Kufa Journal of Engineering
Vol. 14, No. 3, July 2023, P.P. 48-68
Article history: Received: 7 May 2023, accepted: 22 June 2023

MODELING OF TURBIDITY DISTRIBUTION IN WATER NETWORKS USING PMS MODEL - AL-SARAY SECTOR IN KUFA CITY AS A CASE STUDY

Zahraa H. Abed [1] and Kifah M. Khudair[2]

1 Dept. of Civil Eng., College of Eng., Univ. of Basrah, Basrah, Iraq (Email: zahraa.shafeea.1994@gmail.com)

2 Dept. of Civil Eng., College of Eng., Univ. of Basrah, Basrah, Iraq (Email: Kifah.khudair@uobasrah.edu.iq)

HTTPS://DOI.ORG/10.30572/2018/KJE/140304

ABSTRACT

The Water industry faces a significant problem in reducing water turbidity. The introduction and enhancement of proactive operation and maintenance techniques to reduce turbidity can be facilitated by the capacity to predict the geographical probability and severity of turbidity in distribution systems. In this study, the Particle Sediment Model (PSM) is used to simulate turbidity in a water distribution system. This study sought to ascertain how water treatment facilities impact the turbidity of tap Water. The Al-Saray water distribution network in Kufa city /Najaf Governorate is covered by the work The impact of water turbidity on the network revealed that the source of the particles entering the network is the treatment facility. The highest turbidity values in the system were recorded at 9.67, 16.68, 13.38, 11.30, 9.82, and 5.27 NTU when the source sediment quality (effluent turbidity from WTP) met the standard specifications of (5) NTU, while the highest values were noted when the source sediment quality (26.6) NTU was at 51.35, 101.02, 77.64, 62.94, 52.46, and 20.22 NTU. Failure to carry out continuous cleaning of the network and poor water treatment from drinking water treatment plants are among the most important reasons for the rise in turbidity in drinking water.

KEYWORDS: Turbidity, PSM Model, Resuspension Velocity, Deposition Velocity, Water Distribution Network.

Article information: This manuscript was handled by Abbas Al-Hdabi, Managing Editor.

1. INTRODUCTION

Drinking water distribution networks are only supposed to transport dissolved matter, not suspended solid particles. However, removing all suspended solid particles from drinking water is impossible. Turbidity, which is a general measure of particle content in water, is the primary cause of water discoloration. However, the threshold for detecting turbidity with the naked eye is 5 NTU (WHO, 2008).

Turbidity is linked to the release of accumulated particles from distribution networks. As there are particles that accumulate and settle at the bottom wall or any pockets such as dead ends, T-junctions, pipe bends, or a combination of these. During any abnormal flow (e.g., flushing, pipe burst, etc.), these particles re-enter the system at a time of high turbulence, causing turbidity Hossain (2005). Such particles originate from a number of sources, which are frequently categorized as either outside influences or internal system activities, due to their varying sizes and densities. Backflow, invasion, and external pollution are potential outcomes of procedures like pipe repairs Gauthier et al. (1999). Chemical reactions Sly et al. (1990), biological growth (Gauthier et al. (1999); Le Chevallier (1987)). The treatment facility itself may contribute materials to the water, such as carbon and particles of sand, alum or ferrous flocs, and bioparticles formed from biological filters, as a result of inadequate suspended particles removal at the point of treatment. as well as from internal distribution system processes such lining erosion and pipe and fitting corrosion Gauthier et al. (2001).

It is challenging to investigate water turbidity occurrences in actual systems because they frequently take place over brief times for unclear reasons. However, many studies have been conducted to model water discoloration (turbidity) and sediment transport in drinking water distribution networks. Boxall and Saul (2005) suggested calculating the substances that could be generated at the wall of the pipe using a turbidity current. They produced a semi-empirical model called Prediction of the discoloration Occurrence in Distribute Networks (PODDS). Layers of substance with a shear force controlled by the wall stresses (WSS) of the flow at the pipe wall simulate material accumulation. Boxall and Prince (2006) tested a semi-empirical predictive model (PODDS model) on a water distribution network in Melbourne (Australia). The findings demonstrate that, for clay-driven discoloration issues the model may be validated to replicate the turbidity effect observed in real systems as a result of variations in hydraulic variables for clay-driven discoloration problems. Husband et al. (2008) Based upon experiments that showed variations in shear forces at the pipe wall caused by a shift in demand, like a rupture or the opening of a firefighting hydrant, degraded tiny particles conditioned by the system's typical daily flow patterns. Van Thienen et al. (2011) developed a theoretical framework to clarify how suspended particles of various sizes are transported in DWDSs under hydraulic circumstances, however the model was unable to explain why tiny particles predominated on samples of discolored water. Al-Ithari (2013) investigated Perth, Western Australia's Zone M water supply. used the Particle Suspension Model (PSM) and the Resuspension Potential Method (RPM). Based on the outcomes of the fieldwork, the PSM was calibrated, evaluated as a prediction tool, and improved by suggesting a new resuspension velocity. Furnass et al. (2014) presented in detail the shortcomings of the PODDS model as concerned with the cohesive sediment layer regeneration (accumulation) on pipe walls. They developed a new model that tracks the time-varied formation of a sediment layer as a function of shear strength and coded the model in a software using Python programing language. It can be used to predict turbidity distribution in a single pipe. Furnass et al. calibrated and validated the model by comparing its results with field turbidity data collected from a main transmission pipe under three hydraulic conditions.

The performance of the water treatment plants of the main water treatment plant in Najaf governorate was previously evaluated based on the collection of field and experimental data It was concluded that the treatment plants are the main cause of the problem of high turbidity. The aim of this study is to complete a series of comprehensive studies to investigate the problem of high turbidity where the distribution of turbidity in Al-Saray water network case study will be studied to find out how changes in feedwater properties affect the turbidity distribution. Simulated by software developed based on the Particle Sediment Model (PSM) mathematical model and written using MATLAB 2020b software.

2. METHODOLOGY

2.1. Study area

This study dealt with the potable water distribution system in the AL-Saray region, which is considered one of the largest neighborhoods in the city of Kufa, located in the northeastern province of Najaf. AL-Saray is located at a latitude and longitude of 32˚ 2' 29.85" and 44˚ 23' 59.82" E, respectively, see Fig. 1.

2.2. Description of Al-Saray water distribution network

Al- Saray water distribution system is one of the water distribution systems in the city of Kufa, where the source of water supply for the Kufa city network is from the old Kufa water treatment plant. The network serves the Al-Saray neighborhood, which has an area of approximately 42 km^2 and a population density of 7,500, and is made up of different diameters and materials, including 202 ductile iron pipes with a diameter of 110 mm with total length of 11023m, 36 ductile-type pipes with a diameter of 160 mm with total length of 1795 m, and 25 PVC pipes with a diameter of 225 mm with total length of 270m, and the main network outlet pipe with a diameter of 300mm with total length of 503.19 m,.

