Assessment of Water Quality and Quantity of Surface and Subsurface Drainage System in the Command Area of Bareji Distributary Mirpurkhas, Sindh, Pakistan

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Abstract

The global environment is changing every day due to human exploitation of nature, leading to the depletion of water resources. Furthermore, rapid population growth, the expansion of irrigation areas, urbanization, and industrialization are increasing the pressure on water resources. The end-user or lower riparian on the Indus Basin irrigation system of Sindh province is facing a similar water scarcity issue. Therefore, to cope with this issue, the quality and quantity of drainage water quality in the command area of Bareji Distributary Mirpurkhas (BDM) have been assessed in this study. Drainage facilities in this command area were divided into two parts; i) surface drainage and ii) subsurface (tile) drainage. Further three surfaces (4L, 4LA and 3L) and five sub-surfaces (3L-21, 3L-23, 3L-24, SD-22 and SD-24) were taken into account. Different quality parameters were analyzed, followed by SAR, D.O., pH, temperature, E.C., hardness, alkalinity, and TDS. Results showed that the drainage effluent is within the acceptable limits of the World Health Organization (WHO), except for the 3L-sub drain. It can be used for irrigation, fisheries, and livestock purpose. The quality of the 3L-sub drain can be periodically improved by diluting with the freshwater and recommended ratios accordingly.

Keywords—Wastewater, Reusability, TDS, SAR, D.O., Remedial measures

1 Introduction

Water demand increases as the world population grows and becomes more urbanized and affluent. Clean water has been a challenge of the 21st Century, water pollution is becoming a significant threat to a healthy society, and the major impact is climate change affecting the hydrological cycles, from catastrophic droughts to widespread flooding, which also adds to the problem. To cope with these challenges, scientists have developed and designed different water analysis, treatment, and reusability innovations, their valuable contributions towards improving sustainable water worldwide [1, 2].

Water pollution is a significant problem because as the earth progresses, it moves indirectly from pollution. Water pollution, especially in Sindh, is a severe problem because about 90% of the Pakistani economy is produced through irrigation processes by growing various crops while processing using multiple chemicals in high-risk agriculture, not only on crops but also on soil and soil. Its environment and the destruction of ambient water levels pose a risk to aquatic life, livestock, vegetation, and soil [3]. The main reason for the reduction of water quality is water shortages and anthropogenic activities. The ecosystem has two water sources, point and non-point sources [4]. Point sources are easily identifiable and discharged into water directly to be easily measured at drainage pipes.

In comparison, non-point sources are problematic to identify because they may be from construction sites, chemical industries, agricultural activities, and others [5]. Water quality is assessed by analysis of various physiobiochemical components. Important

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parameters are the electrical conductivity (ECw), sodium adsorption ratio (SAR-mg/L), hardness, total dissolved solids (TDS), dissolved oxygen (D.O.), and alkalinity.

SAR is a measure of water's Na^+-Ca^{2+} and Mg^{2+} ions, and its value should not exceed 8. High SAR values destroy soil structure and increase salinity [11, 12]. Hardness as $CaCO_3$ (mg / l) comprises Ca^{2+} and Mg^{2+}. There are two types of hardness i) temporary hardness, which is caused by bicarbonate minerals ($Ca(HCO_3)_2$ and $Mg(HCO_3)_2$), and ii) permanent hardness, which $CaSO_4$ and $MgSO_4$ often cause. Temporary hardness can be reduced by boiling, and permanent hardness by desalination processes, reverse osmosis (R.O.), ion exchange, water softening agents, lime application, and pH adjustment [13 - 16]. TDS (mg/L) contains Na^+, Cl^-, Ca^{2+}, Mg^{2+}, K^+, SO_4^{2} and HCO_3^- salts. High TDS indicates hard water that causes water corrosion of water pipes and valves and shortens their life. High salt dissolved in water resulted in a salty taste and acidic nature of water. Many methods can reduce the TDS of water; deionization, filtration, R.O., and distillation [17 - 20]. D.O. (mg/L) is important for the survival of water bodies, and its value cannot be less than 5 mg/L. Low D.O. will result in fish and other organisms migrating to the water with sufficient D.O. [21-23]. Alkalinity has effective relation with pH. The pH measures H^+, while alkalinity makes acids inactive to maintain pH levels. Alkalinity can be increased with $NaHCO_3$ and reduced with muriatic acid and sodium bisulfate [24, 25].

Various problems have been identified at the time, affecting livestock, aquaculture, biodiversity, and health-related irrigation. The Sindh government embarked on a waste disposal project that produces bulk water, affecting the BDM command area. The purpose of regulating water supply is to manage and control the usage of produced water and its disposal. However, wastewater disposal is a problem, while its efficient use through recycling will provide additional water for agriculture, livestock, and fisheries. This study intends to test the flow of water in the BDM's command area. This study aims to assess the water quality and quantity of surface and sub-surface systems and compare it with the standard allowable limit for wastewater recycling. Studies show that recycling wastewater saves national income and enhances irrigation practices by providing a better environment to the command area.

