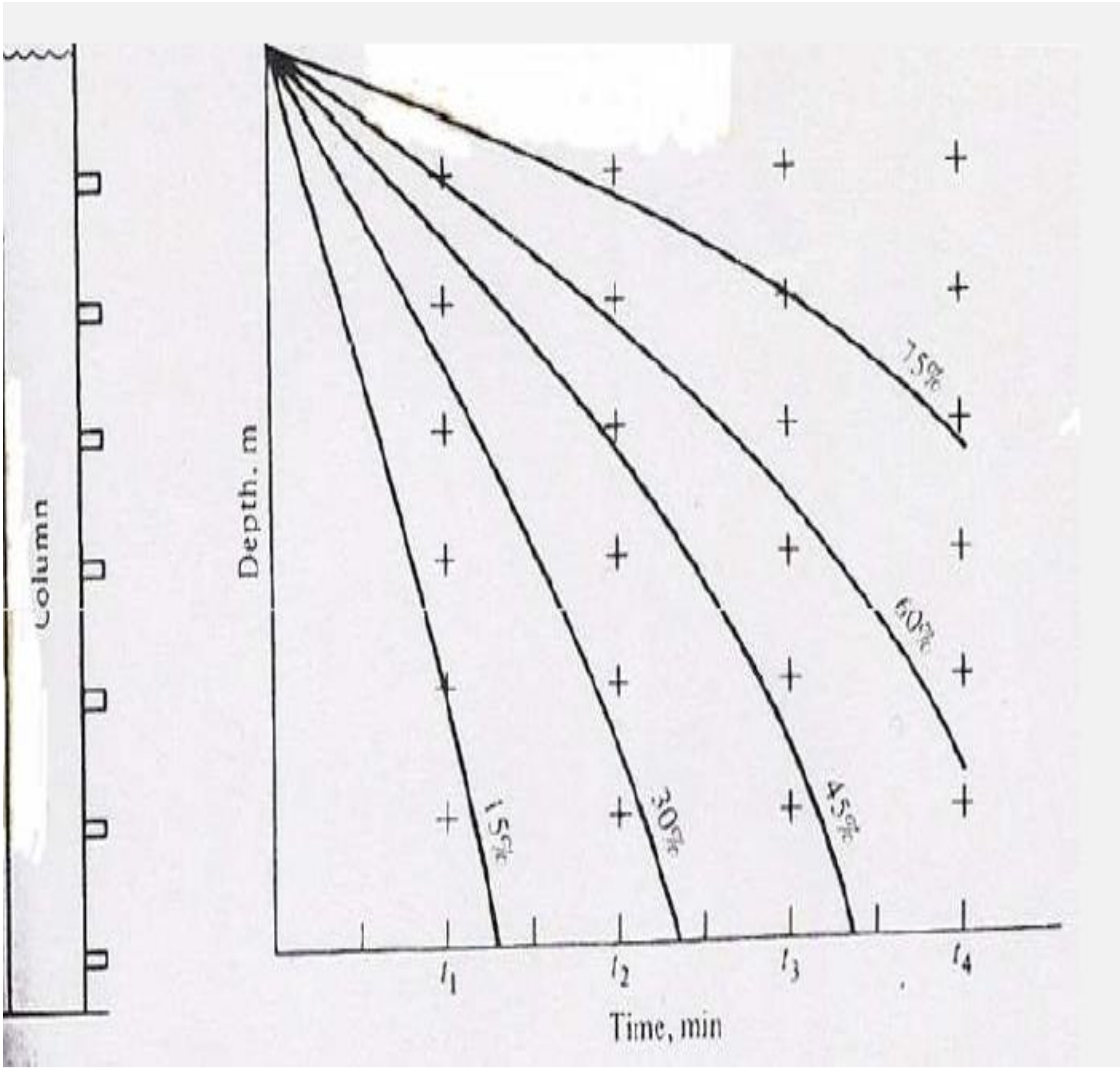

Fig 3.8: Isoremoval lines from settling analysis.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 JAR TESTS

Jar test gives optimum coagulant dosage for effective flock formation. Coagulant used in this research is Alum ($Al_2 (SO_4)_3$.16H2O) and optimum dosage of Alum for different sampling locations are given in table 4.1.

4.1.1 RESULTS AND DISCUSSION

Table 4.1 Jar test results for different locations

Location of sample	Optimum alum dosage
Renuka ji (Giri River)	5 ml/l
Sadhupul (Ashwani River)	4 ml/l
Gumma (Giri River)	5.2 ml/l
Ashwani khad (Ashwani khad)	4.1 ml/l

a) RENUKA JI (GIRI RIVER)

Table 4.2 Alum dosage and corresponding turbidity for location Renuka ji (Giri River)

Jar No.	Alum Dosage(ml/l)	Turbidity (NTU)
1	1	4
2	2	3
3	3	2
4	4	1
5	5	0
6	6	3

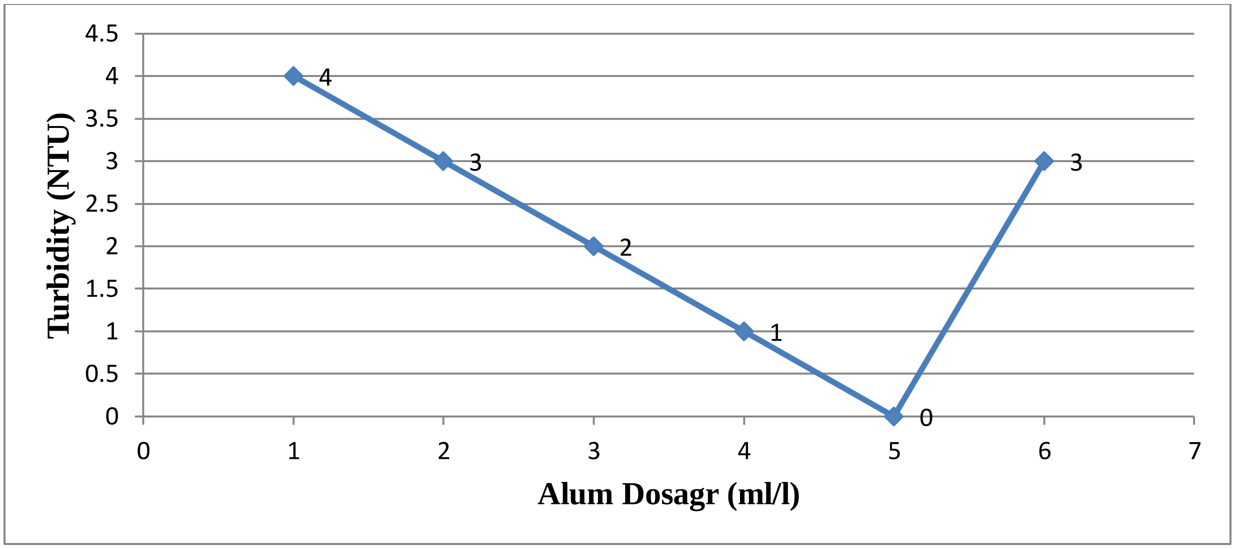

Fig 4.1 plot between alum dosage and turbidity for sampling location Renuka Ji (Giri river) showing optimum dosage.

- Optimum alum dosage from graph is 5 ml/l because at dosage of 5 ml/l turbidity is minimum as there is no residual alum. After more addition of alum up to 6ml/l turbidity increased to 3 NTU due to the presence of residual alum.

b) SADHUPUL (ASHWANI RIVER)

Table 4.3 Alum dosage and corresponding turbidity for location Sadhupul (Ashwani River)

Jar No.	Alum Dosage(ml/l)	Turbidity (NTU)
1	0.5	9
2	1	8
3	1.5	7
4	2	6
5	2.5	5
6	3	3
7	3.5	1
8	4	0
9	4.5	2
10	5	3

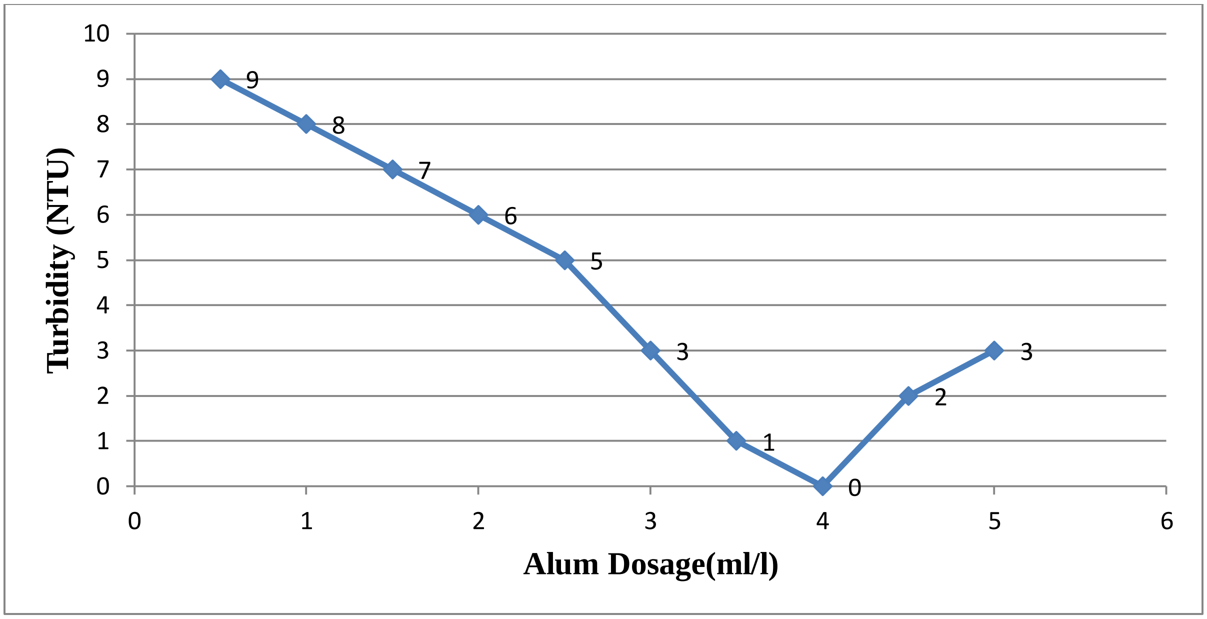

Fig 4.2 plot between alum dosage and turbidity for sampling location Sadhupul (Ashwani River).