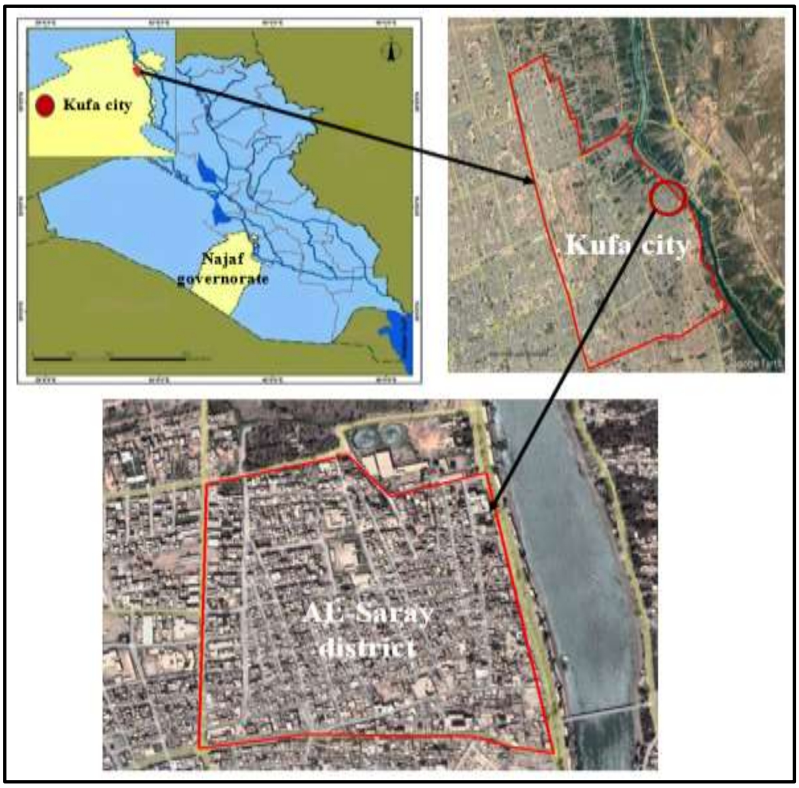

Fig. 1. The study area.

3. PARTICALE SEDIMENT MODEL (PSM)

The Particle Sediment Model (PSM) makes the assumption that no extra processes such as silt accumulation in pipes or other network-related processes occur and that all particles entering the network come from the treatment. Van et al., 2005 (cited in Al-Ithari (2013)).

It is presumptive that the particles will gravitationally settle and/or that they will resuspend once the flow velocity exceeds a certain threshold. The model would then determine how much and where the sediment settles for the entire network as the material was slowly disseminated over the network. The model's methodology does not include bed-load transportation. The (slow) movement of the sediment at the pipe's bottom is known as bed-load transport Van et al., 2005 (cited in Al-Ithari (2013)).

Gravity settling and wall attraction are the two mechanisms that have been seen in the modeling of silt in drinking water networks, see Fig. 2.

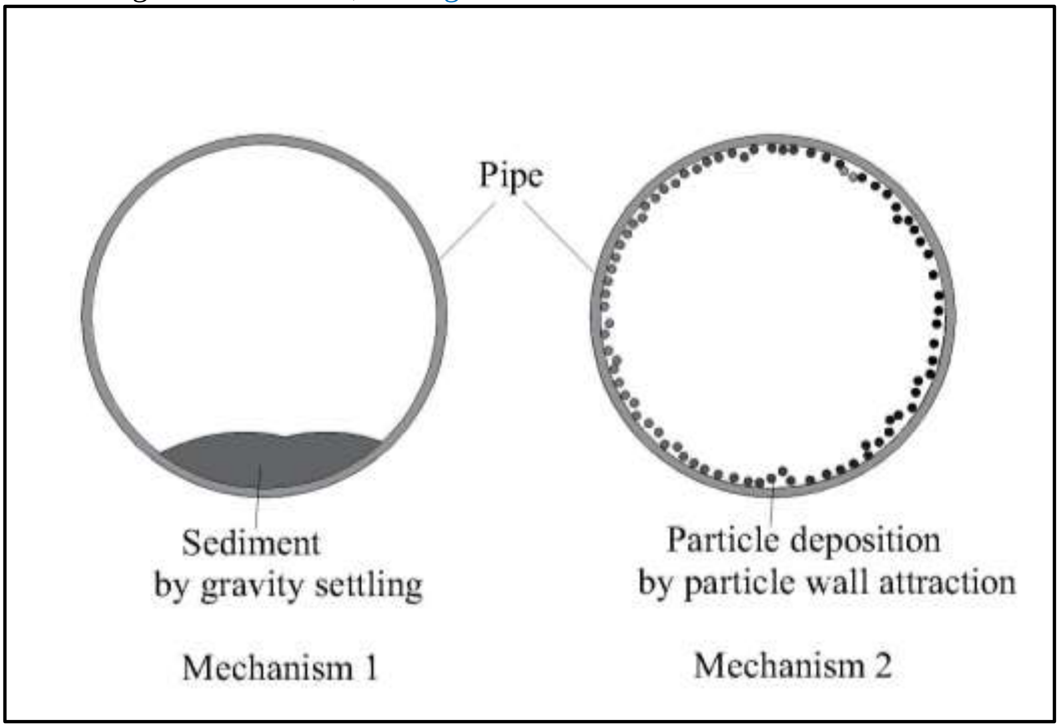

Fig. 2. Sedimentation mechanisms in drinking water pipelines (Ryan et al, 2008).

Mechanism 1: Depending on the flow velocity (V), one of three things may happen (Ryan et al, 2008):

1. V > V_{rs}:

The flow velocity (V)is not only the velocity at which all sediment can be resuspended. V_{rs} is a function of particle diameter, density, and sediment packing; it is the critical velocity beyond which particles are resuspended.

2. V_d ≤ V ≤ V_{rs}:

Because the flow velocity (V) is between the velocity at which the sediment suspends (V_{rs}) and the velocity at which it settles, the particle mass is conveyed down the pipe without settling or resuspension (V_d).

3. V< V_d:
Due to the water's low velocity, which will cause all silt to suspend, all particles will settle.

Mechanism 2: A mass transfer process in which small particles diffuse from suspended in the water onto the pipe wall can be used to describe the deposition of particles on the pipe walls in a reticulation system. According to the theory, particles settle under the Von-Der War force rather than the gravity force when they deposit onto the surface of a wall (Mechanism 1).

The data needed to run the model is:

1. A network model: PSM requires input flow data from hydraulic modeling. Hydraulic modeling was performed using EPANET software

2. Water quality requirements must be established, including sediment characterization velocities and particle concentrations from the treatment facility. These speeds represent the sediment's settling velocity as well as the speeds at which the sediment will either settle or resuspend.

3.1. Governing Equations

The following section is a list of the essential particle mass transfer equations (Ryan et al, 2008).

1. $V > V_{rs}$

In this case, particles are assumed to be resuspended instantly.

1.1 TRD $\leq Pl$

$$SSM(x). = SSM(x) + \frac{SSM(S)}{Pl}, x \in 0, Pl \qquad (1)$$

SSMS=0

$$\text{SSMPO}=\int_{Pl-\text{TRD}}^{Pl} SSM(x).dx \qquad (2)$$

$$SSM(x) = \text{SSM}(x - TRD), x \in \text{TRD}, Pl \qquad (3)$$

$$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}, x \in 0, \text{TRD} \qquad (4)$$

S=1

1.2 TRD $> Pl$

$$\text{SSMPO} = SSMPI * \frac{\text{D}_\text{t} - Pl/\text{V}}{\text{D}_\text{t}} \qquad (5)$$

$$SSM(x) = SSM(x) + \frac{SSMS}{Pl}, x \in 0, Pl \qquad (6)$$

SSMS=0

S=1

$$\text{SSMPO}=\text{SSMPO}+\int_{0}^{Pl} SSM(x).dx \qquad (7)$$

$$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}, x \in 0, Pl \qquad (8)$$

2. $V < \text{V} \leq V_{rs}$

Particles move through the pipe with no change in mass.