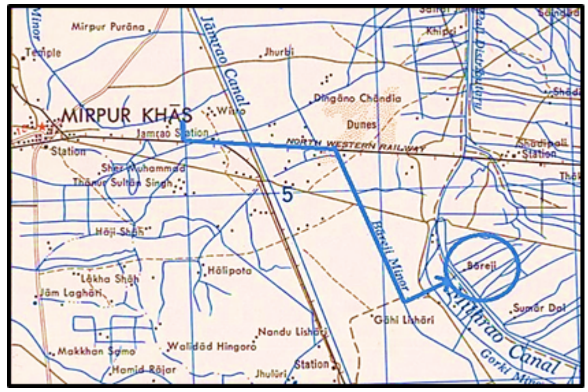

Fig. 1: Location Map of the study area

2 Materials and Methodology

2.1 Study Area

The investigation scheme was designed in the B.D.M's command area, Mirpurkhas district, is shown in Figure 2.1. It covers 11500 hectares, and its planned extraction is about 109 ft3/s. This command area is in the southeast of Mirpurkhas on Umerkot Road, approximately 43.5 miles from Hyderabad, where the Sindh government has installed a Tile Drainage project. It is also part of the left bank outfall drainage (LBOD) drainage system.

The drainage system in the command area was divided into two facilities; i) surface drainage and ii) subsurface (tile) drainage. The surface drainage system is designed to carry water produced by various sources. These drains are constructed at a distance of 1 ft in sub-drains, 2 ft in the branch drains, and 4 ft in the outfall drain. The sub-surface drainage system, groundwater pumps, and the remainder of the irrigated residue will be collected through pipes known as collecting pipes rather than from where the water meets in a sump house. The sump house has a depth in the range of 7.5 to 11 ft, and these sewers are typically installed at 350 to 650 ft intervals, and all debris is dumped into a 6 - 15-inch-wide collection pipe of field rain about 6 - 8 ft below. These pipes are made of polyvinyl chloride (PVC). Each station covers an area of 400 to 1200 hectares, and their operation is subjected to the tile drainage system's efficiency and maintenance.

2.2 Materials

The quantitative data was collected from the Water and Power Development Authority (WAPDA) South Water Wing (WSWW). For the qualitative analysis, 1500 mL plastic bottles were used for the sampling and cleaned with deionized (DI) water. All the chemicals used for the study of different parameters were of sigma-Aldrich. All the tests were conducted at IEEM, MUET Jamshoro, Soil and Water Analysis Laboratory Tandojam, and Pakistan Steel.

2.3 Methodology

The sample collection scheme was divided into two drainage facilities; three samples were collected from surface drainages (4L, 4LA, and 3L), and five samples were collected from sub-surface (tile) drainage (3L-21, 3L-23, 3L-24, SD-22, and SD-24). The parameters were analyzed: alkalinity, D.O., E.C., hardness, pH, TDS, and water temperature. The D.O., E.C., pH, TDS, and temperature were analyzed in the field, and for other parameters, samples were adequately stored and labeled for analysis at Lab.

2.4 Analytical Methods

WTW Cond 3110 meter was used for measuring E.C., and the TDS was calculated using eq(1) given by Ali et al. (2012).

$$TDS(\frac{mg}{L}) = E.C.(\frac{\mu S}{m}) \times 0.65 \tag{1}$$

Salinity, pH, and D.O. were measured through a water logger (IDS 3630). Alkalinity was analyzed through 2320 B, Titration Method (APHA), and hardness was analyzed through 2340-C, EDTA Titrimetric Method (APHA).

3 Results and Discussion

3.1 Quantity of Agricultural Wastewater

Quantification details of surface and sub-surface drainages are provided in Tables 1 and 2, respectively.

3.2 Quantity of Bareji Distributary

The quantity of the BDM's command area is given in Table 3. Water available in this command area was estimated at 2.2 cusec net design discharge considering all losses.

3.3 Assessment of Water Quality

The results of SAR, D.O., pH, temperature, E.C., hardness, alkalinity, and TDS, are shown in Figures 3, 4, 5, 6, 7, 8, 9, and 10, respectively.

The water quality parameters in February indicated that the parameter variation was observed at about 10% for all drainage units, excluding 3L- sub-drain, 4L-A, and 4L, which links the other drains of the LBOD. Similarly, in the three months (March, May, and June), parameters vary by 1-10 % for the same drainage units. So, the overall variation for the drainage units was considered as 1-10 % in the four months.

3.4 Comparison of drainage effluent with standards

3.4.1 SAR

SAR is the parameter that is used to check the suitability of water for agricultural purposes. The researcher recommended its values should be less than 8. The results indicated that from Feb – Jun, the SAR values are in the range of 11-18 and 8.4-21 for sub-surface and surface water, respectively, as shown in Fig. 3. High SAR values could be the cause of soil structure breakdown and water infiltration difficulties. Thus, most results showed that SAR values are near to recommended values. Therefore, mixing freshwater can be used for agricultural purposes without affecting soil characteristics.

3.4.2 Dissolved oxygen

The results indicated that the sub-surface D.O. values are in the range of 3-5 mg/L while surface drain D.O. values are in the range of 2.5 -4.2 mg/L from Feb – Jun as shown in Fig. 4. A lower value of D.O. (less than 2 mg/l) means water quality is poor. It is challenging to sustain sensitive aquatic organisms.