- Optimum alum dosage from graph is 4 ml/l, because at dosage of 4 ml/l turbidity is minimum as there is no residual alum. After more addition of alum up to 5ml/l turbidity increased to 3 NTU due to the presence of residual alum only.

c) GUMMA (GIRI RIVER)

Table 4.4 Alum dosage and corresponding turbidity for location Gumma (Giri River)

Jar No.	Alum Dosage(ml/l)	Turbidity (NTU)
1	1	10
2	2	9
3	3	7
4	4	5
5	5	2
6	6	3
7	7	4
8	8	6

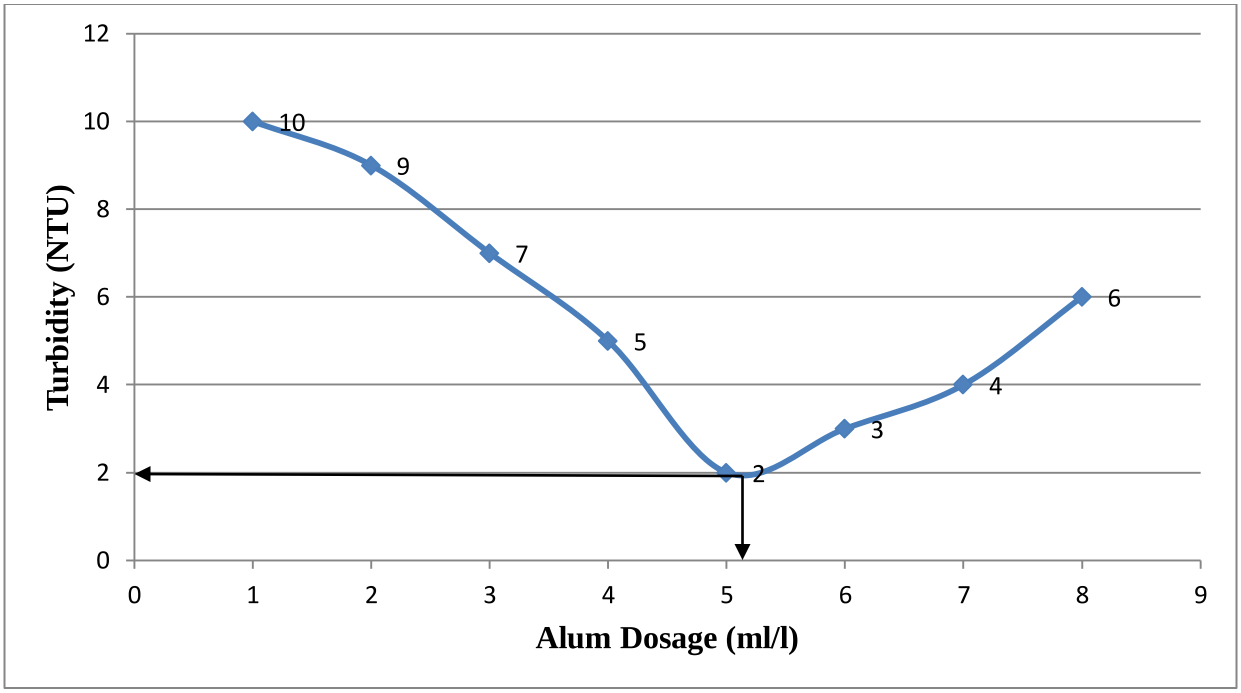

Fig 4.3 plot between alum dosage and turbidity for sampling location Gumma (Giri River).

- Optimum alum dosage from graph is 5.2 ml/l, because at dosage of 5.2 ml/l turbidity is minimum and is near to 2 NTU. After more addition of alum up to 8ml/l turbidity increased to 6 NTU due to the presence of residual alum and remained fine particles.

d) ASHWANI KHAD (ASHWANI RIVER)

Table 4.5 Alum dosage and corresponding turbidity for location Ashwani Khad (Ashwani River)

Jar No.	Alum Dosage(ml/l)	Turbidity (NTU)
1	1	8
2	2	6
3	3	5
4	4	2
5	5	3
6	6	4

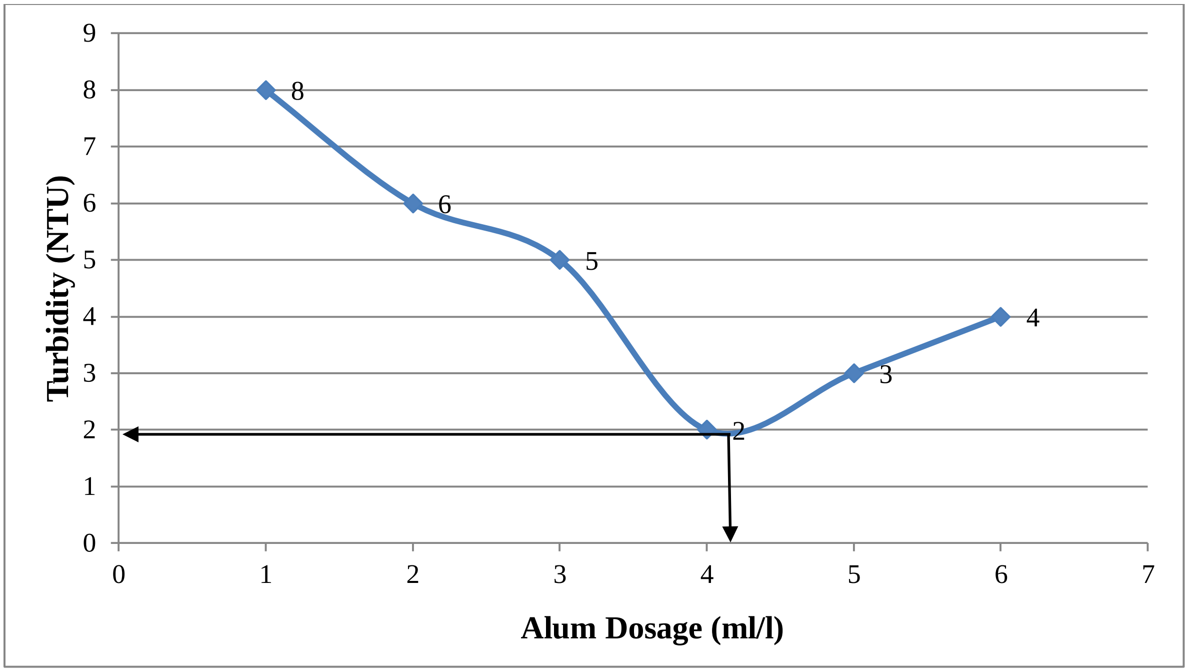

Fig 4.4 plot between alum dosage and turbidity for sampling location Ashwani Khad (Ashwani River).

- Optimum alum dosage from graph is 4.1 ml/l. Optimum alum dosage from graph is 4.1 ml/l, because at dosage of 4.1 ml/l turbidity is minimum and is near to 2 NTU. After more addition of alum up to 6 ml/l. Turbidity increased to 6 NTU due to the presence of residual alum and remained fine particles.

4.2 DISCRETE SETTLING, TYPE-1

In type-1 settling sedimentation of discrete particle present in water suspension takes place by gravitational force when suspension is allowed to settle quiescently.

4.2.1 RESULTS AND DISCUSSION

Results of type-1 settling for different sampling locations are given as follows:

a) RENUKA JI (GIRI RIVER)

Calculation of mass fraction remaining for type-1 analysis is shown in TableA.2, Annexure A.