2.1 $TRD \leq Pl$

$$\text{SSMPO}=\int_{Pl-\text{TRD}}^{Pl} SSM(x).dx \qquad (9)$$

$$SSM(x) = \text{SSM}(x - TRD), x \in TRD, Pl \qquad (10)$$

$$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}, x \in 0, TRD \qquad (11)$$

2.2 $TRD > Pl$

$$\text{SSMPO} = SSMPI * \frac{\text{D}_\text{t} - Pl\ /\text{V}}{\text{D}_\text{t}} \qquad (12)$$

SSMPO= SSMPO+$\int_0^{Pl} SSM(x) . dx$ (13)

$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}$, x ∈ 0 , Pl (14)

3. 0<V≤V_d

Particles settle out with a settling velocity of us, the settling position is described by S.

3.1 $TRD \leq Pl$

If $\frac{V_s . D_t}{D} \geq$S

SSMS=SSMS+ $SSMPI$ (15)

$S_t = \frac{S.D}{V_s}$ (16)

Dx=V.S_t (17)

$SSMS = SSMS + \int_0^{Pl-\text{Dx}} SSM(x) . dx + 0.5\int_{Pl-\text{Dx}}^{Pl} SSM(x) . dx$ (18)

SSMPO=0.5$\int_{Pl-\text{Dx}}^{Pl} SSM(x) . dx$ (19)

$SSM(x)$ =0, x ∈ 0 , Pl

S=0

If $\frac{V_s . D_t}{D}$ <S

$SSMS1 = 0.5\frac{V_s . D_t}{S.D} \int_{Pl-\text{TRD}}^{Pl} SSM(x) . dx$ (20)

SSMPO=$\int_{Pl-\text{TRD}}^{Pl} SSM(x) . dx$- SSMS1 (21)

$SSM(x)$ =SSM (x- TRD), x ∈ TRD , Pl (22)

$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}$, x ∈ 0 , TRD (23)

SSMS=$\frac{V_s . \text{Dt}}{S.D} \int_0^{Pl} SSM(x) . dx$+SSMS1 (24)

SSMS=SSMS+SSMS (25)

$SSM(x) = SSM(x) - SSM(x). \frac{V_s . D_t}{S.D}$,x ∈ 0 , Pl (26)

S=S-$\frac{V_s . D_t}{D}$ (27)

3.2 $TRD > Pl$

If $\frac{Pl.V_s}{D.V} \geq$S:

SSMS=SSMS+ $SSMPI$ (28)

$DX = \frac{S.D}{V_s} . V$ (29)

SSMS=$\int_0^{Pl-Dx/2} SSM(x). dx$ (30)

SSMS=SSMS+ SSMS (31)

SSMPO=$\int_{Pl-Dx/2}^{Pl} SSM(x). dx$ (32)

M(x)=0, x ∈ 0 ,L

If $\frac{Pl.V_s}{D.V}$ <S:

Dy=$\frac{Pl.V_s}{V}$ (33)

SSMS=$\frac{Dy}{2S.D}\int_0^{Pl} SSM(x).dx$ (34)

SSMS=SSMS+ SSMS (35)

SSMPO=$\int_0^{Pl} SSM(x).dx -$ SSMS (36)

SSMS1=$\frac{Pl.V_s}{V.S.D}$ .SSMPI (37)

SSMS=SSMS+ SSMS1 (38)

SSMPO= SSMPO+(1-$\frac{Pl.V_s}{V.S.D}$). (1-$\frac{Pl}{\text{TRD}}$) (39)

$SSM(x) = \frac{\text{SSMPI}}{\text{TRD}}$ (1-$\frac{Pl.V_s}{V.S.D}$), x ∈ 0 , Pl (40)

4. V=0

Particles settling out, zero mass in and out of the pipe.

If $\frac{V_s.D_t}{D}$ ≥S:

SSMS=SSMS+$\int_0^{Pl} SSSM(x).dx$ (41)

$SSSM(x)$=0, x ∈ 0 , Pl

SSMPO=0

S =0

If $\frac{V_s.D_t}{D}$ <S

S>0

SSMS=SSMS+$\frac{V_s.D_t}{S.D}\int_0^{Pl} SSM(x).dx$ (42)

S =S+$\frac{V_s.\text{t}}{D}$ (43)

$SSM(x)$= $SSM(x)$- $SSM(x)$. $\frac{V_s\text{t}}{S.D}$, x ∈ 0 , Pl (44)

SSMPO=0

Where:

V_{rs} is re-suspended velocity (m/sec).

V_d is deposition velocity(m/sec).

V_s is settling velocity (m/sec).

D is pipe diameter (m).

Pl is pipe length (m).

SSMPI is particle mass transport into the pipe, during time step Δt; (kg)

SSMPO is particle mass transport out of the pipe, during time step Δt; (kg)

$SSM(x)$ is particle mass per unit length distribution along the pipe at time t;(kg/m)

SSMS is particle settled at time t; (kg)

S is the ratio of particle cloud height over pipe diameter (-)

t is time (s)

V is average velocity in pipe (m/s)

Dt is time step (s)

S_t isSettling time (sec).

TRD travel distance (m), (TRD=V*DT)

4. HYDRAULIC MODELING OF THE WATER DISTRIBUTION NETWORK

4.1. EPANET software

EPANET was created by the US Environmental Protection Agency. It is a computer program that performs in-depth simulations of the behavior of hydraulic systems and the quality of water in pressurized pipe networks. Pipes, nodes (pipe connections), pumps, valves, and reservoirs or storage tanks make up a network.

During a simulation period made up of numerous time steps, EPANET continuously measures the volume of water flowing through each pipe, the amount of pressure at each junction, the height of the water level in each tank, and the concentration of a chemical species throughout the network. Water age and source tracing can also be replicated in addition to chemical species.

4.2. Assumptions

The following assumptions have been used when modeling this pipe water supply system:

1. The value of the Hazen-Williams coefficient "C" is used as 150 for PVC pipes and 140 for ductile pipes.
2. Here in the model, a flow control valve is used.
3. Base Demand = population * water consumption per capita per day.
4. To simulate the fluctuations of demands in nodes, a roof tank demand pattern (rather than a fixed demand) has been used at the nodes of the system. The values for this pattern were taken from prior research in which the daily variations of water demand were recorded, as shown in Fig. 3.