3.4.3 pH

The results of the February to June months indicated the pH values are in the range of 6.9 – 8.2 and 7 – 8.6 for sub-surface surface drain, respectively. Thus, the maximum values are within the allowable limit of 6.5 to 8.5. Higher pH values indicated water is abnormal in quality and tends to basicity. In contrast, lower pH values tend to the acidic nature of water. Almost all samples showed pH within the permissible limit; however, a few locations showed slightly higher pH, as shown in Fig. 5.

3.4.4 Temperature

The temperature was observed in the range of 25-31 ℃, as shown in Fig. 6. for both sub-surface and surface drain water, which are under the allowable limits.

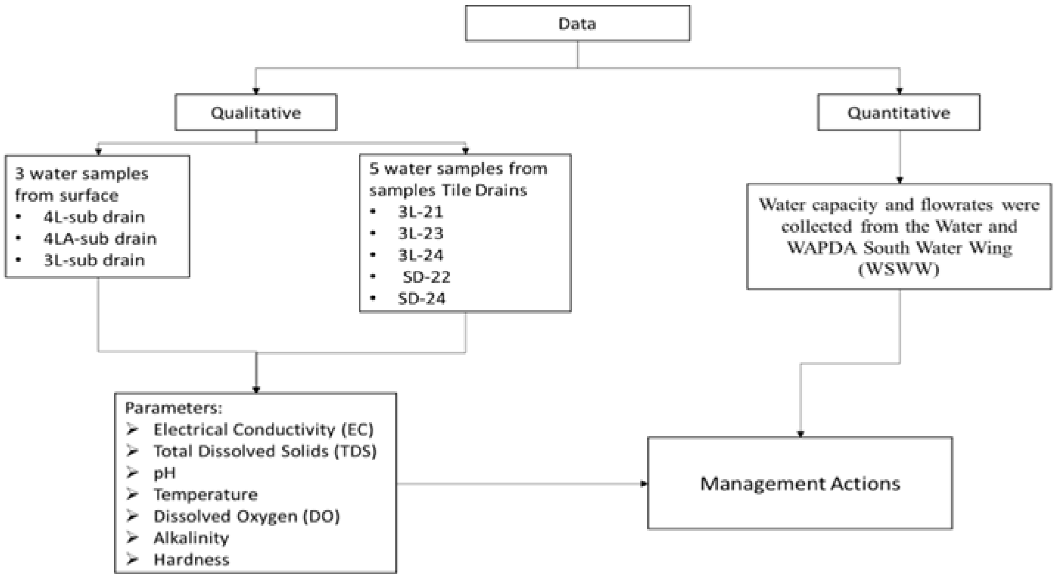

Fig. 2: Methodological scheme

TABLE 1: Quantity of surface drainage systems under the BDM's command area

Name of sub-drain	Length (km)	Length under the command area (km)	Design discharge (ft^3/s)	Disposed to
4L	7	4.70	25.6	S R.D. 585+500
4LA	5	1.00	16.5	RD 6+00
Spinal Drain	-	10.06	-	Arabian sea

TABLE 2: Characteristics of sub-surface drainage systems under the BDM's command area

<table>
<tr><th>Name</th><th>Area (acres)</th><th>Design discharge (ft^3/s)</th><th>Lateral Length (ft)</th><th>Collector Length (ft)</th><th>Disposed to</th><th>Disposal channel type</th><th>Disposal channel length (ft.)</th><th>Spacing (ft.)</th><th>Motor Hp</th></tr>
<tr><td>SD – 24</td><td>701.5</td><td>2.5</td><td>60,740</td><td>22,324</td><td>3L sub drain</td><td>Lined</td><td>4,100</td><td rowspan="2">300 – 400</td><td>15</td></tr>
<tr><td>3L-24</td><td>550.5</td><td>1.5</td><td>59,430</td><td>12,660</td><td>3L-IR</td><td>Unlined</td><td>227</td><td>10</td></tr>
<tr><td>SD-21A</td><td>491.7</td><td rowspan="2"></td><td>49,490</td><td>17,080</td><td></td><td rowspan="11"></td><td>154</td><td rowspan="11"></td><td rowspan="2"></td></tr>
<tr><td>3L-22B</td><td>533.2</td><td>39,100</td><td>15,390</td><td rowspan="3">Spinal drain</td><td></td></tr>
<tr><td>3L-26</td><td>733.6</td><td rowspan="6">2.5</td><td>76,340</td><td>23,520</td><td>305</td><td>15</td></tr>
<tr><td>3L-25A</td><td>587.7</td><td>56,000</td><td>15,810</td><td>130</td><td rowspan="5"></td></tr>
<tr><td>SD-22</td><td>747.9</td><td>50,160</td><td>22,690</td><td>3L-IR</td><td>678</td></tr>
<tr><td>SD-19</td><td>795</td><td>57,080</td><td>22,484</td><td rowspan="6">3L sub-drain</td><td>350</td></tr>
<tr><td>3L-23</td><td>877.7</td><td>56,459</td><td>23,256</td><td>190</td></tr>
<tr><td>3L-22A</td><td>758.1</td><td>63,530</td><td>21,070</td><td>1,325</td></tr>
<tr><td>3L-20</td><td>1078</td><td rowspan="3">3</td><td>104,180</td><td>35,220</td><td>3,150</td><td rowspan="3">20</td></tr>
<tr><td>3L-17</td><td>1023.3</td><td>103,490</td><td>33,350</td><td>1,286</td></tr>
<tr><td>3L-21</td><td>1045.4</td><td>73,070</td><td>27,406</td><td>1,460</td></tr>
</table>

TABLE 3: Water quantity of BDM's command Area.