Table 4.6 Mass fraction remaining and corresponding settling rate for location Renuka ji (GiriRiver)

Time, min	Conc, mg/l	mass fraction remaining	velocity, m/min X 10^{-1}
0	265	1	
5	195	0.91	3.6
10	159	0.74	1.8
15	132	0.6	1.2
20	117.5	0.5	0.9
25	109.5	0.44	0.72
30	104	0.41	0.6

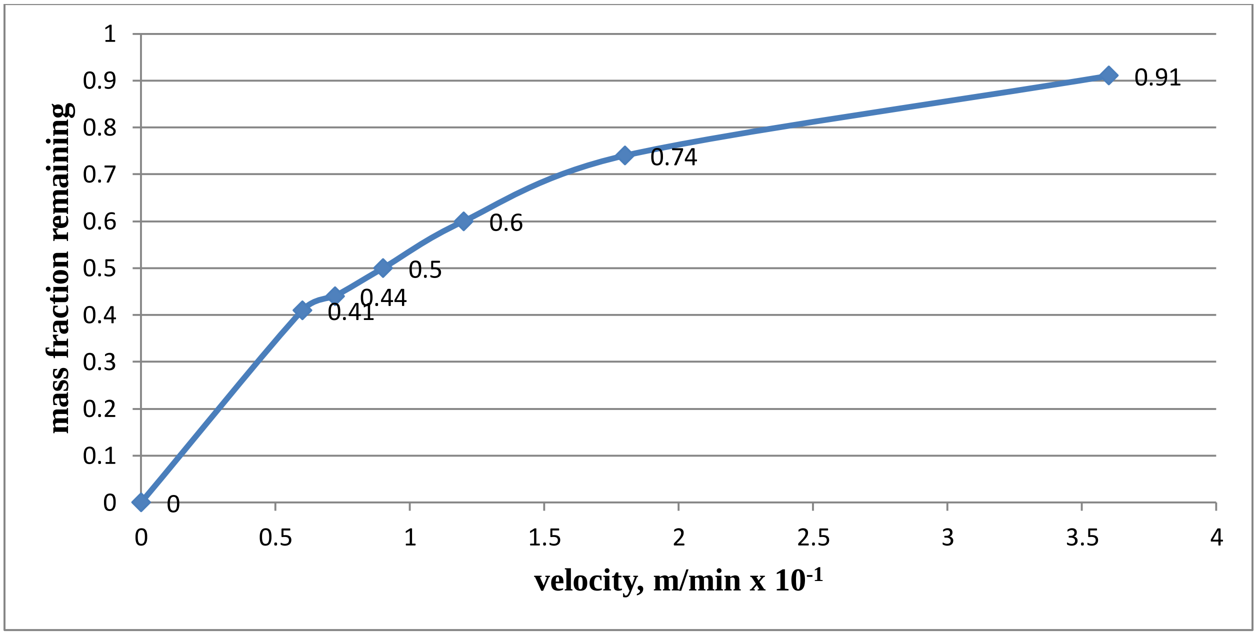

Fig 4.5 Plot between mass fraction remaining and settling velocity for location Renuka ji (Giri River).

From fig 4.5, determining overall efficiency(X) at settling velocity ($v_{o)}$ = 1.5 and x_o = 0.32

The value of $\sum(\Delta x \,.\, v_i)$ = 0.3436, Table A.3, Annexure A

$$X = 1 - x_o + \sum(\Delta x \cdot v_i)/v_o$$

$$= 0.68 + 0.3436/1.5$$

$$= 90.90\ \%$$

Removal efficiency at time t=12 min, v_o is .15 m/min. Overall removal efficiency of system is 90.90 %. Particles have settling velocity equal or more than v_o will be removed 100 %. particles having settling velocity less than v_o will be partially removed.

b) SADHUPUL (ASHWANI RIVER)

Calculation of mass fraction remaining for type-1 analysis is shown in Table B.2, Annexure B.

Table 4.7 Mass fraction remaining and corresponding settling rate for location Sadhupul (Ashwani River)

Time, min	Conc, mg/l	Mass fraction remaining	velocity, m/min X 10^{-1}
0	212.5	1	
5	192	0.9	3.6
10	132.5	0.62	1.8
15	104.5	0.49	1.2
20	84	0.4	0.9
25	79	0.37	0.72
30	72.5	0.34	0.6

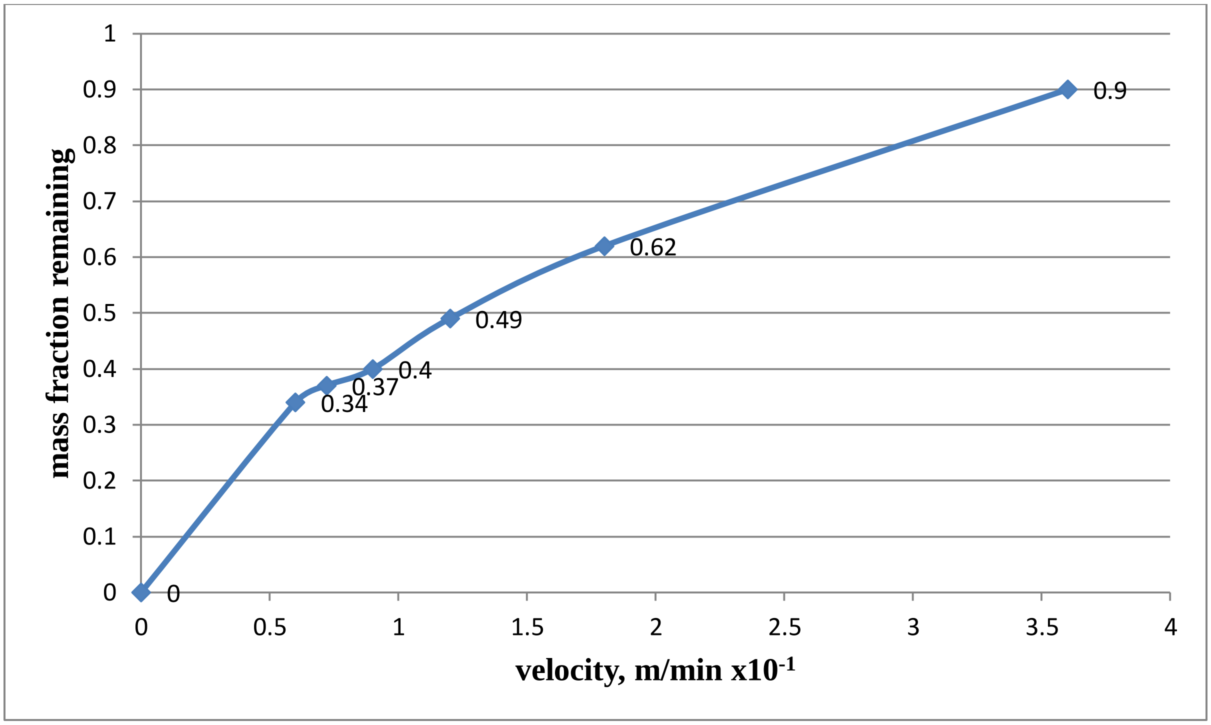

Fig 4.6 Plot between mass fraction remaining and settling velocity for location Sadhupul (Ashwani River).

From Fig. 4.6, Determining Overall efficiency (X) at settling velocity ($v_{o)}$ = 1.5 and x_o = 0.32

The value of $\sum(\Delta x \,.\, v_i)$ = 0.1732, Table B.3, Annexure B

$$X = 1 - x_o + \sum(\Delta x \,.\, v_i)/v_o$$

$$= 0.68 + 0.1732/1.5$$

$$= 79.55\ \%$$

Removal efficiency at time t=12 min, v_o is .15 m/min. Overall removal efficiency of system is 79.55 % . Particles have settling velocity equal or more than v_o will be removed 100 %. particles having settling velocity less than v_o will be partially removed.

c) GUMMA (GIRI RIVER)

Calculation of mass fraction remaining for type-1 analysis is shown in Table D.2, Annexure D.