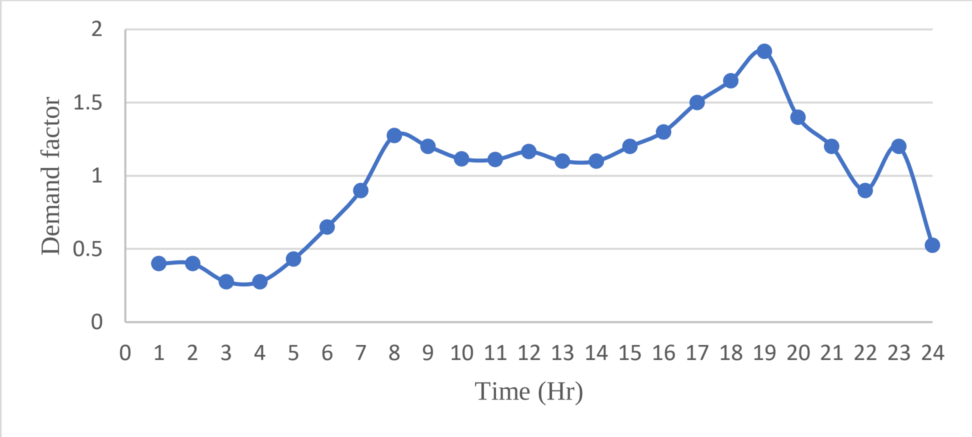

Fig. 3. Demand Pattern Curve for Daily Water Consumption (Steel and McGhee (1960)).

4.3. Data Inputs into the Nodes

Information was collected from the water treatment project in the city, where the project pumps water at frequencies according to the different seasons of the year (4500) m^3 / hour for the entire network of the city of Kufa, where the basic demand for each node was calculated in the complete model of Al-Saray neighborhood. It was (20.595) m^3 / day of the total expenditures for equipping the neighborhood for 7500 capita (3521.74) m^3 / day. In addition to the heights, the intersection ID and the number of tubes connected to the nodes.

4.4. Data Inputs into the Pipes

The individual identifier for each pipe is marked after labeling the data pipelines. The layout has been preserved with 'START NODE' and 'END NODE' from the original data. For the full model, the diameter, material of each pipe is indicated using information from the Najaf Governorate Water Directorate. The researcher calculated the data to determine the length of each tube using Google Earth Maps.

5. SETTLEMENT AND RESUSPENSION CHARACTERISTICS OF SEDIMENT

The PSM model uses sediment properties as inputs, hence it is necessary to ascertain the rates at which sediments pause, resuspend or stabilize. Using the Master Sizer 2000 device, particle size distribution analysis was performed on five samples of treated water obtained from the filtration unit of the water treatment facility in the research area. The Master Sizer 2000 uses the technique of laser diffraction to measure the size of particles. It does this by measuring the intensity of the light scattered as a laser beam passes through a dispersed particulate sample. This data is then analyzed to calculate the size of the particles that created the scattering pattern. d50was for the samples (204.4, 104.9, 287.1, 283.2 and 656.3) µm, respectively. The results of analysis the of the particle size distribution in water samples are displayed in Figs. 4-8, where size (µm), cmmu% and diff% stand for the particle diameter, cumulative volume, and laser diffraction ratio, respectively.

For the five samples the average particle diameter (d50) value was (307.18) µm.

The particle density (1440) kg / m^3 as calculated in the laboratory work (by taking the volume (1.25) ml of the deposited clay with a weight of (1.8) g).

The settling velocity was calculated by Stock Law using the following equation (Van Summeren and Blokker (2017)):

$$V_s=\frac{g\,S\,(d_{50})^2}{18\nu} \quad (45)$$

Where:

V_s is settle velocity (m/sec).

g is the gravitational acceleration (m/sec^2).

s is specific gravity (-).

d_{50} is the particle diameter (m).

ν is kinematic viscosity(m^2/sec).

According to the Shields diagram (Van Rijn (1984)) where the Shields curve is depicted by a collection of 5 power relationships, the deposition velocity V_d should be calculated as follows:

$$\theta_{cr}=\frac{{V_{*cr}}^2}{(s-1)g\,d_{50}} \quad (46)$$

$$D_*=d_{50}\left(\frac{(s-1)g}{\nu^2}\right)^{\left(\frac{1}{3}\right)} \quad (47)$$

Where:

θ_{cr} is critical Shields parameter for incipient motion of particles (-).

V_{*cr} is the critical bed-shear velocity (deposition velocity) (m/sec).

d_{50} is the median grain size (m).

D_* is the dimensionless particle diameter.

g is the gravitational acceleration (m/sec2).

s is specific gravity (-).

ν is kinematic viscosity m^2/sec.

In (Ryan et al, 2008), V_{rs} correction equation: pipe diameter effect from the following equation:

$$V_{rs}=V_{rs100}\sqrt{\frac{f_{100}}{f}} \quad (48)$$

$$f= (1.14\text{-}2log_{10}(\frac{\varepsilon}{D}+\frac{21{,}25}{{R_e}^{0.9}}))^{-2} \quad (49)$$

Where:

V_{rs100} is resuspension velocity of D =100 mm.

f is the pipe friction coefficient [18].
ε is the pipe roughness (m)[3].
R_e is Reynolds number (-).

D is the pipe diameter (mm)

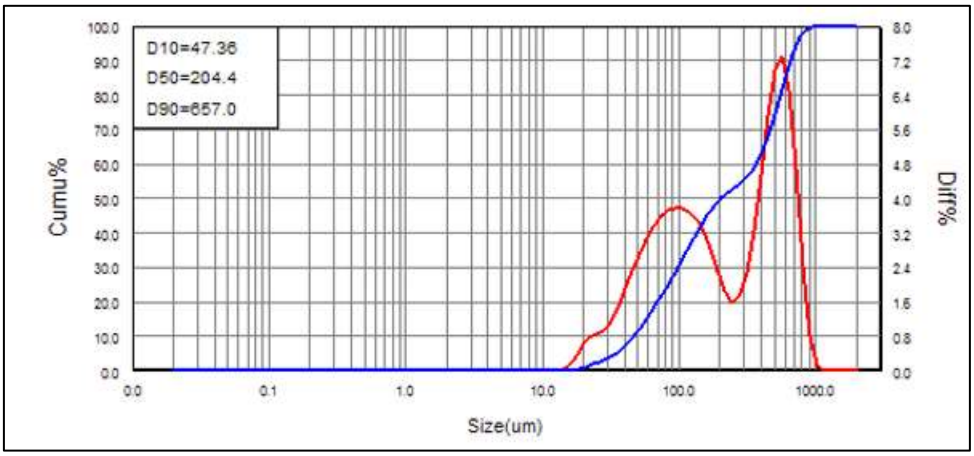

Fig. 4. Particles size distribution results for water sample No. 1.

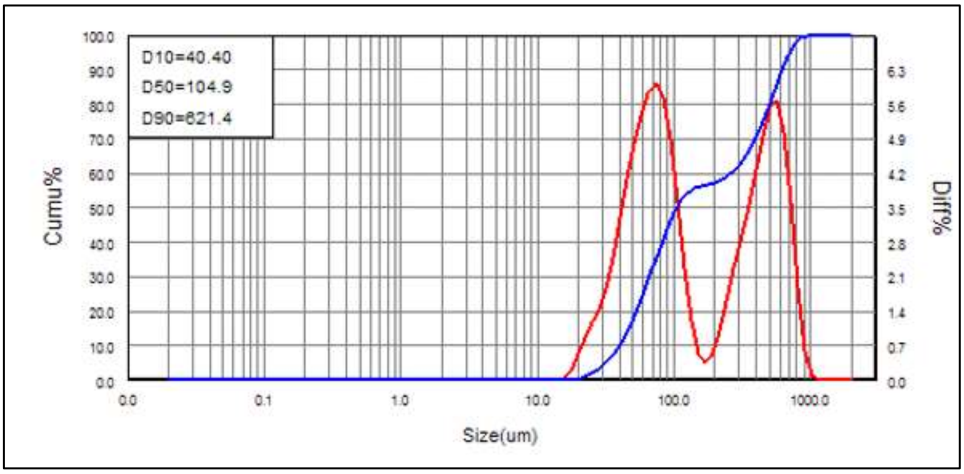

Fig. 5. Particles size distribution results for water sample No. 2.