Name of Sump house	Design discharge (ft^3/s)	Average 7 % Losses	Losses in Disposal Channel	Disposal channel length (ft.)	Net design discharge	Per annum discharge
1	2	3	4	5	6(2-4)	
3L-24				227	1.395	
3L-22B	1.5		0.105	154	1.395	
SD-21A				168	1.395	
SD-19				350	2.325	
3L-26				305	2.325	
SD-24				410	2.325	896,728,320
3L-25A	2.5	0.07	0.175	130	2.325	Cubic ft. per Annum
SD-22				678	2.325	
3L-23				190	2.325	
3L-22A				132	2.325	
3L-20				315	2.790	
3L-17	3.0		0.210	128	2.790	
3L-21				146	2.790	
Sum	31	9.1	2.17	13,523	28.83	Source: Sindh Irrigation and Drainage Authority
Mean	2.38	0.7	0.16	1,040	2.22	
Maximum	3	0.7	0.21	4,100	2.79	
Minimum	1.5	0.7	0.105	130	1.39	

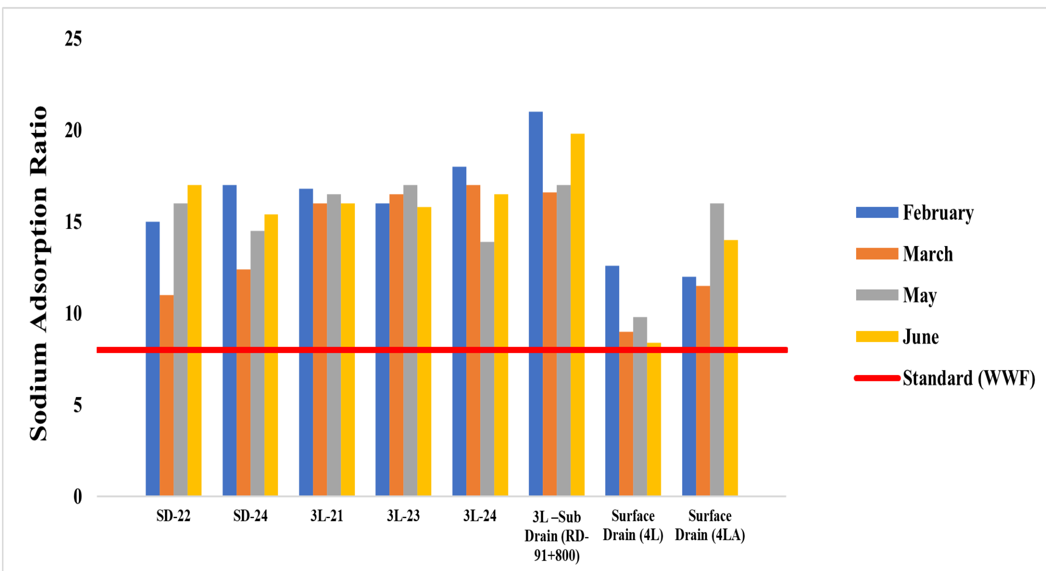

Fig. 3: Water quality of drainage effluent of Feb, Mar, May, and Jun for SAR

3.4.5 Electrical conductivity

The results of electrical conductivity (E.C.) showed that surface and sub-surface have the value in the range of 1.1- 3 and 0.8- 1.9 dS/m, respectively, as shown in Fig. 7. According to E.C. results, almost all samples showed that the water is suitable for agricultural purpose except 3L – sub-drain, which indicates slightly high E.C. values due to saline patches. Results of June showed that the effluent is not ideal for fisheries and livestock purposes, but in other months like February, March, and May, it can be used. High E.C. values mean high salinity, which is a problem for the proper growth of crops and soil infiltration. E.C. values for surface and subsurface drain water in the study area is not much higher than the permissible limits, so it can be used for agriculture, fisheries, and livestock after mixing at a specific ratio.