Table 4.8 Mass fraction remaining and corresponding settling rate for location Gumma (Giri River)

Time, min	Conc, mg/l	mass fraction remaining	velocity, m/min X 10
0	250	1	
5	192	0.9	3.6
10	132.5	0.62	1.8
15	104.5	0.49	1.2
20	84	0.4	0.9
25	79	0.37	0.72
30	72.5	0.34	0.6

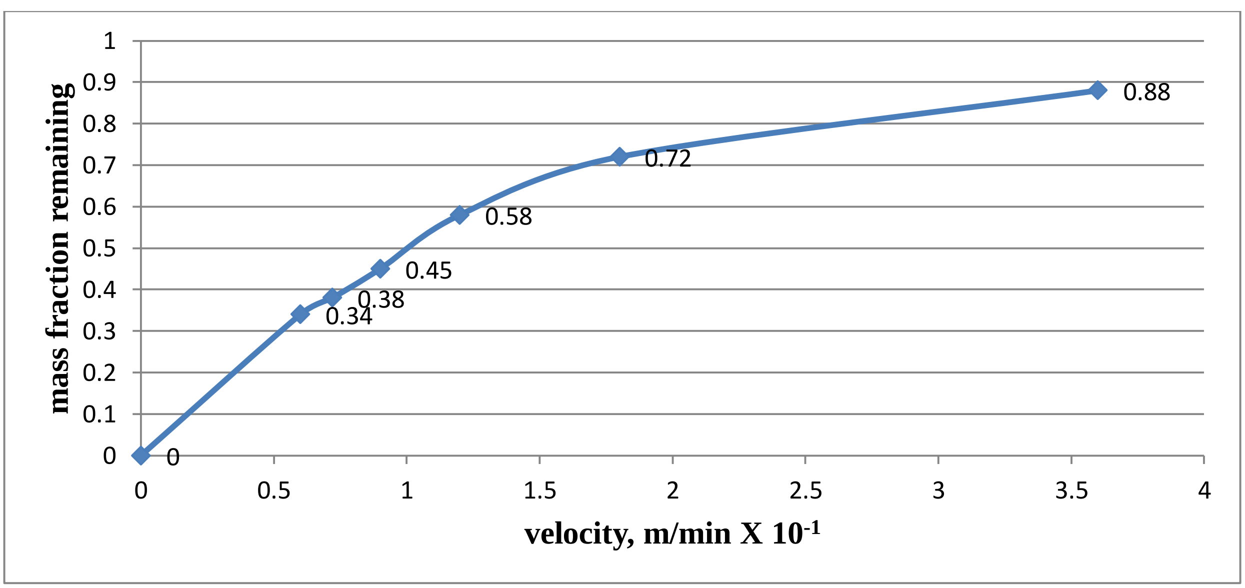

Fig 4.7 Plot between mass fraction remaining and settling velocity for location Gumma (Giri River).

Determining Overall efficiency at settling velocity (v_{o}) = 1.5 and x_o at v_o = 0.32

The value of $\sum(\Delta x \cdot v_i)$ = 0.426385, Table D.3, Annexure D

$$X = 1 - x_o + \sum(\Delta x \cdot v_i)/v_o$$

$$= 0.68 + 0.426385/1.5$$

$$= 96.4\ \%$$

Removal efficiency at time t=12 min, v_o is .15 m/min. Overall removal efficiency of system is 96.40 %. Particles have settling velocity equal or more than v_o will be removed 100 %. Particles having settling velocity less than v_o will be partially removed.

d) ASHWANI KHAD (ASHWANI RIVER)

Calculation of mass fraction remaining for type-1 analysis is shown in Table C.2, Annexure C

Table 4.9 Mass fraction remaining and corresponding settling rate for location Gumma (Giri River)

Time, min	Conc, mg/l	mass fraction remaining	velocity, m/min X 10
0	250	1	
5	173	0.84	3.6
10	135	0.66	1.8
15	100	0.49	1.2
20	67	0.33	0.9
25	51	0.25	0.72
30	41	0.2	0.6

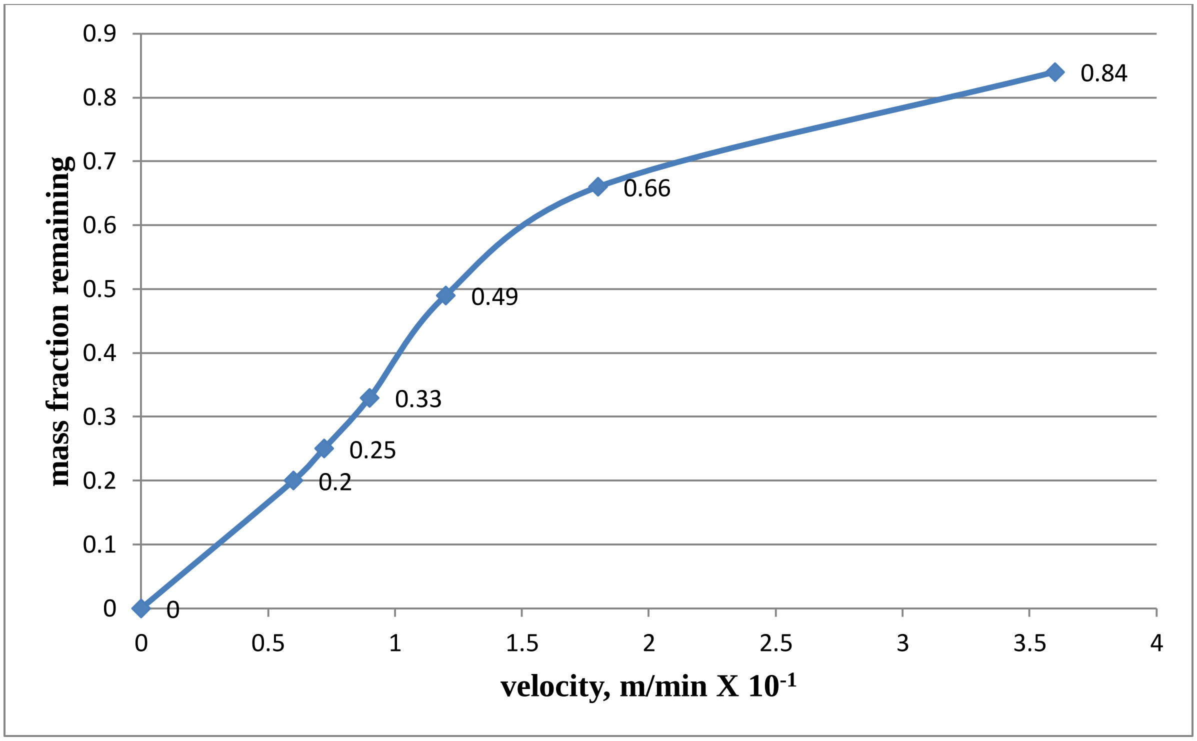

Fig 4.8 Plot between mass fraction remaining and settling velocity for location Ashwani Khad (Ashwani River).

From Fig 4.8, Determining Overall efficiency at settling velocity (v_{o}) = 1.5 and x_o = 0.32

The value of $\sum(\Delta x \,.\, v_i)$ = 0.1676, Table C.3, Annexure C

$$X = 1 - x_o + \sum(\Delta x \,.\, v_i)/v_o$$

$$= 0.68 + 0.1676/1.5$$

$$= 79.17\ \%$$

Removal efficiency at time t=12 min, v_o is .15 m/min. Particles have settling velocity equal or more than v_o will be removed 100 % and particles having settling velocity less than v_o will be partially removed. Overall removal efficiency of system is 79.17 %.

4.3 FLOCCULANT SETTLING, TYPE-2

In type-2 settling, sedimentation of flocculant particles takes place by agglomeration of flocculant particles. Agglomeration of particles raises the size of particle which leads to increase in settling velocity.

4.3.1 RESULTS AND DISCUSSION

Results of type-2 settling for different sampling location are given as follows:

a) RENUKA JI (GIRI RIVER)

Calculation of removal rate of particle is given in Table A.1, Annexure A.

Table 4.10 Removal rate of particles present in water suspension at each depth and time for location Renuka ji (Giri River)

Depth, m	Time of sampling, min					
	5	10	15	20	25	30
0.3	0.3	41.7	64.91			
0.6	0.6	37.74	50.19	73.91	82.26	
0.9	0.9	26.98	45.28	66.04	75.66	82.45
1.2	1.2	17.92	39.81	60.75	72.08	77.36
1.5	1.5	16.79	34.53	50.38	66.23	73.96
1.8	1.8	11.7	29.62	44.15	63.02	70

Removal efficiency at time 15 min, $R = \mathrm{ro} + \sum \frac{\Delta r \times Zi}{1.8} R$

The value of $\sum(\Delta r \times Zi)$ = 0.5392, Table A.4, Annexure A

Where, r_o is .4459 as 44.59 % iso removal line meets at 15 minutes in x-axis.

$$= .4459 + \sum \frac{0.5392}{1.8}$$

$$= 74.54\ \%$$

The Slope of isoremoval line as shown in fig. 4.9 at any point gives the instantaneous velocity of fraction of particles represented by that line. Slope of isoremoval line become steeper at greater depth, shows that velocity becomes greater at greater depth. This is because of the increase in the particle size due to flocculation in the raw water suspension which causes continued collision and aggregation with other particles. For assumed detention time of 15 minutes removal efficiency is 74.54%.