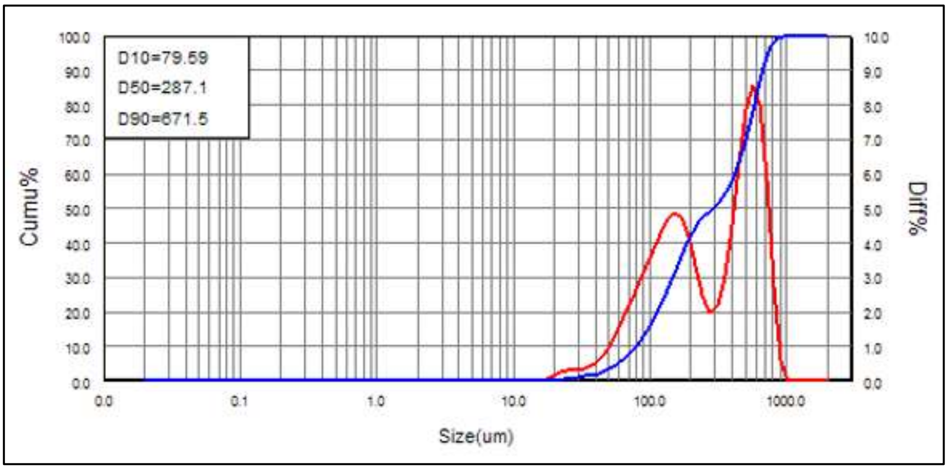

Fig. 6. Particles size distribution results for water sample No. 3.

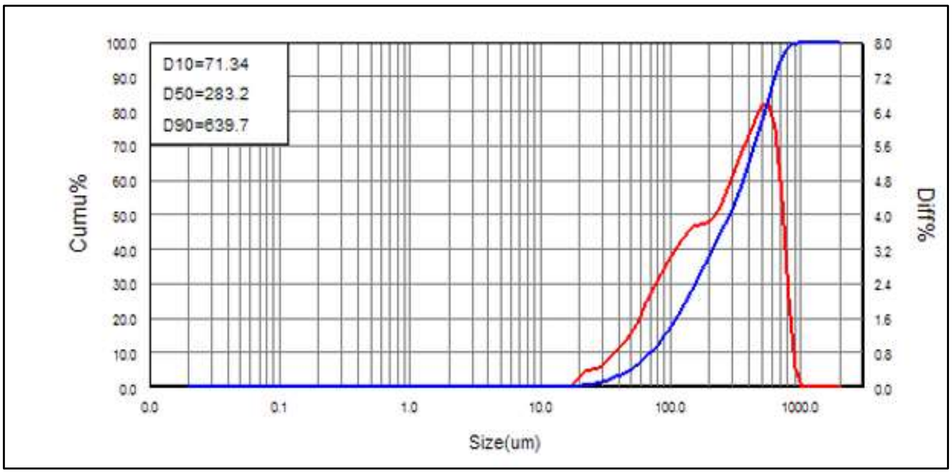

Fig. 7. Particles size distribution results for water sample No. 4.

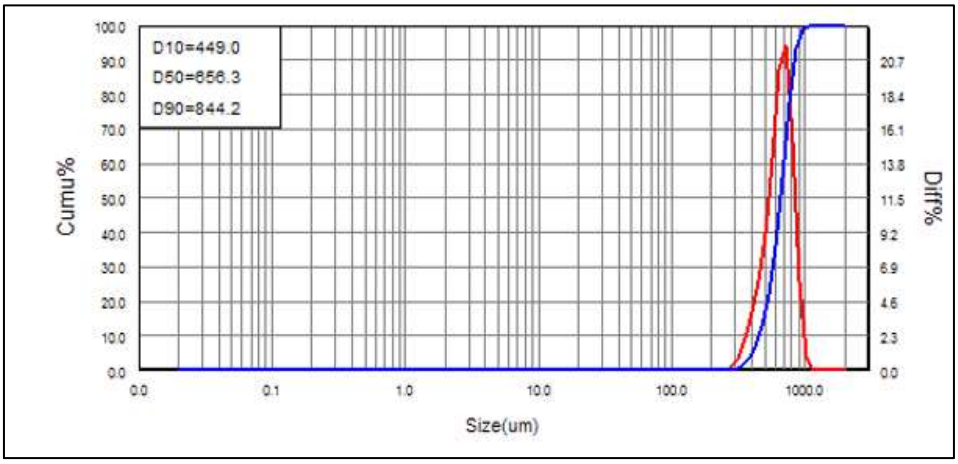

Fig. 8. Particles size distribution results for water sample No. 5.

6. RELATION BETWEEN TSS AND TURBIDITY

Since the output of the PSM model is the distribution of particle mass per unit length along the tube at time t ($SSM(x)$), Equation No. (50) was used to convert the particle mass distribution per unit length along the tube at time t from (kg/m) to the concentration of the suspended matter (CSS) in (mg/L).

It is also necessary to find a relationship between turbidity (TUR) and suspended matter concentration (CSS), where samples were taken from the treated water coming out of the filtration units, turbidity values and total suspended matter were calculated and the relationship between them, the following Fig. 9 and Fig. 10 show the Relationship between TSS solids and turbidity, turbidity and TSS.

$$CSS=\frac{SSM(x)}{A}.1000 \qquad (50)$$

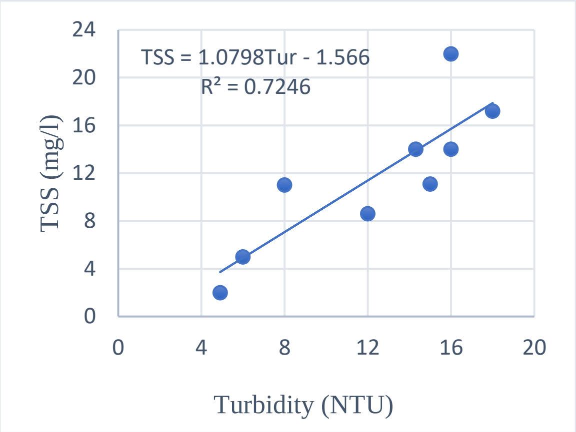

Fig. 9. Relationship between TSS solids and turbidity.

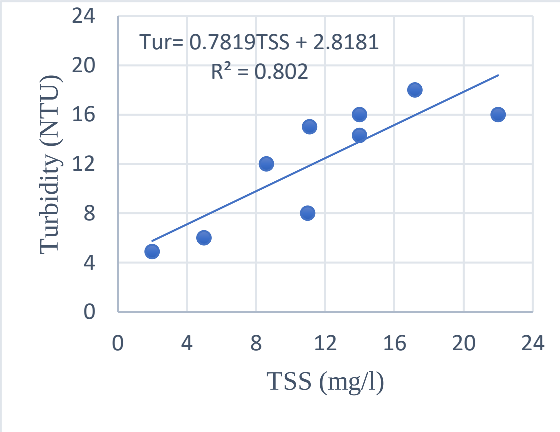

Fig. 10. Relationship between turbidity and TSS.