3.4.6 Alkalinity

The results indicated that the alkalinity values range between 3 - 7.2 mg/L and 3 – 9 mg/L from February to June for sub-surface and surface drains, respectively. Alkalinity is essential for aquatic life because it protects or buffers against rapid pH changes. U.S

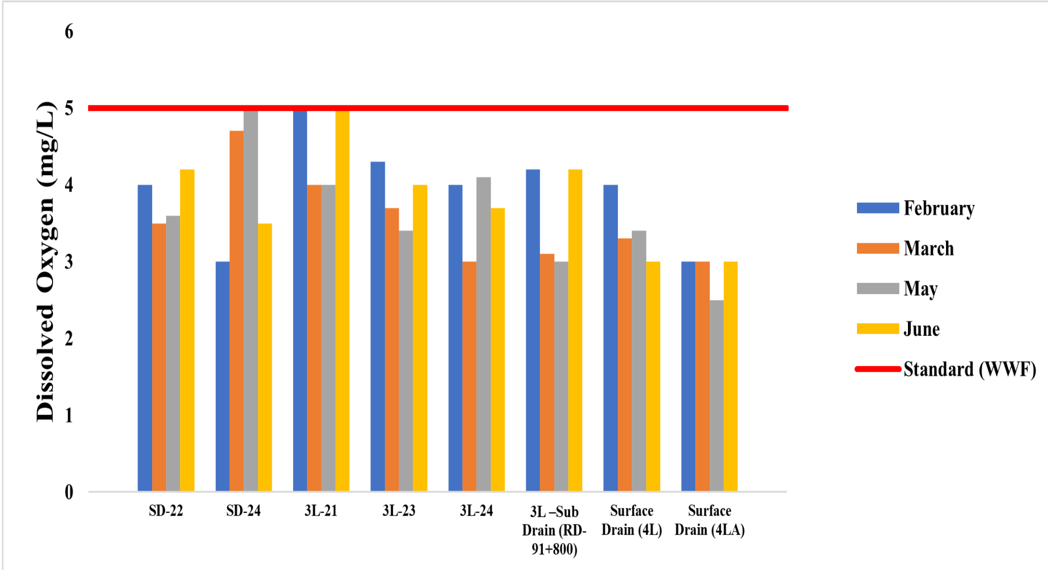

Fig. 4: Water quality of drainage effluent of Feb, Mar, May, and Jun for D.O.

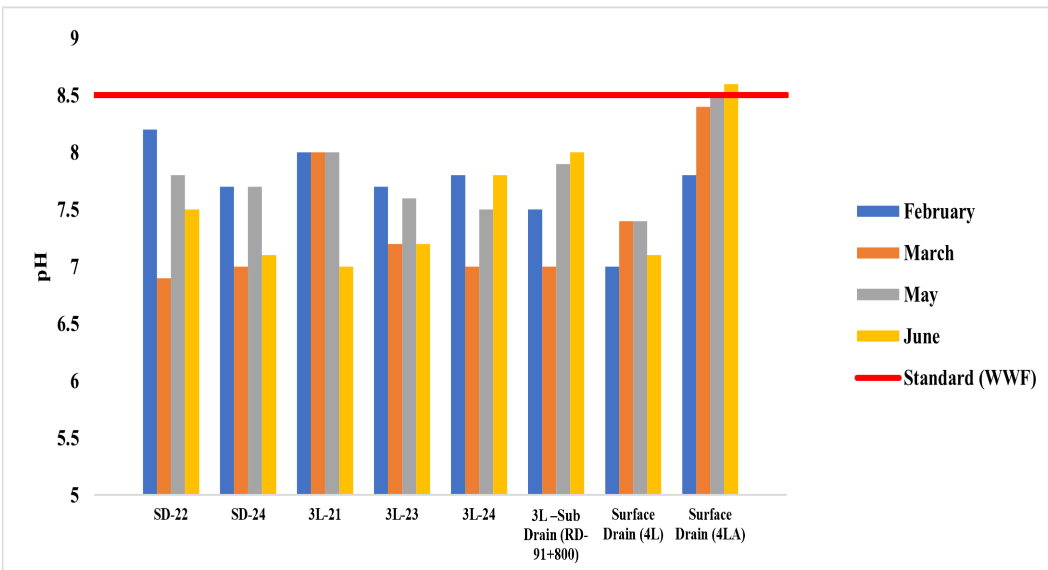

Fig. 5: Water quality of drainage effluent of Feb, Mar, May, and Jun for pH.

Environmental Protection Agency (USEPA) classified the lakes and ponds based on alkalinity as calcium carbonate (CaCO3) [26]. USEPA is acidic if CaCO3 concentration is less than 1 mg/L and pH is less than 5. USEPA is further classified as critical (¡ 2 mg/L), endangered (2-5 mg/L), highly sensitive (5-10 mg/L), sensitive (10-20 mg/L), and not sensitive (¿20 mg/L). The alkalinity of water can be increased by adding sodium carbonate and reduced by lowering the pH by adding sodium bisulfate or muriatic acid.

3.4.7 Hardness as CaCO3

The results showed that the sub-surface and surface drains had hardness values of 490 – 990 mg/L and 320 -1250 mg/L, respectively, from February – June. Hardness has two types, (i) temporary and (ii) permanent. The temporary hardness contains calcium and magnesium ions, which can be reduced by boiling. In comparison, the permanent hardness contains bicarbonate, carbonate, sulfates, chlorides, and other anions of mineral acids. It can be reduced by softening (Ion exchange, Water-softening agents, Desalination processes such as R.O., use of lime, pH adjustment, and Controlling water temperatures).