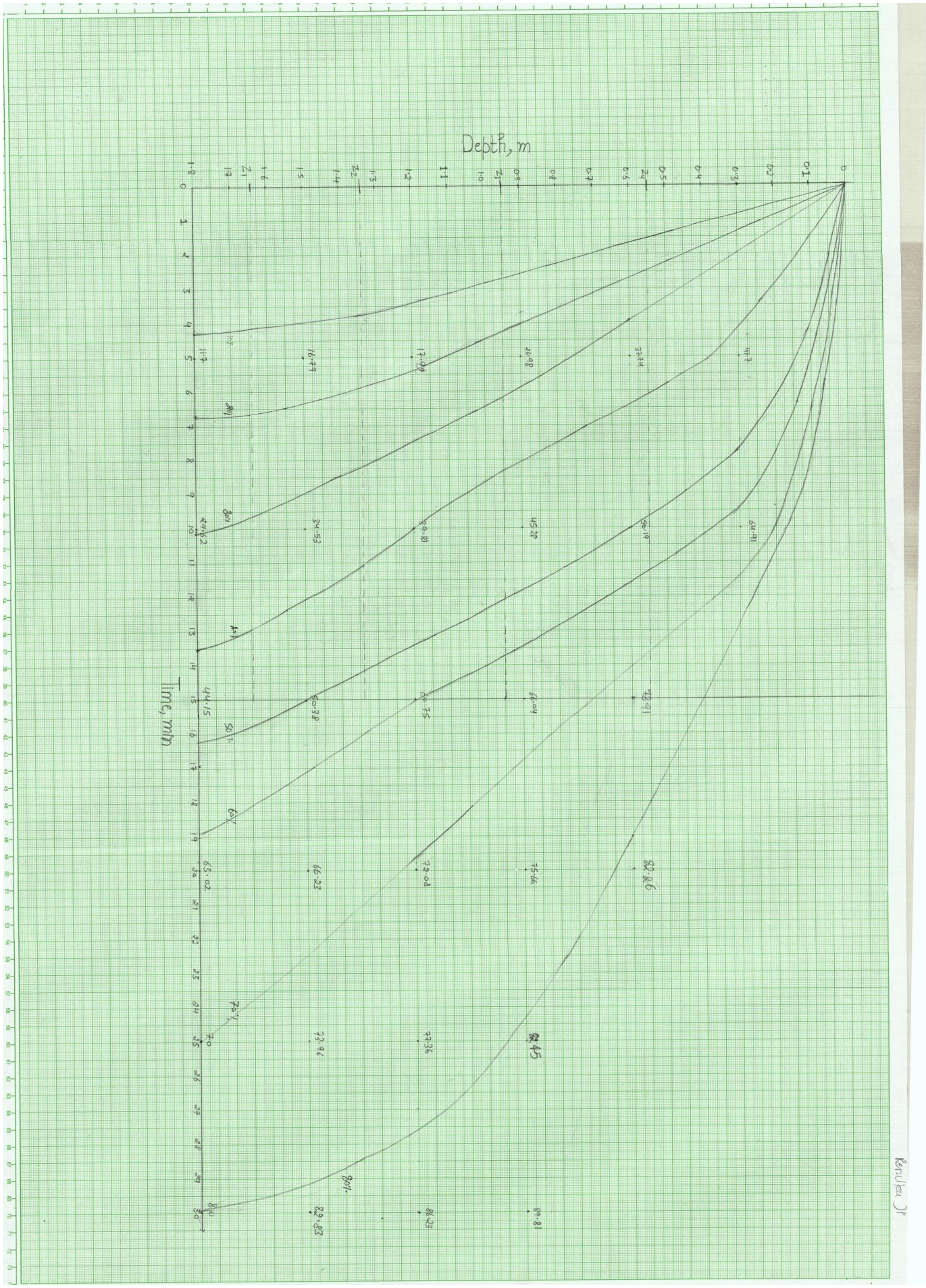

Fig4.9 Isoremoval lines from settling analysis for Renuka ji (Giri River).

b) SADHUPUL (ASHWANI RIVER)

Calculation of removal rate of particle is given in Table B.1, Annexure B..

Table 4.11 Removal rate of particles present in water suspension at each depth and time for location Sadhupul (Ashwani River)

Depth, m	Time of sampling, min					
	5	10	15	20	25	30
0.3	50.35	64.47				
0.6	40.71	48.47	60.71	71.53		
0.9	38.59	43.53	54.12	68.71	74.12	84.71
1.2	26.82	36.94	51.76	65.65	69.88	79.76
1.5	15.76	21.41	37.88	53.41	66.12	75.53
1.8	10.12	19.53	34.59	49.65	60.47	67.76

Removal efficiency at time 15 min, is calculated by equation [6] $R = ro + \sum \frac{\Delta r \text{ x } Zi}{1.8}$

The value of $\sum(\Delta r \text{ x } Zi)$ = 0.37546, Table B.4, Annexure B

Where, r_o is .3459 as 34.59 % iso removal line meets at 15 minutes in x-axis.

$$= .3459 + \sum \frac{0.37546}{1.8}$$

$$= 55.45\%$$

The Slope of isoremoval line as shown in fig. 4.10 at any point gives the instantaneous velocity of fraction of particles represented by that line. Slope of isoremoval line become steeper at greater depth, shows that velocity becomes greater at greater depth. This is because of the increase in the particle size due to flocculation in the raw water suspension which causes continued collision and aggregation with other particles. For assumed detention time of 15 minutes removal efficiency is 55.45%.

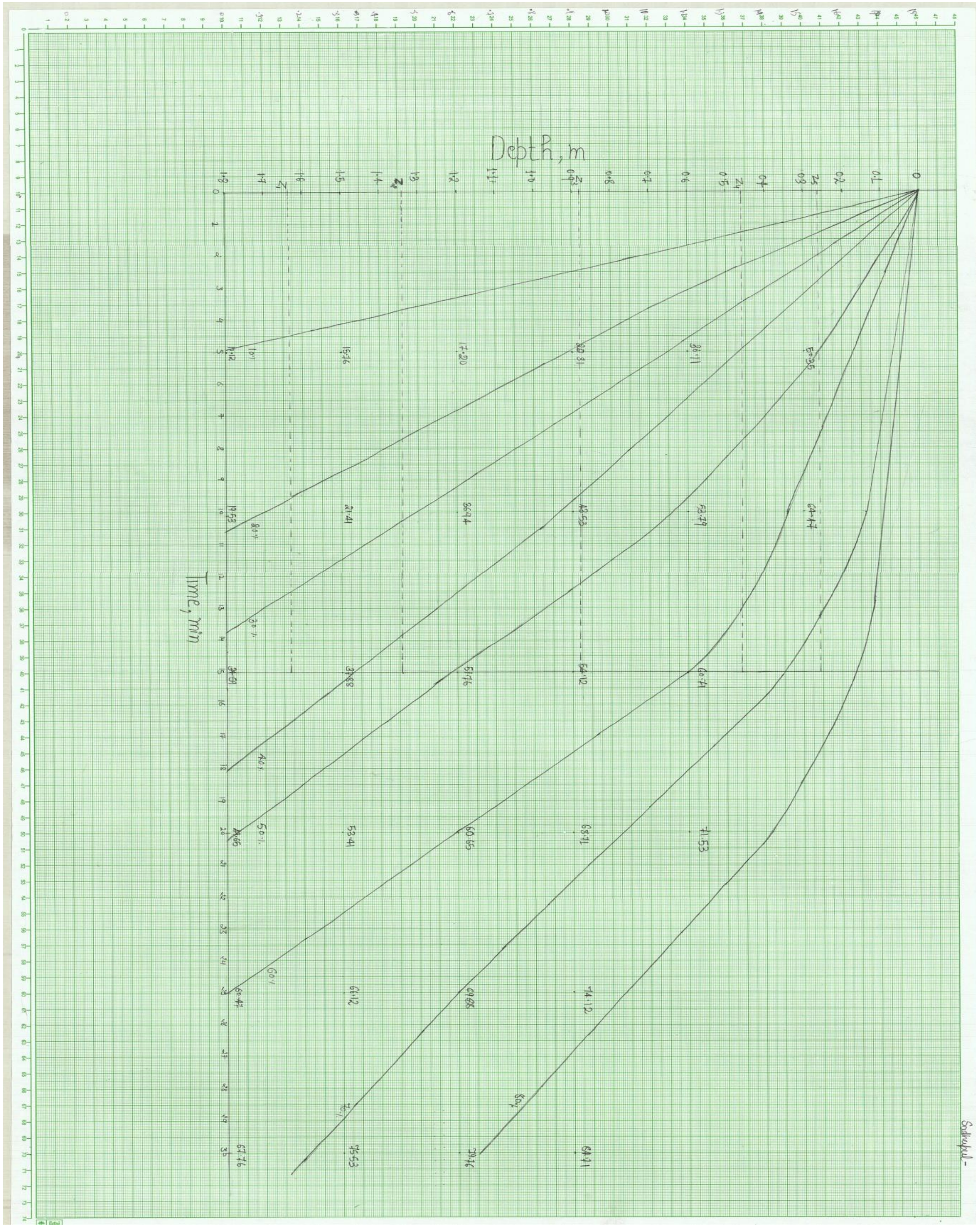

Fig4.10 Isoremoval lines from settling analysis for Sadhupul (Ashwani River).

c) GUMMA (GIRI RIVER)

Calculation of removal rate of particle is given in Table D.1, Annexure D.

Table 4.12 Removal rate of particles present in water suspension at each depth and time for location Gumma (Giri River)

Depth, m	Time of sampling, min					
	5	10	15	20	25	30
0.3	40.4	60.8				
0.6	22.4	42.8	54.4	66		
0.9	12.8	34	47.2	58.4	67.6	72.4
1.2	8.8	26	38	48	56	64
1.5	6	22	36	44.8	52.8	60.8
1.8	4	18.8	32	40.8	48.8	56

Removal efficiency at time 15 min, is calculated by equation [6] $R = ro + \sum \frac{\Delta r \text{ x } Zi}{1.8}$

Where, r_o is .32 as 32% iso removal line meets at 15 minutes in x-axis.