7. INPUT DATA

The data required to run the PSM model to simulate the performance of WDS are shown in Table 1.

Table 1. Input data of PSM model.

Influent flowrate in reservoir, Q (m3/day)	Number of Pipes	Number of Node	source sediment quality (Effluent Turbidity from WTP) (NTU)
(3521.74)	270	172	(5,26.6) NTU

V_{rs} is resuspended velocity (m/sec).	V_d is deposition velocity(m/sec)	V_s is settling velocity (m/sec).	Time step (sec)
Depending on pipe diameter	0.0798	0.022604355	3600

Out of a total of (4500) (m^3/hr) flows from the station, the influent flowrate in the reservoir (Q) was computed for daily consumption by (7500 capita) from the study area's population.

The “source sediment quality” was nominally entered as (5,26.6) NTU for three days which are field-measured values by the researcher for treated water from the plant in the study area's (Abed and Khudair (2023)).

dependent on the diameter of the tubes and particle diameter (d50), the velocities of the suspension, deposition, and settling are estimated by the equations (45,46,48), in section.5.

A software package has been written to solve equations of the numerical model (PSM). It was carried out using MATLAB 2020b software. The PSM was run for three days using a single tank.

All comparisons were made using the velocities calculated from the discharges obtained from the EPANET program.

The studied pipes are pipe 264 of the ductile type, with a length of 503.19 m and a diameter of 300 mm, and the other pipes (207, 206, 95, 269, 259) of the PVC type, and their lengths range between (226.95, 38.80, 79.73, 1, and 74.54) m, respectively. with a diameter of 213 mm.

8. RESULTS AND DISCUSSION

Fig. 10 shows the hydraulic model of the network after conducting the analysis, with an illustration of the locations of the studied pipes on the path.

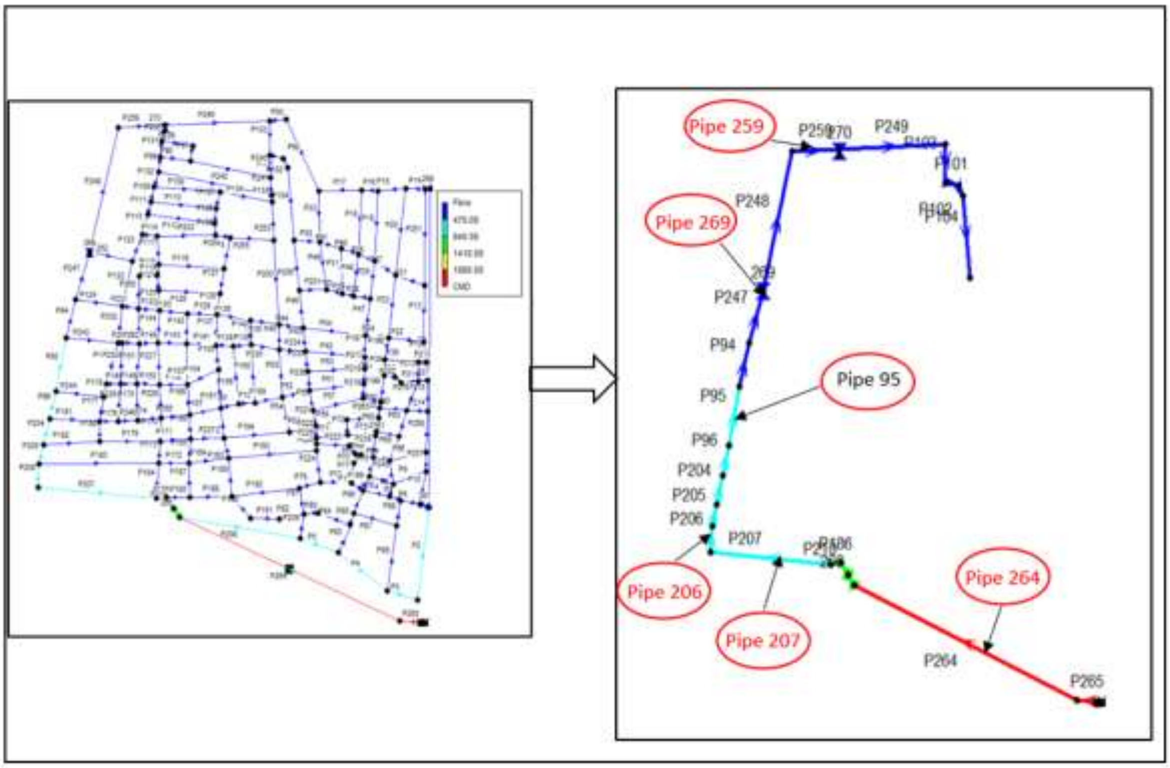

Fig. 10. The hydraulic model of the network with an illustration of the locations of the studied pipes.

Figs. 11, 12, 13 and 14 show the tracking of turbidity distribution, flow rates, settled mass, and resuspension velocity in the grid on the third day after an operation period of three days with a constant source of turbidity (5 NTU). We note a high turbidity exceeding 5 NTU in most of the studied pipes, with the highest value of turbidity (9.67, 16.68, 13.38, 11.30, 9.82, and 5.27 NTU) recorded in the pipes was recorded in the pipes (264,206,207,95,269 and 259) respectively and the lowest values of turbidity (zero) in the all pipes.

It can be notice in all the studied pipes exceeded the standard value, with the exception of pipe 259, whose value was equal to or less than 5 NTU because the velocity in the pipe is less than the value of the (Vrs) and higher than the deposition velocity (v_d) Therefore, the materials continue to move in the tube without changing their mass. In general, observed a fluctuation in speeds as a result of different daily demand patterns, where the velocity in the studied pipes exceeded the speed of re-suspension, and this means that all the previously deposited mass in the pipes returns to the state of suspension.

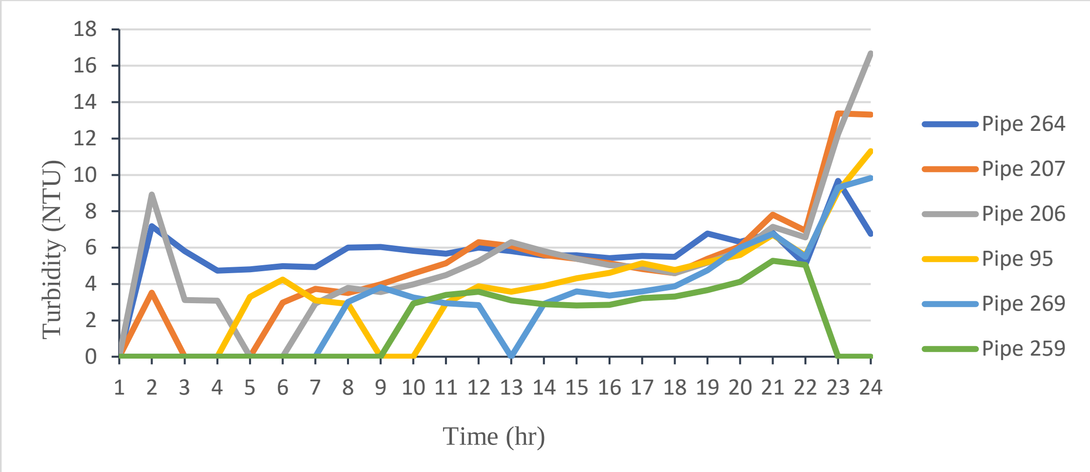

Fig. 11. Turbidity distribution in studied pipes for source sediment quality 5 NTU.