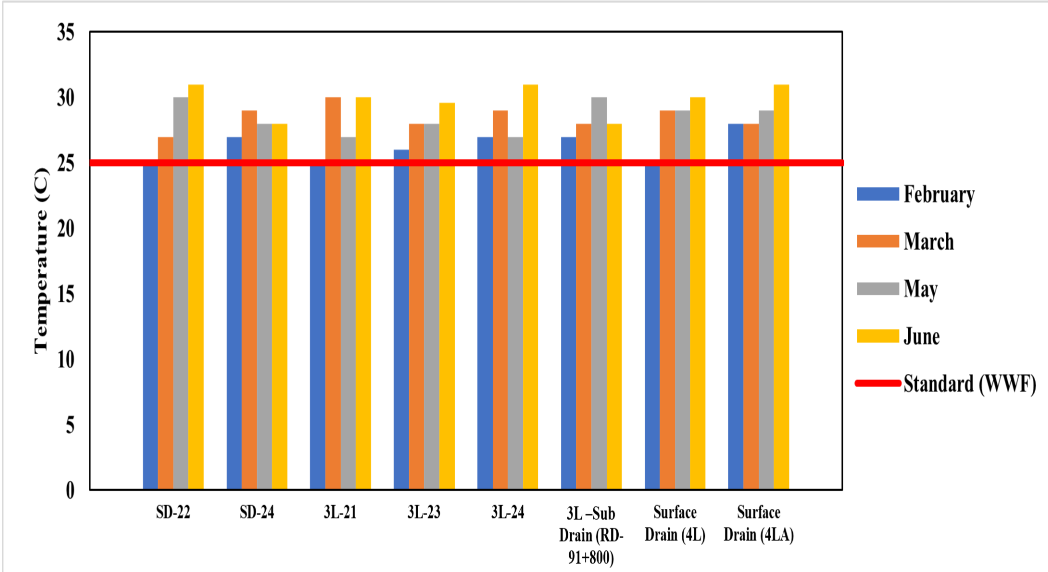

Fig. 6: Water quality of drainage effluent of Feb, Mar, May, and Jun for temperature

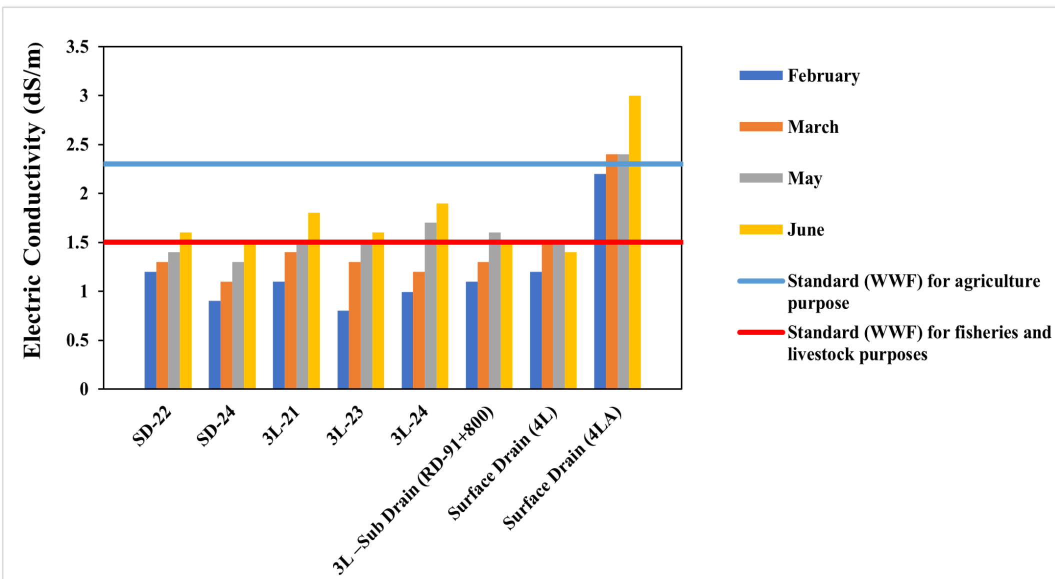

Fig. 7: Water quality of drainage effluent of Feb, Mar, May, and Jun for E.C.

3.4.8 *Total dissolved solids*

Total dissolved solids (TDS) includes Na+, Cl-, Ca2+, Mg2+, K+, SO42-, and HCO3-. High values of TDS result in unwanted taste, i.e. salty, bitter, or metallic, and it also indicates the nature of water as hard water. Results showed that the sub-surface and surface drains have TDS 530 – 990 and 600 - 1150 mg/L, respectively, during the months Feb – Jun. Almost all samples showed that TDS values are within usable norms.

3.5 3.5 Recommendations and suggestions

The following recommendations and suggestions have been proposed as in Tabe 4. For drainage effluent reusability by using the dilution method.

$$DilutionFormula = \frac{C_1Q_1 + C_2Q_2}{Q_1 + Q_2} \quad (2)$$

where C_1 = Drainage Effluent, Q_1 = Designed Discharge, C_2 = Concentration of Fresh Water, and Q_2 = Quantity of Fresh Water to be mixed with Drainage Effluent.