The value of $\sum(\Delta r \text{ x } Zi) = 0.506$, Table D.4, Annexure D

$$=.32 + \sum \frac{0.506}{1.8}$$

$$= 60.11\ \%$$

The Slope of isoremoval line as shown in fig. 4.11 at any point gives the instantaneous velocity of fraction of particles represented by that line. Slope of isoremoval line become steeper at greater depth, shows that velocity becomes greater at greater depth. This is because of the increase in the particle size due to flocculation in the raw water suspension which causes continued collision and aggregation with other particles. For assumed detention time of 15 minutes removal efficiency is 60.11%.

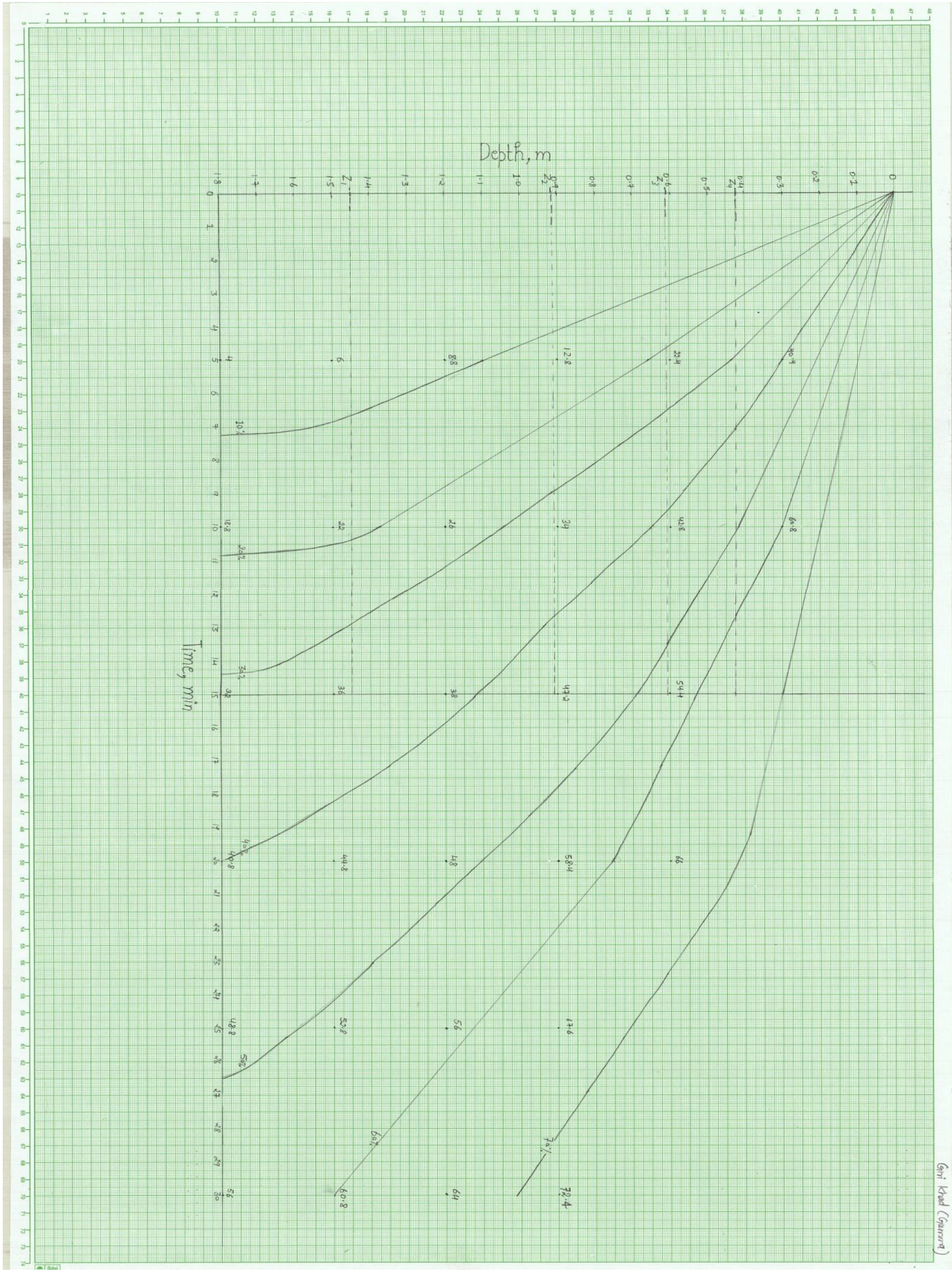

Fig4.11 Isoremoval lines from settling analysis for Gumma (Giri River).

d) ASHWANI KHAD (ASHWANI RIVER)

Calculation of removal rate of particle is given in Table C.1, Annexure C.

Table 4.13 Removal rate of particles present in water suspension at each depth and time for location Ashwani Khad (Ashwani River)

Depth, m	Time of sampling, min					
	5	10	15	20	25	30
0.3	66	86				
0.6	47.2	69.2	82	93.2		
0.9	38	59.2	72	82	91.2	96
1.2	28.8	46.8	60	70	78	86
1.5	26	42.4	56.4	65.2	77.2	85.2
1.8	28	42.8	56	64.8	72.8	80

Removal efficiency at time 15 min, is calculated by equation 3.5 [6] $R = ro + \sum \frac{\Delta r \text{ x } Zi}{1.8}$

Where, r_o is .56 as 56 % iso removal line meets at 15 minutes in x-axis.

The value of $\sum(\Delta r \text{ x } Zi)$ = 0.33, Table C.4, Annexure C

$$= .56 + \sum \frac{0.33}{1.8}$$

$$= 74.33\ \%$$

The Slope of isoremoval line as shown in fig. 4.12 at any point gives the instantaneous velocity of fraction of particles represented by that line. Slope of isoremoval line become steeper at greater depth, shows that velocity becomes greater at greater depth. This is because of the increase in the particle size due to flocculation in the raw water suspension which causes continued collision and aggregation with other particles. For assumed detention time of 15 minutes removal efficiency is 74.33%

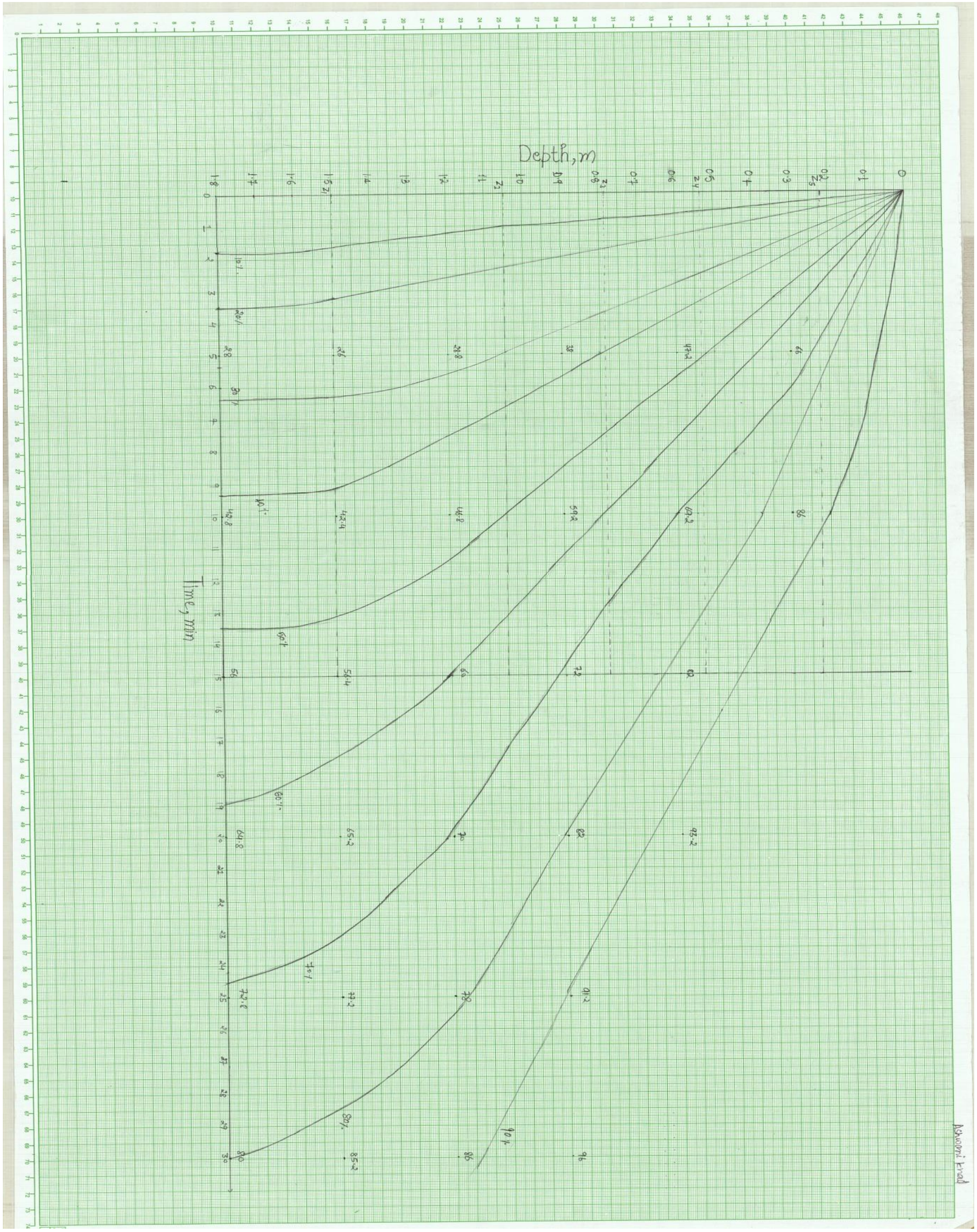

Fig4.12 Isoremoval lines from settling analysis for Ashwani Khad (Ashwani River).