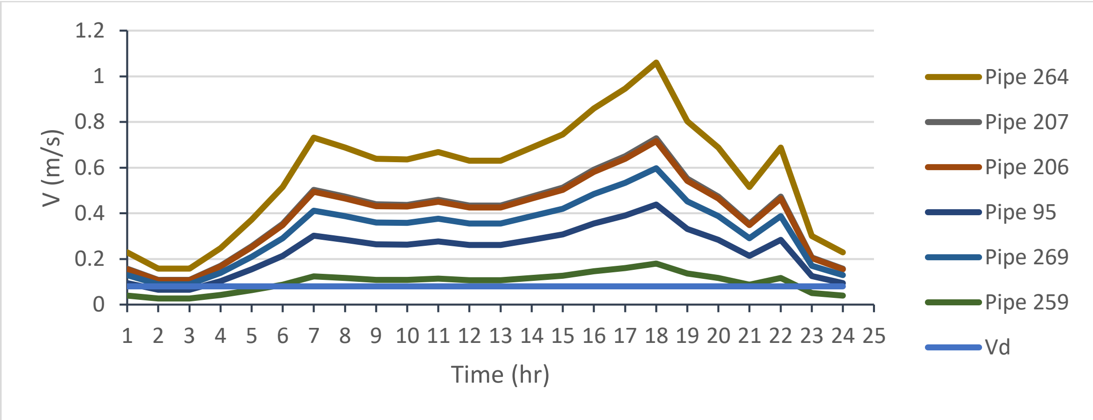

Fig. 12. The Velocity in studied pipes and deposition velocity.

While the precipitated mass was zero across all pipes due to the materials' transformation into suspension. With the exception of pipe 259, where settled mass values of (0.0076) kg are observed for the first five and last two hours since its velocity values are lower than the deposition velocity (Vd).

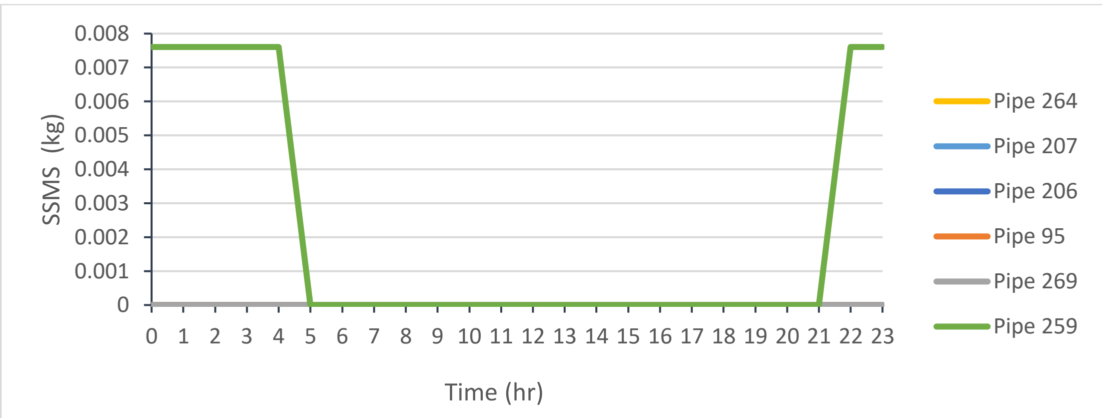

Fig. 13. The settled mass (SSMS) in studies pipes for source sediment quality 5 NTU.

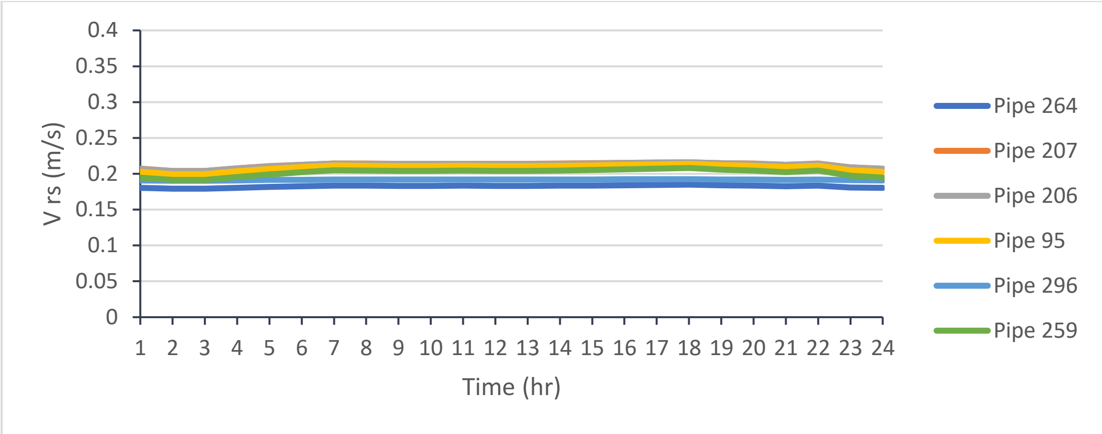

Fig. 14. Resuspension velocity in studies pipes.

Figs. 15 and 16 show the tracking of turbidity distribution and settled mass, in the grid on the third day after an operation period of three days with a constant source of turbidity (26.6 NTU). It notices also a high turbidity with the highest value of turbidity (51.35, 101.02, 77.64, 62.94, 52.46, and 20.22) NTU recorded in the pipes was recorded in the pipes (264,206,207,95,269 and 259) respectively and the lowest values of turbidity was also (zero) in the all pipes. While the precipitated mass was zero across all pipes due to the materials' transformation into suspension. However, the value of the stable mass in pipe (259) was (0.054) kg is observed for the first five and last two hours since

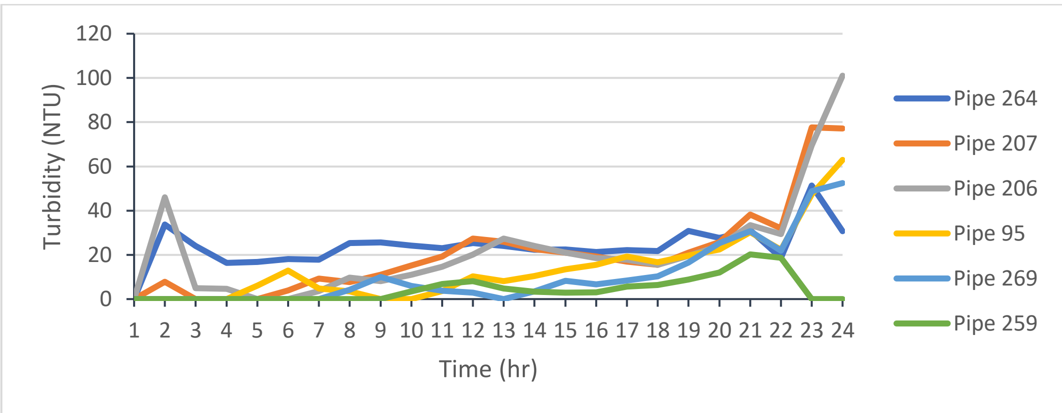

Fig. 15. Turbidity distribution in studied pipes for source sediment quality 26.6 NTU.