TABLE 4: Water quality parameters after mixing

Sampling Drain	C1	Q1	C2	Q2	(C1Q1+C2Q2)/ (Q1+Q2)	Dilution Ratio
Sodium Adsorption Ratio (SAR)						
(3L-24)	16.35	1.5	3	2.5	8.01	1.67
(SD-24)	14.82	2.5		3	8.37	1.20
(SD-22)	14.75			3	8.34	1.20
(3L-23)	16.32			4	8.12	1.60
(3L-21)	16.32	3		5	8.00	1.67
3L SUB-DRAIN	13.37	-		-	-	-
(4L)	9.95	25.6		12	7.73	0.47
(4LA)	18.6	16.5		33	8.20	2.00
Dissolved Oxygen (mg/L)						
(3L-24)	3.7	1.5	5	3	4.57	2
(SD-24)	4.05	2.5		5	4.68	
(3L-23)	3.85				4.62	
(SD-22)	3.82				4.61	
(3L-21)	4.5	3		6	4.83	
3L SUB-DRAIN	3.62	-		-	-	-
(4L)	3.4	25.6		25.6	4.20	1.00
(4LA)	2.87	16.5		16.5	3.94	1.00
pH						
(3L-24)	7.5	1.5	6.5	1.5	7.00	1
(SD-24)	7.3	2.5		2.5	6.90	
(3L-23)	7.4				6.95	
(SD-22)	7.6				7.05	
(3L-21)	7.7	3		3	7.10	
3L SUB-DRAIN	7.6	-		-	-	-
(4L)	7.2	25.6		25.6	6.85	1.00
(4LA)	8.3	16.5		16.5	7.40	1.00
Electrical Conductivity (dS/m)						
(3L-24)	1.44	1.5	3	1	1.78	0.67
(SD-24)	1.2	2.5			1.51	0.40
(3L-23)	1.3				1.59	0.40
(SD-22)	1.37			1.5	1.72	0.60
(3L-21)	1.45	3		1.5	1.73	0.50
3L SUB-DRAIN	1.3	-		-	-	-
(4L)	1.4	25.6		25.6	1.85	1.00
(4LA)	2.6	16.5		16.5	2.45	1.00
Hardness (mg/L)						
			500			
(3L-24)	552.5	1.5		1.5	526.25	1
(3L-23)	537.5	2.5		2.5	518.75	
(SD-22)	577.5				538.75	
(SD-24)	810				655.00	
(3L-21)	555	3		3	527.50	
3L SUB-DRAIN	515	-		-	-	-
(4L)	397.5	25.6		25.6	448.75	1.00
(4LA)	1097.5	16.5		16.5	798.75	1.00
Total Dissolved Solids (mg/L)						
(3L-24)	772.5	1.5		1.5	886.25	1
(SD-24)	697.5	2.5		2.5	848.75	
(3L-23)	802.5				901.25	
(SD-22)	752.5				876.25	
(3L-21)	652.5	3		3	826.25	
3L SUB-DRAIN	780	-		-	-	-
(4L)	760	25.6		25.6	880.00	1.00
(4LA)	1107	16.5		16.5	1053.50	1.00

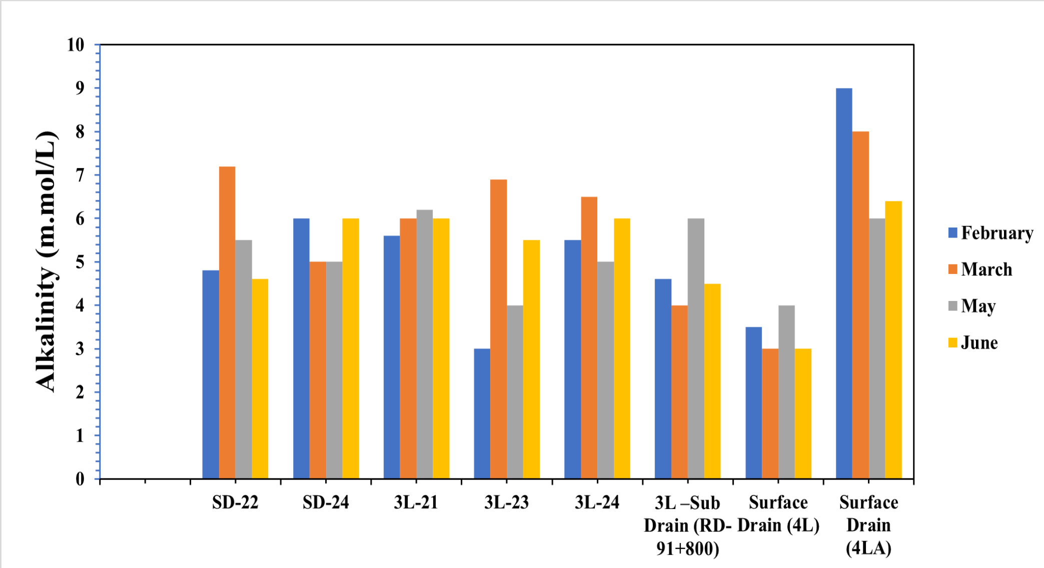

Fig. 8: Water quality of drainage effluent of Feb, Mar, May, and Jun for alkalinity