CHAPTER 5: CONCLUSION

Type-1 and type-2 settling analysis done for analysis of settling characteristics of particles present in raw water. The study was done for different water samples. Type-1 settling gives the plot between settling velocity and fraction of particle remaining. From plot it can be concluded that settling velocity of particle governs the efficiency of system. Type-2 gives the plot between depth of settling column and time. From graph it can be concluded that depth of system is an important parameter. With depth flock formation is high.

Type-1 settling of raw water samples collected from different location Renuka ji, Sadhupul, Gumma and Ashwani khad has different removal efficiencies 90.90%, 79.55%, 96.41%, and 79.17% respectively at assumed detention time of 12 minutes. Raw water sample collected from Renuka ji and Gumma are from same river (Giri River) having removal efficiency in the nineties showing that most of the particles atleast reaches the settling velocity. Raw water sample collected from Sadhupul and Ashwani Khad are from same river (Ashwani River) having removal efficiencies about 80%, showing that lesser no of particles than in the case of Giri River are reaching or exceeding settling velocity. This shows that the particle size in the Giri River is greater than particles present in the Ashwani River.

Type-2 settling of raw water samples collected from different location Renuka ji, Sadhupul, Gumma and Ashwani khad have different removal efficiencies 74.54%, 55.45%, 60.11%, and 74.33% respectively at assumed detention time of 15 minutes. In case of Renuka Ji and Ashwani Khad removal efficiencies are near to 74%.Which shows presence of flocculating particles much more than non-flocculating particles. Where as in case of Gumma and Sadhupul removal efficiencies are 55.45% and 60.11% respectively showing the flocculating particles present being less than in the case Renuka ji and Ashwani Khad. In case of type-2 settling it can also be concluded that sampling location Gumma is situated at upstream to the location Renuka ji. Terrain of Gumma location is hillier as compared to Renuka ji and river bed at location renuka ji is wider than Gumma. That’s why particles present in location Renuka ji have more flocculating particle leading to more removal efficiency for Renuka ji as compare to Gumma. Simillarly Sadhupul is upstream to Ashwani Khad and removal efficiency of Sadhupul is less than that of Ashwani Khad.

This study is done for 35 minutes detention time, but for having better insight about settling characteristics of particles study for different detention times (60,90,120 minutes etc.) can be done in future using settling columns used in this study as this will provide more data calculations resulting in increase in the accuracy of results.

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ANNEXURE A

A.1 CALCULATION FOR RENUKA JI (GIRI RIVER)

Table A.1: Showing calculation of removal efficiency for type-2 analysis.

Sample No.	Turbidity(NTU)	Initial wt. of filter paper before filtration (g)	Final wt. of filter paper after filtration (g)	Wt. of suspended solid (mg/200 ml)	Wt. of suspended solid (mg/l)	Removal efficiency (%)
A1	30	1.217	1.2479	30.9	154.5	41.70
A2	10	1.211	1.2296	18.6	93	64.91
B1	23	1.318	1.351	33	165	37.74
B2	12	1.329	1.3554	26.4	132	50.19
B3	5	1.29577	1.3096	13.83	69.15	73.91
B4	4	1.1576	1.167	9.4	47	82.26
C1	30	1.2232	1.2619	38.7	193.5	26.98
C2	17	1.2529	1.2819	29	145	45.28
C3	11	1.267	1.285	18	90	66.04
C4	7	1.25	1.2629	12.9	64.5	75.66
C5	7	1.208	1.2173	9.3	46.5	82.45
C6	1	1.2121	1.2175	5.4	27	89.81
D1	37	1.2367	1.2802	43.5	217.5	17.92
D2	23	1.2991	1.331	31.9	159.5	39.81
D3	15	1.2921	1.3129	20.8	104	60.75
D4	6	1.261	1.2758	14.8	74	72.08
D5	8	1.2278	1.2398	12	60	77.36
D6	2	1.275	1.2823	7.3	36.5	86.23
E1	48	1.3019	1.346	44.1	220.5	16.79
E2	20	1.298	1.3327	34.7	173.5	34.53
E3	11	1.2582	1.2845	26.3	131.5	50.38
E4	6	1.2831	1.301	17.9	89.5	66.23
E5	5	1.294	1.3078	13.8	69	73.96
E6	3	1.279	1.2881	9.1	45.5	82.83
F1	41	1.2905	1.3373	46.8	234	11.70
F2	23	1.23	1.2673	37.3	186.5	29.62
F3	17	1.301	1.3306	29.6	148	44.15
F4	11	1.283	1.3026	19.6	98	63.02
F5	8	1.249	1.2649	15.9	79.5	70.00
F6	4	1.3013	1.3119	10.6	53	80.00

Table A.2: Showing calculation of mass fraction remaining for type-1 analysis.

Sample No	Time, min	Weight of filter paper before filtration(g)	Weight of filter paper after filtration (g)	Weight of suspended solid (mg/l)	Percent mass fraction remaining (%)	velocity, m/min X 10^{-1}
0	0	1.236	1.289	265	1.00	
1	5	1.272	1.311	195	0.74	3.6
2	10	1.274	1.3058	159	0.60	1.8
3	15	1.221	1.2474	132	0.50	1.2
4	20	1.238	1.2615	117.5	0.44	0.9
5	25	1.273	1.2949	109.5	0.41	0.72
6	30	1.25	1.2708	104	0.39	0.6

Table A.3: Showing calculation for determination of $\sum \Delta x \cdot v_t$.

Δx	v_t	Δr x v_t
0.04	0.05	0.002
0.04	0.09	0.0036
0.2	0.26	0.052
0.2	0.55	0.11
0.2	0.88	0.176
	$\sum \Delta x \cdot v_t$	0.3436

Table A.4: Showing calculation for determination of $\sum \Delta r \times Z_i$.

Δr	Z_i	Δr x Z_i
0.08	1.645	0.1316
0.08	1.345	0.1076
0.2	0.95	0.19
0.2	0.55	0.11
	$\sum \Delta r \times Z_i$	0.5392

ANNEXURE B

B.1 CALCULATION FOR SADHUPL (ASHWANI RIVER)

Table B.1: Showing calculation of removal efficiency for type-2 analysis.

Sample No.	Turbidity(NTU)	Initial wt. of filter paper before filtration (g)	Final wt. of filter paper after filtration (g)	Wt. of suspended solid (mg/200 ml)	Wt. of suspended solid (mg/l)	Removal efficiency (%)
A1	22	1.3036	1.3247	21.1	105.5	50.35
A2	11	1.1645	1.1796	15.1	75.5	64.47
B1	20	1.3401	1.3653	25.2	126	40.71
B2	15	1.2488	1.2707	21.9	109.5	48.47
B3	14	1.1801	1.1968	16.7	83.5	60.71
B4	8	1.29	1.3021	12.1	60.5	71.53
C1	22	1.2762	1.3023	26.1	130.5	38.59
C2	18	1.2332	1.2572	24	120	43.53
C3	16	1.2703	1.2898	19.5	97.5	54.12
C4	9	1.2587	1.272	13.3	66.5	68.71
C5	6	1.3432	1.3542	11	55	74.12
C6	6	1.2875	1.294	6.5	32.5	84.71
D1	23	1.2664	1.2975	31.1	155.5	26.82
D2	16	1.2807	1.3075	26.8	134	36.94
D3	14	1.2513	1.2718	20.5	102.5	51.76
D4	8	1.2727	1.2873	14.6	73	65.65
D5	7	1.2335	1.2463	12.8	64	69.88
D6	4	1.3252	1.3338	8.6	43	79.76
E1	29	1.2554	1.2912	35.8	179	15.76
E2	13	1.3001	1.3318	31.7	158.5	25.41
E3	10	1.3592	1.3856	26.4	132	37.88
E4	9	1.318	1.3378	19.8	99	53.41
E5	6	1.3047	1.3191	14.4	72	66.12
E6	4	1.2365	1.2469	10.4	52	75.53
F1	31	1.2689	1.3071	38.2	191	10.12
F2	15	1.1893	1.2235	34.2	171	19.53
F3	11	1.3311	1.3589	27.8	139	34.59
F4	9	1.3578	1.3792	21.4	107	49.65
F5	7	1.317	1.3338	16.8	84	60.47
F6	5	1.269	1.2827	13.7	68.5	67.76

Table B.2: Showing calculation of mass fraction remaining for type-1 analysis.