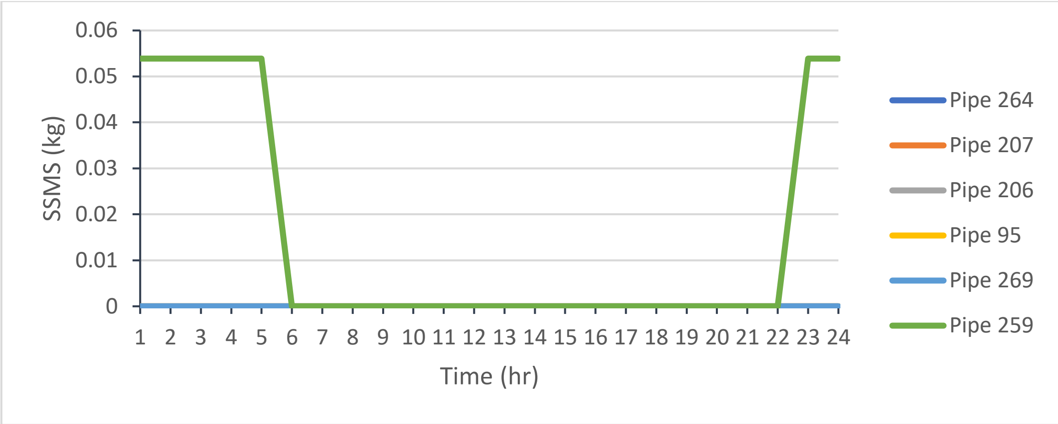

Fig. 16. The settled mass (SSMS) in studies pipes for source sediment quality 26.6 NTU.

In general, that even if the treated water's turbidity values meet Iraqi standard requirements, continuing pumping without first performing network cleaning operations causes materials to build up, which then causes them to be re-suspended at high speeds as a result of the population's shifting daily demand patterns. Severe turbidity causes a high network turbidity and high sedimentation values when the velocity in the pipes is low; as a result, these masses are re-suspended when the velocity in the pipes is increased.

9. CONCLUSIONS

Investigating the problem of Impact of Feedwater Characteristics Change on Turbidity Distribution in A Water Network in Najaf governorate /Al-Saray network case study has led to the following conclusions:

1. The particles entering the network originate from the treatment plant. In the case of source turbidity 5 NTU, the highest turbidity values were (9.67, 16.68, 13.38, 11.30, 9.82, 5.27 NTU) in tubes (264,206,207,95,269 and 259) respectively, while were notice the highest turbidity value (51.35, 101.02, 77.64, 62.94, 52.46, 20.22) in tubes (264,206,207,95,269 and 259) respectively, in the case of source turbidity (26.6 NTU).

2. In the pipes in which the velocity exceeds the velocity of resuspension, all precipitated materials turn into suspension.

3. When the velocity is less than the resuspension velocity and higher than the sedimentation velocity, the mass moves through the tube without any change.

4. When the velocity is less than the sedimentation velocity, the materials settle at the bottom of the pipe.

10. SOLUTION MEASURES FOR HIGH TURBIDITY PROBLEM

1. The water coming out of the stations must be in conformity with the standard specifications.
2. The network must be cleaned even if the external turbidity conforms to the standard specifications, because continuous pumping without cleaning leads to accumulation of materials due to changing demand patterns.
3. Commitment to the specified expenses of the station, because increasing the discharge by adding additional pumps as a result of population expansion or during the summer season leads to an increase the velocity in the network and thus an increase in turbidity.

11. REFERENCES

Abed, Z. H., and Khudair, K. M. (2023) Investigation of high-turbidity tap water problem in Najaf governorate/middle of Iraq, Open Engineering,13(1).

Al-Ithari, A. (2013). Evaluating and improving the tools for predicting discoloration events in potable water supply system (Doctoral dissertation, Curtin University).

Blevins, R. D. (1984) Applied fluid dynamics handbook, Van Nostrand Reinhold, New York.

Boxall, J. B., & Prince, R. A. (2006). Modelling discoloration in a Melbourne (Australia) potable water distribution system. Journal of Water Supply: Research and Technology AQUA, 55(3), 207-219.

Boxall, J. B., & Saul, A. J. (2005). Modeling discoloration in potable water distribution systems. Journal of Environmental Engineering, 131(5), 716-725.

Clark, R. M., Grayman, W. M., Males, R. M., & Hess, A. F. (1993). Modeling contaminant propagation in drinking-water distribution systems. Journal of environmental engineering, 119(2), 349-364.

Furnass, W. R., Collins, R. P., Husband, P. S., Sharpe, R. L., Mounce, S. R., & Boxall, J. B. (2014). Modelling both the continual erosion and regeneration of discolouration material in drinking water distribution systems. Water Science and Technology: Water Supply, 14(1), 81-90.

Gauthier, V., Barbeau, B., Millette, R., Block, J. C., & Prevost, M. (2001). Suspended particles in the drinking water of two distribution systems. Water Science and Technology: Water Supply, 1(4), 237-245.

Gauthier, V., Gérard, B., Portal, J. M., Block, J. C., & Gatel, D. (1999). Organic matter as loose deposits in a drinking water distribution system. Water Research, 33(4), 1014-1026.

Hossain, A. (2005). CFD investigation for turbidity spikes in drinking water distribution networks (Doctoral dissertation, Swinburne University of Technology, Faculty of Engineering and Industrial Sciences).

Husband, P. S., Boxall, J. B., & Saul, A. J. (2008). Laboratory studies investigating the processes leading to discoloration in water distribution networks. Water Research, 42(16), 4309-4318.

LeChevallier, M. W., Babcock, T. M., & Lee, R. G. (1987). Examination and characterization of distribution system biofilms. Applied and environmental microbiology, 53(12), 2714-2724.

Ryan, G., Mathes, P., Haylock, G., Jayaratne, A., Wu, J., Noui-Mehidi, N., Grainger, C., and Nguyen, B. V. (2008). Particles in water distribution systems, Cooperative Research Centre for Water Quality and Treatment, Salisbury, Australia. Research report 33.

Sly, L. I., Hodgkinson, M. C., & Arunpairojana, V. (1990). Deposition of manganese in a drinking water distribution system. Applied and environmental microbiology, 56(3), 628-639.

Steel, E. W., and McGhee, T. J. (1960). Water supply and sewerage, McGraw-Hill Book Company, New York, 5 th edition, (05: 06: 07 A STE), 1979, 679.

Van Rijn, L. C. (1984). Sediment transport, part I: bed load transport. Journal of hydraulic engineering, 110(10), 1431-1456.

van Summeren, J., & Blokker, M. (2017). Modeling particle transport and discoloration risk in drinking water distribution networks. Drinking Water Engineering and Science, 10(2), 99-107.

Van Thienen, P., Vreeburg, J. H. G., & Blokker, E. J. M. (2011). Radial transport processes as a precursor to particle deposition in drinking water distribution systems. Water research, 45(4), 1807-1817.

World Health Organization, (2008). Guidelines for Drinking-Water Quality: Third edition incorporating the first and second addenda, Vol. 1, Recommendations World Health Organization, Geneva ISBN 9789241547611.