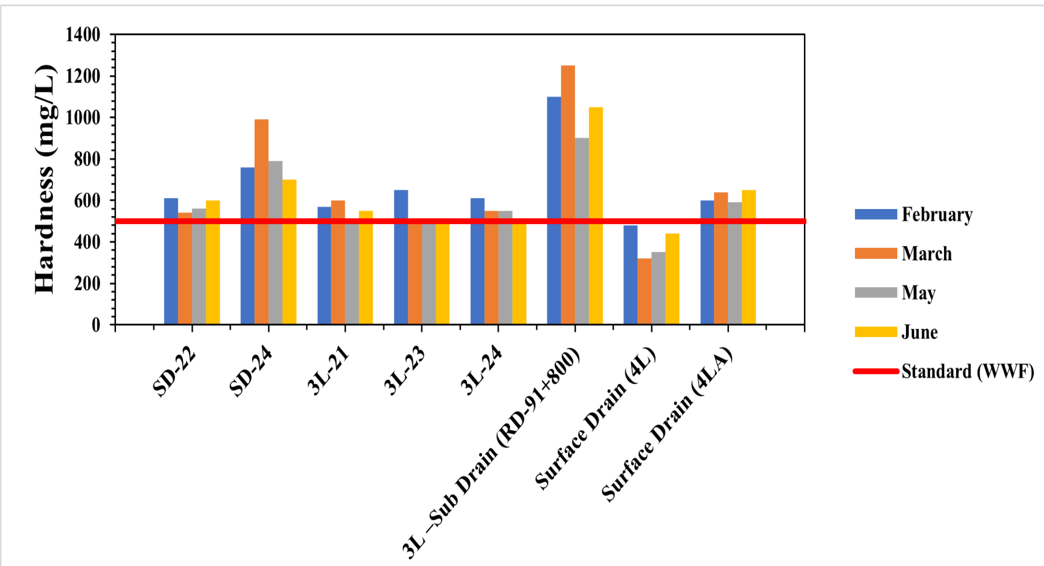

Fig. 9: Water quality of drainage effluent of Feb, Mar, May, and Jun for hardness

4 Conclusion

It is concluded that the results of most samples indicated that the drainage effluent is within the permissible limits for WHO alkalinity from 3 - 7.2 mg/L and 3 – 9 mg/L, hardness 490 – 990 mg/L and 320 -1250 mg/L, and TDS 530 – 990 and 600 - 1150 mg/L, respectively for sub-surface and surface drains. It can be used for irrigation, fisheries, and livestock purposes, while the 3L-Sub drain showed slightly lousy water quality due to the saline patches of agricultural land. This water quality can be improved by diluting it with fresh water at recommended ratios. These parameters must be monitored and controlled. It is also recommended that the area with high salinity can be cultivated through drainage effluent. It will solve environmental pollution issues and overcome waterlogging, problems of scarcity, and salinity.

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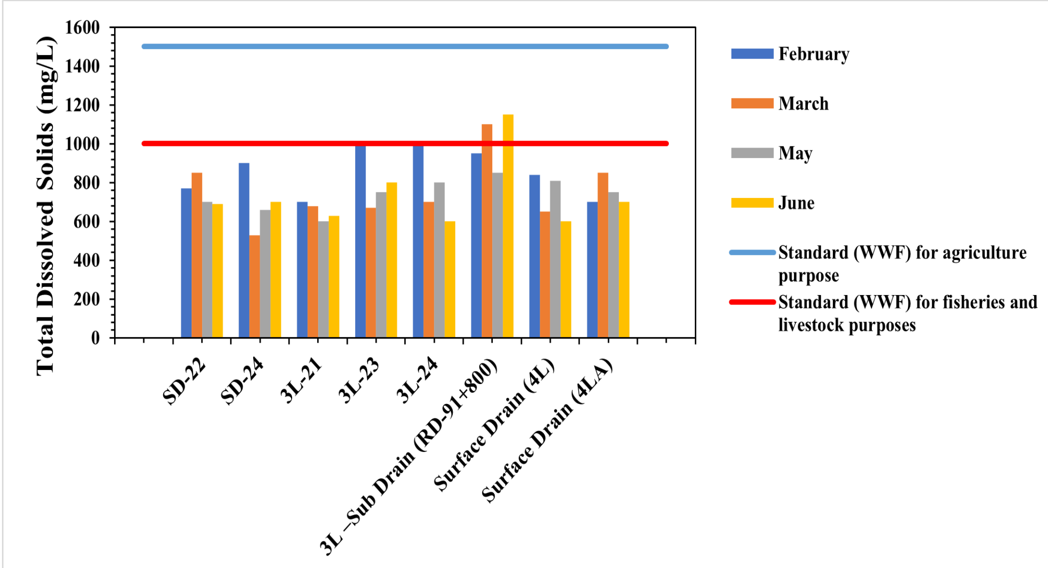

Fig. 10: Water quality of drainage effluent of Feb, Mar, May, and Jun for TDS

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