Sample No	Time, min	Turbidity (NTU)	Weight of filter paper before filtration(g)	Weight of filter paper after filtration (g)	Weight of suspended solid (mg/l)	Percent mass fraction remaining (%)	velocity, m/min X 10^{-1}
0	0	55	1.229	1.2715	212.5	1.00	
1	5	46	1.3143	1.3527	192	0.90	3.6
2	10	34	1.3453	1.3718	132.5	0.62	1.8
3	15	28	1.2551	1.276	104.5	0.49	1.2
4	20	25	1.31	1.3268	84	0.40	0.9
5	25	20	1.2251	1.2409	79	0.37	0.72
6	30	18	1.3047	1.3192	72.5	0.34	0.6

Table B.3: Showing calculation for determination of $\sum \Delta x \cdot v_t$

Δx	v_t	$\Delta x \cdot v_t$
0.08	0.05	0.00007
0.08	0.09	0.000315
0.2	0.26	0.056
0.2	0.55	0.136
	$\sum \Delta x \cdot v_t$	0.1732

Table B.4: Showing calculation for determination of $\sum \Delta r \times Z_i$.

Δr	Z_i	$\Delta r \times Z_i$
0.027	1.64	0.04428
0.027	1.34	0.03618
0.2	0.895	0.179
0.2	0.46	0.092
0.2	0.12	0.024
	$\sum \Delta r \times Z_i$	0.37546

ANNEXURE C

C.1 CALCULATION FOR ASHWANI KHAD (ASHWANI RIVER)

Table C.1: Showing calculation of Removal efficiency for type-2 analysis.

Sample No.	Turbidity(NTU)	Initial wt. of filter paper before filtration (g)	Final wt. of filter paper after filtration (g)	Wt. of suspended solid (mg/200 ml)	Wt. of suspended solid (mg/l)	Removal efficiency (%)
A1	22	1.3036	1.3247	21.1	105.5	50.35
A2	11	1.1645	1.1796	15.1	75.5	64.47
B1	20	1.3401	1.3653	25.2	126	40.71
B2	15	1.2488	1.2707	21.9	109.5	48.47
B3	14	1.1801	1.1968	16.7	83.5	60.71
B4	8	1.29	1.3021	12.1	60.5	71.53
C1	22	1.2762	1.3023	26.1	130.5	38.59
C2	18	1.2332	1.2572	24	120	43.53
C3	16	1.2703	1.2898	19.5	97.5	54.12
C4	9	1.2587	1.272	13.3	66.5	68.71
C5	6	1.3432	1.3542	11	55	74.12
C6	6	1.2875	1.294	6.5	32.5	84.71
D1	23	1.2664	1.2975	31.1	155.5	26.82
D2	16	1.2807	1.3075	26.8	134	36.94
D3	14	1.2513	1.2718	20.5	102.5	51.76
D4	8	1.2727	1.2873	14.6	73	65.65
D5	7	1.2335	1.2463	12.8	64	69.88
D6	4	1.3252	1.3338	8.6	43	79.76
E1	29	1.2554	1.2912	35.8	179	15.76
E2	13	1.3001	1.3318	31.7	158.5	25.41
E3	10	1.3592	1.3856	26.4	132	37.88
E4	9	1.318	1.3378	19.8	99	53.41
E5	6	1.3047	1.3191	14.4	72	66.12
E6	4	1.2365	1.2469	10.4	52	75.53
F1	31	1.2689	1.3071	38.2	191	10.12
F2	15	1.1893	1.2235	34.2	171	19.53
F3	11	1.3311	1.3589	27.8	139	34.59
F4	9	1.3578	1.3792	21.4	107	49.65
F5	7	1.317	1.3338	16.8	84	60.47
F6	5	1.269	1.2827	13.7	68.5	67.76

Table C.2: Showing calculation of mass fraction remaining for type-1 analysis.

Sample No	Time, min	Turbidity (NTU)	Weight of filter paper before filtration(g)	Weight of filter paper after filtration (g)	Weight of suspended solid (mg/l)	percent mass fraction remaining (%)	velocity, m/min X 10^{-1}
0	0	55	1.1985	1.2395	205	1.00	
1	5	46	1.2472	1.2818	173	0.84	3.6
2	10	34	1.2538	1.2808	135	0.66	1.8
3	15	28	1.2724	1.2924	100	0.49	1.2
4	20	25	1.3241	1.3375	67	0.33	0.9
5	25	20	1.2855	1.2957	51	0.25	0.72
6	30	18	1.3146	1.3228	41	0.20	0.6

Table C.3: Showing calculation for determination of $\sum \Delta x \cdot v_t$.

Δx	v_t	$\Delta x \cdot v_t$
0.1	0.05	0.002
0.1	0.09	0.0036
0.2	0.26	0.052
0.2	0.55	0.11
	$\sum \Delta x \cdot v_t$	0.1676

Table C.4: Showing calculation for determination of $\sum \Delta r \times Z_i$.

Δr	Z_i	$\Delta r \times Z_i$
0.04	1.5	0.06
0.1	1.15	0.115
0.1	0.79	0.079
0.1	0.54	0.054
0.1	0.22	0.022
	$\sum \Delta r \times Z_i$	0.33

ANNEXURE D

D.1 CALCULATION FOR GUMMA (GIRI RIVER)

Table D.1: Showing calculation of Removal efficiency for type-2 analysis.

Sample No.	Turbidity (NTU)	Initial wt. of filter paper before filtration (g)	Final wt. of filter paper after filtration (g)	Wt. of suspended solid (mg/200 ml)	Wt. of suspended solid (mg/l)	removal efficiency (%)
A1	22	1.2232	1.253	29.8	149	40.4
A2	11	1.2341	1.2537	19.6	98	60.8
B1	20	1.2237	1.2625	38.8	194	22.4
B2	15	1.2861	1.3147	28.6	143	42.8
B3	14	1.1664	1.1892	22.8	114	54.4
B4	8	1.3272	1.3442	17	85	66
C1	22	1.2321	1.2757	43.6	218	12.8
C2	18	1.2445	1.2775	33	165	34
C3	16	1.289	1.3154	26.4	132	47.2
C4	9	1.3102	1.331	20.8	104	58.4
C5	6	1.2191	1.2353	16.2	81	67.6
C6	6	1.2304	1.2442	13.8	69	72.4
D1	23	1.2286	1.2742	45.6	228	8.8
D2	16	1.2431	1.2801	37	185	26
D3	14	1.3381	1.3691	31	155	38
D4	8	1.3101	1.3361	26	130	48
D5	7	1.2982	1.3202	22	110	56
D6	4	1.3252	1.3432	18	90	64
E1	29	1.2319	1.2789	47	235	6
E2	13	1.2623	1.3013	39	195	22
E3	9	1.2413	1.2733	32	160	36
E4	11	1.2992	1.3268	27.6	138	44.8
E5	6	1.3142	1.3378	23.6	118	52.8
E6	8	1.2292	1.2488	19.6	98	60.8
F1	31	1.2753	1.3233	48	240	4
F2	15	1.2625	1.3031	40.6	203	18.8
F3	11	1.245	1.279	34	170	32
F4	9	1.2327	1.2623	29.6	148	40.8
F5	7	1.2691	1.2947	25.6	128	48.8
F6	8	1.3141	1.3361	22	110	56

Table D.2: Showing calculation of mass fraction remaining for type-1 analysis.

Sample No	Time, min	Turbidity (NTU)	Weight of filter paper before filtration(g)	Weight of filter paper after filtration (g)	Weight of suspended solid (mg/l)	percent mass fraction remaining (%)	velocity, m/min X 10^{-1}
0	0	64	1.2756	1.3256	250	1.00	
1	5	57	1.3246	1.3686	220	0.88	3.6
2	10	45	1.2955	1.3315	180	0.72	1.8
3	15	38	1.2874	1.3162	144	0.58	1.2
4	20	29	1.3109	1.3333	112	0.45	0.9
5	25	23	1.2675	1.2867	96	0.38	0.72
6	30	20	1.3056	1.3228	86	0.34	0.6

Table D.3: Showing calculation for determination of $\sum \Delta x \cdot v_t$.

Δx	v_t	$\Delta x \cdot v_t$
0.035	0.002	0.00007
0.035	0.009	0.000315
0.2	0.28	0.056
0.2	0.68	0.136
0.2	1.17	0.234
	$\sum \Delta x \cdot v_t$	0.426385

Table D.4: Showing calculation for determination of $\sum \Delta r \times Z_i$.

Δr	Z_i	$\Delta r \times Z_i$
0.08	1.45	0.116
0.2	0.92	0.184
0.2	0.61	0.122
0.2	0.42	0.084
	$\sum \Delta r \times Z_i$	0.506

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